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Chair: Alan Shore, Photonics Academy for Wales and Bangor University (United Kingdom)
Vice Chair: Deb Kane, Macquarie University (Australia)
66 papers; Proceedings of the 2009 ETOP Conference

K-12 Education

1.4.26 Lessons Learned from Primary School students with Photonics Learning-by-Playing Approach.
Suwannee Phoojaruenchanachi, Sarun Sumriddetchkajorn & Sataporn Chanhorm - Photonics Technology Laboratory, NECTEC.

1.4.41 The Day of the Light - Optics demonstration for high school students
S. Chaitanya Kumar, Manoj Mathew, Giorgio Volpe, Osamu Takayama, Alejandra Valencia - The Institute of Photonic Sciences, Mediterranean Technology Park.

1.4.66 University for Children - The Magic of Light
Dan Curticapean - University of Applied Sciences.

3b.8.15 Kindergarten Optics
Manual F Costa, Julia Campos, Madalena Lira & Sandra Franco - Universidade do Minho, Departmento de Fisica.

10.4.51 Guided Poster Sessions: a way to introduce Optical Technology in a primary-secondary school
J. C. Escalera, C. Abelló, O. Ferreras, P. Matheu, M. Torres, and M. J. Yzuel

Outreach

2.18.21 Optics history as effective instrument for education in optics and photonics
Sergey Stafeef, Maxim Tomilin

2.18.37 Automated optical aurora detectors: Using natural optics to motivate education and outreach
Joe Shaw

2.18.4 Multiple Dimensional Outreach Activities Attract Students to the Electro-Optics Program
Feng Zhou, Pat Scott, Devki Talwar

3a.13.76 Student Chapters: effective dissemination networks for informal optics and photonics education
Dirk Fabian, Nathalie Vermeulen

6a.1.23 New optical museum at Saint-Petersburg for education and training
V.N. Vasil’ev, S.K. Stafeef, M.G. Tomilin

6a.1.55 Optics Outreach in Irish Context
Emer McHugh, Arlene Smith

6a.1.8 The new Aquitaine Outreach and communication centre in photonics
Jean Paul Prulhiere, Laurant Sarger

6b.19.27 Elevation of Optics and Photonics Education in Thailand
Suwanne Phoojaruenchanachai, Sarun Sumriddetchkajorn

Developing Nations

2.19.58 Development of Optics Kit for Schools in Developing Countries - International School of Photonics Model
Praveen Cheriyan Ashok, Jemy James, Yedhu Krisha, Jenu Varghese chacko, V.P.N.Nampoori
Outreach in Optics for Developing Countries - International School of Photonics Model

Jemy James, Jijo P.U & V.P.N.Nampoori, Praveen Cheriyan Ashok

Technician Training

Use of Hybrid, On-Line Course for Retraining Employed Technicians
John C Souders Jr, OP-TEC & Greg Kepner, Indian Hills CC

Efforts of the National Center for Optics and Photonics education (OP-TEC) to prepare the technician workforce for photonic industries: Preparing the Technician Workforce for Photonics Industries
Dan Hull, John C Souders Jr - OP-TEC. (USA)

PYLA: A European training facility for Optics, Laser Technology and Applications
Laurant Sarger - University Bordeaux 1. & Elisabeth Boeri - ADERA and University Bordeaux

The Laser Institute of Technology for Education and Research at Camden County College - How it has Changed and Evolved after 20 years
Fred P. Seeber

Interactive Learning

Active learning in intermediate optics through class tutorials & concept building laboratories
Mark F Masters, Timothy T Grove

Active and Interactive Teaching Based on Exploring Forefront Topics in Information Optics
Yuhong Wan, Shiquan Tao, Zhuqing Jiang & Dayong Wang

Holography as a Tool for Advanced Learning Optics and Photonics
Víctor V. Dyomin, Igor G Polovtsev, Alexey S Olshukov

Hands-On Optics, Training Courses for School Teachers
Manual F M Costa, Jose B. Vazquez-Dorrio

Using students' misconceptions of primary coloured lights to design a hands-on coloured light mixer
Suchai Nopparatjamjomras, Ratchapak Chitaree

An Experimental Education Package on Optical Fibre Raman Amplifiers for Student Teaching Labs
Iain Mauchline, Douglas Walsh, Walter Johnstone, Brian Culshaw

Experimental modules covering imaging, diffraction, Fourier optics & polarization based on liquid crystal cell SLM
Andreas Hermerschmidt

Stokes parameters in Undergraduate Laboratory Exercises
Gregory A Topasna, Daniela M Topasna

Optics in Eastern Connecticut
Nancy Magnani, Judith Donnelly

More Training Modules for an Advanced Interactive Course on Optical Design
Brian Blandford, Heidi Malaka

A Conceptual Course on LASERs for general education
Mark F. Masters

Computer-Based Learning

A Web-based Photonic Simulator for Secondary School Students
Judith M. Dawes, Sam Campbell, Adam Strickland, Robert Williams, Nemanja Jovanovic, Benjamin F. Johnston, Kali Madden

Development of an Intelligent Learning Resource using Computer Simulation about Optical Communications
Marcelo Mamud, Sandra Stump

Using mobile camera for a better exploitation & understanding of interference and diffraction experiments
Z Ben Lakhdar, Z Dhauadi, H Ghalila, S Lahmar
Industry

6b.20.52 From University to Company - education of optical communications in cooperation with industry at Technical University of Ostrava
Vladimir Vasinek, Jan Skapa, Petr Siska, Frantisek Hanacek, Jan Latal, Petr Koudelka & Iva Petrikova

6b.20.64 Precision Engineering for Optical Applications: Knowledge Transfer into UK industry
Christopher Sansom, Paul Shore

8.2.54 Education services available to optoelectronic sector in Wales
Nick Tyson, Vicky Barwis, Faris Maghuk

8.8.13 Creating and Using Industry-Based Problem-Based Learning Challenges in Photonics: Lessons Learned
Judith Donnelly, Michele Dischino, Fenna Hanes, Nicholas Massa

University Programs in Optics & Photonics

2.5.70 A laboratory of polarization in a Master degree of Photonics
Juan Campos, Angel Lizana, Octavi Lopez, M.J. Yzuel

3a.17.10 An International Interdisciplinary Graduate School in Laser and Material Science
Evelyne Fargin, Laurant Sarger, Malte Kaluza, Stefan Nolte, Martin Richardson, Kathleen Richardson

4.5.24 Thematic Course Design for an undergraduate photonics engineering course
Barry Shoop

7.5.40 Evolution of photonics education at the Australian National University
John Love

7.5.42 Should optics be taught to Optometry students?
V. Nourrit

7.5.48 Development of an Automated Modern Undergraduate Optics Laboratory using LabVIEW
Amit Garg, Reena Sharma, Vishal Dhingra

7.5.47 The Undergraduate Optics Course at Millersville University
Tariq H. Gilani, Natalia M. Dushkina

7.5.57 Education Programs of the Institute for Optical Sciences at the University of Toronto
Emanuel Istrate, R J Dwayne Miller

9.6.7 A Holography Course in Toronto
E. Istrate, R J Dwayne Miller

Education Approaches for Teaching Optics

1.3.29 Ingenuity in Photonics Design
Ray Davies

1.4.30 The Concept of Perceptive Empirical Design
Ray Davies

3b.8.75 The Human Eye: A model system for teaching optics.
Vasudevan Lakshminarayanan

4.7.17 Teaching diffraction gratings by means of a phasor analysis
M M Sanchez-Lopez, I Moreno, A Martinez-Garcia

4.7.35 Students Misconceptions about Light in Algeria
Djanette Blizak, F. Chafiqi, Maroc, D. Kendil,

5.5.14 Optical Phase Measurement Emphasized
Ertan Salik

5.5.45 Optoelectronic Technology Profiles - Motivating & Developing research skills in undergraduate students.
D M Kane

6b.20.65 University to Night School, to Graduate School to Training to Short Course
E.J Fjarlie
Training Physics degree students in a research optics laboratory
Josep Vidal, Alba Peinado, Elena Aso, David Lopez, Angel Lizana, Juan Campos, Maria J Yzuel, Josep Nicolas

Problem-based learning in photonics technology education: Assessing student learning
Nicolas Massa, Michele Dischino, Judith Donnelly, Fenna Hanes

Practical Framework for Bloom's Based Teaching and Assessment of Engineering Outcomes.
Patricia F. Mead & Mary M. Bennett

Laboratory Report Writing on Optical Physics Undergraduate Labs - Draft and Feedback Processes to Facilitate Student Learning & Skill Development
D M Kane & P G Browne

Optics and radiometric magnitudes: are their connections clear?
M A Illarramendi, A Oleaga, I Aramburu, J Zubia, G Aldabaldetreku, G Durana

A new technique to teach basic concepts of refraction and reflection of light
Jung Hye Yoo, Bok Hee Cho, Dae-Kyu Kim, Seung-Han Park

Posters

Numerical Modeling of Thin Film Optical Filters
Daniela M. Topasna & Gregory A. Topasna

New microscopy based on liquid crystals and its application to students' education and researches
M.G. Tomilin

A simple wavelength division multiplexing system for active learning teaching
Mourad Zghal, Hassen Ghalila, Zohra Ben Lakhdar

Demonstration of spin-orbit interaction of a photon in a multimode rectilinear optical fiber
Nataliya D. Kundikova

Design and development with educational purposes of an Optical Spectrum Analyzer for the visible range and of an Optical Time Domain Reflectometer for the second window
G Durana, G Aldabaldetreku, A. Berganza, J Zubia, M Illarramendi, I. Bikandi

The Townes Laser Institute
Martin Richardson
Lessons Learned from Primary School Students with Photonics Learning-by-Playing Approach

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ABSTRACT

We encourage primary school students in the grades 4-6 to challenge themselves on exploring light in everyday life. At the beginning, we bring in the critical-thinking approach where we use open-ended questions in applications of photonics around them. Later on, we engage them to our photonics lessons via our “Long Len” photonics kit. With our educational kit, we observe that most students in 21 schools from different parts of Thailand are amazed about photonics. They try to play with our kit in their ways, enjoy learning with their friends, and give us back many interesting questions. Based on their evaluations on our approach, 90-98% of them understand more about topics they already know. They also gain new knowledge and can see how it is applied to everyday life. The remaining percentage relates to students who are shy to interact with us.

KEYWORDS

Photonics playing, Primary learning, Learning-by-playing, Inquiry-Based Process, Critical thinking, Photonics educational kit, Hand-on learning, Optics suitcase.

1. INTRODUCTION

Science and Technology (S&T) has become one of the crucial factors for the development and sustainability of all countries. Today, most countries around the world have focused in building knowledge societies with qualified workforces through science learning and thinking processes. For optics and photonics (OP), it is a fascinating subject for science learning because it inherently composes of art and science at the same time and it surrounds us in our everyday activities. With this awareness, several international and local organizations have offered optics programs, ideas, and processes in teaching optics suitable for primary and secondary school students. They also promote the use of elementary optics in daily life in the development of physical thinking for primary school students. A variety of innovative ideas and methods in teaching optics

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has also been proposed for teachers\textsuperscript{3-9}. Apart from the ideas for teaching OP, many educational kits have been developed as hand-on demonstration tools\textsuperscript{10-20}.

![Figure 1. Core theme of science learning in Thailand.](image1)

![Figure 2. Learning topics in OP for primary and secondary levels.](image2)

For Thailand, the core theme\textsuperscript{21} of S&T learning has been recently established where the S&T learning process\textsuperscript{22} is applied as shown in Figure 1. With this core theme, teachers or instructors can arrange the proper courses followed the core curriculum and related them to the students and local communities. From those seven areas of science learning, OP is contained in the energy and astronomy sections. They cover basic properties of light such as laws of reflection and refraction, absorption, energy conversion, propagation behaviors of different light sources, and dispersion of white light (see Figure 2). However, as OP is not clearly emphasized in the course, it comes to primary school students as a new technical word that sometimes steers them stay away from learning with it. In addition, there is a discontinuity in learning OP in that they will learn more about it 3-4 years after finishing the K4 level. Additionally, lack of simple educational kits, inefficiency in demonstration, and unskilled science teachers are three key limiting factors that prevent students in primary and secondary schools to pay their attention to science and OP in their future study. With these issues in mind, we bring in our learning-by-playing approach to teach and motivate students in primary schools\textsuperscript{23}. We also develop the inquiry-based\textsuperscript{24} with critical thinking process and combine it with child aspect consideration. This paper shows our assessment and lessons learned from 21 schools in different parts of Thailand.
2. OUR PEDAGOGICAL KEY APPROACH

Realizing that primary school students are playful by nature, we utilize this attribute into our approach so that they enjoy learning our activity. In order to assist them envisage the basic OP and its applications in everyday life, a combination of the inquiry-based with critical thinking process and the learning-by-playing approach is our key approach to leverage the OP education in primary schools. We arrange the topics in accordance with fundamental optics and applications that can easily be observed around students. All topics in our approach are shown in Table 1. In addition, we bring into the field optical devices and components that the students have seen or used them before but they do not realize the principles behind. For example, an optical fingerprint scanner is used for their exploration of law of refraction and total internal reflection phenomenon. A multicoated eyeglasses is used to guide them to the optical interference. The use of a CD or a DVD helps us to easily demonstrate the diffraction of white light and to investigate the spectrum of laser and other light sources.

Table 1. OP learning topics in our approach.

<table>
<thead>
<tr>
<th>Core Contents</th>
<th>Topics</th>
<th>Expected Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Light Dispersion</td>
<td>• What is White Light?</td>
<td>• Properties of white light</td>
</tr>
<tr>
<td></td>
<td>• Your Own Rainbow</td>
<td>• Natural refraction in dispersion of white light</td>
</tr>
<tr>
<td></td>
<td>• Color Filter</td>
<td>• Simple method to filter color light</td>
</tr>
<tr>
<td></td>
<td>• Colorful CD</td>
<td>• Dispersion by CD diffraction</td>
</tr>
<tr>
<td></td>
<td>• Interference Rainbow</td>
<td>• Dispersion by interference</td>
</tr>
<tr>
<td>Light Intensity and Imaging</td>
<td>• Eye</td>
<td>• Light intensity effect to the human eye</td>
</tr>
<tr>
<td></td>
<td>• How to see the image</td>
<td>• Imaging on human eye</td>
</tr>
<tr>
<td></td>
<td>• Motion pictures</td>
<td>• Imaging of motion pictures</td>
</tr>
<tr>
<td>Reflection and Color</td>
<td>• Reflection angle</td>
<td>• Law of reflection</td>
</tr>
<tr>
<td></td>
<td>• Thousand faces</td>
<td>• Multiple reflection</td>
</tr>
<tr>
<td></td>
<td>• Color reflection</td>
<td>• Absorption and reflection of light</td>
</tr>
<tr>
<td>Refraction</td>
<td>• Light deviation</td>
<td>• Snell’s law and total internal reflection</td>
</tr>
<tr>
<td></td>
<td>• Invisible glass rod</td>
<td>• An application of refraction</td>
</tr>
<tr>
<td></td>
<td>• Virtual image</td>
<td>• Virtual image from refraction</td>
</tr>
<tr>
<td>Energy Conversion</td>
<td>• Power of light</td>
<td>• Potential of light</td>
</tr>
<tr>
<td></td>
<td>• Solar energy</td>
<td>• Light conversion in electrical energy</td>
</tr>
</tbody>
</table>
2.1 “Long Len” Photonics Kit

An educational kit is a vital tool in our learning-by-playing approach. Previously we developed our educational photonics kit suitable for practical teaching in both primary and secondary levels. Its name is “Long Len” which in Thai language means “Just plays with it”. The kit is able to demonstrate six main contents in OP as shown in Figure 3.

Components in our educational kit consist of four main parts: optics, electronics, accessories, and manual written in Thai language. Even its plastic suitcase can also be used as a component during some demonstrations. Some parts can be used in several topics. In addition, they can be used for topics that are not related to OP depending on adaptability of teachers or instructors. Our instruction in the manual is designed to guide them along the main topics of OP. Examples of components and demonstrations are shown in Figure 4.

Figure 3. Our Long Len kit and its educational topics.

Figure 4. Examples of our demonstrations using our Long Len kit.
2.2 Learning-by-playing Approach

Procedure diagram of our learning-by-playing approach is called 5E’s and it is shown in Figure 5.

**Figure 5. Our 5E-Learning process.**

**Step 1: Posing Question**

This step is significant to initially inspire primary school students, and therefore the first question to engage them should be simple and it should be related to OP around them. If most students in the class can answer the question, we then encourage them in the following open-ended question in order to bring them into our critical thinking process. Examples of our open-ended questions are shown in Table 2.

<table>
<thead>
<tr>
<th>Core Contents</th>
<th>Questions in Critical Thinking</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Light Dispersion</td>
<td>• What is the difference among bulb, fluorescent, and laser?</td>
</tr>
<tr>
<td></td>
<td>• What is white light?</td>
</tr>
<tr>
<td></td>
<td>• How is white light dispersion?</td>
</tr>
<tr>
<td></td>
<td>• What is the nature phenomenon about white light dispersion?</td>
</tr>
<tr>
<td>Light Intensity and Imaging</td>
<td>• What is the imaging on our retina?</td>
</tr>
<tr>
<td></td>
<td>• What is the difference imaging obtained from our eyes and the camera?</td>
</tr>
<tr>
<td></td>
<td>• How does the light intensity affect our eye cells?</td>
</tr>
<tr>
<td>Core Contents</td>
<td>Questions in Critical Thinking</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Reflection and Color</td>
<td>• What is the law of reflection?</td>
</tr>
<tr>
<td></td>
<td>• What is the benefit of reflection in everyday life?</td>
</tr>
<tr>
<td></td>
<td>• What is the color reflected from the red object under the green light source?</td>
</tr>
<tr>
<td>Refraction</td>
<td>• What is the law of refraction?</td>
</tr>
<tr>
<td></td>
<td>• How is the rainbow happening?</td>
</tr>
<tr>
<td>Energy Conversion</td>
<td>• Why do you sense hot when touching the bulb or under the sun?</td>
</tr>
<tr>
<td></td>
<td>• How can we use the solar energy in everyday life?</td>
</tr>
</tbody>
</table>

### Step 2: Playing

In this step, we challenge the students to explore or prove the discussion or solution from our questions in the step 1. We give them all needed components from our Long Len kit that are related to the topics. Prior to playing, we have to introduce students the safety rule concerning using a laser pointer, a light emitting diode (LED) regulator, a light detector, an electrical light bulb, and other electronics equipments. The students subsequently involve in hand-on playing in order for them to explore their critical thinking. At this stage, we are now their assistant. Close observation is also vital to conduct and guide the students before they get confused.

### Step 3: Concluding

This step is to assist the students to analyze what and how they learn from the above step in order to gain the asset of OP knowledge and scientific skill. We lead the students gradually to explain what they have learned during their playing. We also bring them into the critical thinking process again. The students have to conclude points of learning and knowledge gained during the above steps.

### Step 4: Expanding

This step needs students to be able to expand their knowledge to things around them. We can pick up a phenomenon of light to start with. Moreover, if we observe any application of optics or photonics in the class, we use it as a problem for the students to find out the explanation.

### Step 5: Quiz

We end up our approach with quizzes. This step is to evaluate the understanding of the individual student. We ask each student to review his or her thinking and knowledge. Since our approach is informal and no point affects students, we have to make this step more exciting in order to get their cooperation. This can be done by giving them some souvenirs if they can answer our questions correctly.

### 3. EVALUATIONS AND LESSONS LEARNED

We visit 21 primary schools in every part of Thailand. In particular, we focus on the schools in the rural area in Payao, Ratchaburi, Ubolratchathani, Nakornsridhamarach, and Srisakes provinces. There are 1018 students covering 96 in the grade four, 340 in the grade five, and 582 in the grade six. It can be seen that 57.2% of students is in the grade six because they already learned some basic optics and we anticipate
them to gain some benefits so that they can more or less plan their future study. Due to our limited 2-3 hours of demonstrations, we separate students in each school into two groups. The first group is focused on white light dispersion, imaging light intensity, and color reflection. The other group learns more about reflection, refraction, and energy conversion.

![Image](image_url)

Figure 6. Snapshots of student activities for (a) energy conversion with the use of a solar cell, (b) white light dispersion with LEDs and a prism, (c) imaging using a plastic ball and a convex lens, (d) color dispersion, and (e) an application of refraction by combining a laser pointer with a cylindrical lens to generate a line of light.

3.1 Evaluations

To examine our approach, we end our demonstration with the student evaluation. Our evaluation form has two parts. The first part contains choice assessment while the latter part is for open-minded outlook. For the first part of the evaluation, students mark their desired choice in each topic. Analysis of all evaluation data in this case is shown in Table 3.
Table 3. Evaluation results from primary school students.

<table>
<thead>
<tr>
<th>Topics</th>
<th>Joy and Gain</th>
<th>Norm</th>
<th>Boredom</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Light Dispersion</td>
<td>99.26%</td>
<td>0.18%</td>
<td>0.18%</td>
</tr>
<tr>
<td>Imaging</td>
<td>98.16%</td>
<td>0.74%</td>
<td>0.74%</td>
</tr>
<tr>
<td>Reflection</td>
<td>99.25%</td>
<td>0.19%</td>
<td>0.37%</td>
</tr>
<tr>
<td>Color Reflection</td>
<td>97.61%</td>
<td>0.74%</td>
<td>0.92%</td>
</tr>
<tr>
<td>Refraction</td>
<td>98.69%</td>
<td>0.19%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Energy Conversion</td>
<td>99.44%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>

Table 3 indicates that our learning-by-playing approach with critical-thinking process helps students gain more knowledge about OP with fun. In this high evaluation, we also find that some of them knew some topics but they understood more. Less than one percent of students consider all topics excluding energy conversion are normal. The remaining percentage of students regards our approach boring because they gained nothing in particular to the color absorption and the imaging.

We intensely look into the percent of students in the boredom section in order to find out what are the motives behind their evaluations. We believe that communication skill of each instructor, personality of both the instructor and the student, and misconception of students play important roles. We also find that a few students in this group are in the schools located at the frontier and have weak communication in Thai language. Some students need specific teaching style. Those two student types are shy to encounter and interact with us. In addition, based on advices from some students, putting them in the front seat helps get their involvement.

3.2 Lessons Learned

We obtain a variety of lessons learned from the primary school students with our learning-by-playing approach. Our lessons have two main parts.

The first part receives directly from the observation and interaction:

- Thai students are good quality of knowledge in basic OP but they lack skill in concluding what they learn as well as in explaining their ideas. To solve this problem, inspiration and confidence build-up are needed.
- Some students are aware of the safety in plugging in some electrical components to the AC supply and in using the laser pointer. This is valuable to us for the improvement of our electronic components in our Long Len kit.
- In addition to the enjoyment, interactions among students as well as curious questions from student show that they have creative thinking in learning things. For example, they use the color filter to learn the absorption of light without our advice.
- Process of learning approach should be flexible related to the interaction among students and us.

The second part gets from the evaluation form:

- High percent of assessment is achievable because we encounter the students with relaxing and playing. As a result, most students have fun while learning even though they thought OP seems difficult.
Based on students’ feedbacks collected after our activity, some students show an interest in studying OP in the future because they enjoy learning OP.

From the open-minded outlook part, some students are planning to share their experiences gained during our activity to their family.

Apart from having their hands-on our photonics kit, plain-text explanation and friendly conversation are necessary to get their cooperation.

4. CONCLUSIONS

With our learning-by-playing approach, most of primary school students in the grades 4-6 are capable of understanding advance optics and photonics. Our open-playing technique assists the students in opening their mind for learning. A significant point in this approach for Thai students is that instructors or teachers have to effectively organize students into the topics. Inspiring them is a first step in getting student attention. Then with proper demonstrations and communication skill, students are able to have critical thinking in some topics and show more interactions through the end of the class. From our assessment, we discover that most of participated students have fun during our class and gain more knowledge in OP. In addition, we have learned many lessons from the primary school students that will be taken into consideration to improve our activities. Further works include more effective ways to inspire students, to keep them learning OP, and to embed them with a critical-thinking process.

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El Día de la Luz – II (The Day of Light -II) – Optics Demonstration for High School Students

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ABSTRACT: Photonics is an upcoming field that offers immense possibilities in frontier science, technology, and industry. The topic needs to be introduced among the young students to motivate their interest and passion for light. However, the potential of optics and photonics as a very exciting part of science is not always fully explored in high school education. With the motivation to contribute an initiative along these lines, a two-hour program was developed and successfully implemented at ICFO-The institute of photonics sciences. Further recent efforts were directed towards the improvement of this program which resulted in the advanced version. This improved version focuses on explaining the ray and wave nature of light, as well as the demonstration of the conservation of energy in relation to optics. The event was organized and the demonstrations were carried out by ICFO PhD students enrolled in the ICFO Optical Society of America (OSA) and SPIE student chapters.

Keywords: Optics education, Optics experimental demonstrations, Educational outreach, Fascination of light.

1. INTRODUCTION

Science and technology of photonics have revolutionized almost every aspect of our life in the last decade. From the use of lasers in CD players and bar code readers to very high speed data communication through optical fibers, photonics has provided many a advances in fields ranging from entertainment to information technology. On the other hand using tools of photonics, scientists have gained insight into many aspects of fundamental science ranging from quantum physics to biology and medicine. In the coming years, the field of photonics will be full of advancements with newer optical tools, techniques and devices that are being introduced at a very rapid rate1.

One prime requirement to sustain such an explosive growth in photonics is well trained workforce. Hence training in photonics is of utmost importance. At the graduate level many efforts are devoted to this aim. Many universities have been building up infrastructure to introduce new courses in photonics and optical engineering and upgrading the curriculum in traditional physics and engineering courses to introduce topics in photonics.

This effort in building up workforce in photonics needs a sustained effort starting from an early stage, specifically at the high school level. High school is the time when students make career choices. If universities need to attract talented students to these efforts, at the high school level much has to be done in creating awareness and interest for this field. Photonics needs to be introduced among the young students to motivate their interest and passion for light. However, the potential of optics and photonics as a very exciting part of science is not always fully exposed in high school education. There are two main reasons for this: 1) Optics that forms the very basics of photonics, in general, is not a part of high school science curriculum and 2) schools lack resources to introduce optics through experimental demonstrations that would introduce optics as an exciting applied science. In schools which do teach optics, very often the teaching material is not sufficiently comprehensive. The lack of awareness among high school students that optics is now in the forefront of technology and that it can open up many avenues for future careers, has driven some talented students away from taking up photonics related courses at the graduate level. However, simple experimental demonstrations, invoking various skills like, observing, comparing, describing, inferring and predicting are excellent tools to make optics a topic of interest among the youth2, 3.
With the motivation to contribute an initiative in creating awareness about optics, its prospects as the foundation of photonics and the immense possibilities offered by this field, a two-hour program for secondary school students, “El día de la luz”, was developed and implemented earlier at ICFO and various schools in Barcelona. On successful implementation of the program, we further focused our efforts towards the introduction of some key concepts, resulting in an advanced version of the program, “El día de la luz-II”. This version of the program explains the ray and wave nature of light, as well as the demonstration of the conservation of energy in relation with optics.

1.1 ICONS

ICONS stands for “ICFO Network and Organization of Students,” based at ICFO-The Institute of photonic sciences, Barcelona, Spain, and is the joint student organization of OSA and SPIE student chapters. A number of post-graduate students from more than 15 countries, with light as their passion, are enrolled in OSA and SPIE chapters as a part of ICONS. ICONS organizes a variety of events like weekly colloquium by researchers from ICFO, coffee sessions with eminent scientists in the field of optics and photonics, regular laboratory visits for students from various universities, science week in Barcelona, etc. As a part of the local outreach activities, it has been actively contributing to the promotion of optics and photonics among young students through programs like “El día de la luz” (The day of light). ICFO-OSA student chapter, which is now a part of ICONS, is also the founder “International Network of OSA Student chapters”, (IONS), an exchange program among OSA student chapters to meet optics students all over the world by networking and opening up new avenues for international collaborations.

ICONS has also played a significant role in setting the stage for the “Fascination of Light”. Fascination of light is an itinerary exhibition that aims at bringing the physics and technologies based on light to the general public and school kids. The age range for the participants is from 8 years old until 17 years and also for public not directly involved in science. Fascination of light is an initiative of the German ministry of education and the European Union. The exhibit has travelled around various cities in Europe and at the end of year 2008, the exhibition visited Barcelona. It was hosted at ICFO and a great part of the logistics of this event was the responsibility of ICONS. In Barcelona, fascination of light had more than 1200 visitors in a three weeks period. The visits were organized in such a way that the schools set an appointment to visit the exhibit. At ICFO we had two visits per day. The exhibit was distributed in 5 main sections and small groups of around eight people were visiting each room at a time. In each room an ICONS member was in charge of explaining the different displays of the exhibition. The visit lasted about 90 minutes. As an original part of the hosting of fascination of light in Barcelona, it is worth mentioning that before bringing the visitor to the exhibit a small introduction to ICFO and to some of the fascinating
issues behind light was presented. In this introduction a brief explanation of why we are able to see in three dimensions (3D) was given based on games with the eyes, as shown in Fig. 1(a, b). Finally, some 3D pictures were shown and the appropriate glasses to see them were given. The content of this introduction was taken from activities that are done by the student chapter in the “El día de la luz” program.

2. EL DÍA DE LA LUZ (THE DAY OF LIGHT)

With motivation to expose secondary school students to the field of optics and photonics using daily applications, we developed and implemented a two hour-long hands-on introduction to optics for high school students under the name “El día de la luz”. In this workshop, we started by instigating some fundamental questions such as, origin of light, various sources of light and its applications in our daily life, after which we introduce the basic concepts of light, namely, wavelength, reflection, refraction, polarization, and stereoscopic vision. The concepts of reflection and refraction are then used to practically demonstrate total internal reflection and its application in guiding light through an optical fiber. The introduction to polarization is used to explain the working principle of liquid crystals and their application in various optical and electronic gadgets. The stereoscopic vision is practically demonstrated by 3D images and 3D glasses, making the students realize the need for two eyes. This program has the advantage of not being very lengthy, which allows school teachers and students to attend it without sacrificing regular curricular activities. The workshop does not require sophisticated equipment so that teachers and students can easily learn how to reproduce the demonstration themselves with the help of take home materials, such as liquid crystal cells and 3D pictures, provided during the event.

3. EL DÍA DE LA LUZ - II (THE DAY OF LIGHT - II)

This section deals with the improved version of “El día de la luz” for high school students. The event starts with a general introduction to optics and describing the evolutionary aspects of light starting from the particle nature of light as proposed by Empedocles, Pythagoras and Isaac Newton. Further more, light as wave is presented in conjunction with the classic works of Christian Huygens, James Clerk Maxwell and Heinrich Hertz. The dual nature of light is then described by referring to the discoveries by Max Planck and Albert Einstein. This method of approach not only gives the students a perspective for the
evolution of light in the way it is understood today, but also makes them aware of renowned mathematicians and physicists who made significant contributions for the advancement of the science of light. Based on the discussions in the introduction, the demonstrations are classified into three categories as shown in Fig. 2.

They are,

1. Geometrical optics
2. Wave optics
3. Optical energy conversion

Then the students are divided into three groups to undergo the demonstrative sessions, giving insight using simple experiments. They are also provided with a leaflet that summarizes our demonstrations as shown in Fig. 2. Some of the demonstrations used in this program are home made and some are from the “Optics Suitcase”.

3. Geometrical optics

First of all, basic concepts of geometrical optics are introduced using a few slides. The students learn that geometrical optics, or ray optics, describes light propagation in terms of “rays”: rays are bent at the interface between two dissimilar media, and may be curved in a medium in which the refractive index is a function of position. Geometrical optics provides rules for propagating these rays through an optical system, which indicates how the actual wave-front will propagate and are very useful in everyday life at the moment of designing a pair of glasses, for instance.

Geometrical optics, moreover, can be used to describe the working principle of some of the optical instruments like telescope, microscope, kaleidoscope, periscope and pinhole camera. All these devices are usually well known to the students, but they do not usually know how they work. Practical demonstration of their working principle helps them visualizing the concepts that have been introduced previously on the slides. A gadget pen, made of two lenses, allow us to explain at the same time a very basic example of a telescope and a microscope and how light rays that form an image can be expanded or compressed by using a couple of lenses with different focal lengths, looking from one side to the other small objects are magnified, while farther objects can be magnified when reverting the order of the lenses in front of the eye.

A student playing with the kaleidoscope is shown in Fig. 3. The periscope is again a good tool to explain the ray approximation in Geometric Optics: the students can see how mirrors can bend and direct light, guiding the formation of images. A pinhole camera is a very simple camera with no lens and a single very small aperture. Simply explained, it is a light-proof box with a small hole in one side. Light from a scene passes through this single point and projects an inverted
image on the opposite side of the box. Cameras using small apertures, and the human eye in bright light, both act like a pinhole camera. Again this can easily be explained to the students interpreting it according to the ray description of light used in Geometrical Optics. In our case the pinhole camera is a home made one. We use a carton box with a small hole which projects the inverted image on a white paper.

3.2 Wave optics

In the part of wave optics, we conduct a series of hands-on experiments to demonstrate the wave nature of light such as polarization, birefringence, and interference of light with diffraction gratings.

We start with a review of previous “El Día de la Luz”, that is, refraction, reflection, and polarization. To demonstrate refraction, we dip a pen in water in which the pen looks bent in the water due to refraction as shown in Fig. 4(a). By this simple example, students realize that light changes its direction when light passes from one medium to another with different refractive index.

We used a hemi-cylindrical plastic container with a protractor on top and a laser beam to demonstrate the total-internal reflection. Following the procedure shown in Fig. 4(b), the students are able to measure the critical angle for different liquids such as water and juice.

![Fig. 4. Simple experiments to demonstrate (a) refraction of light and (b) total internal reflection.](image)

With plastic polarizers, students learn that light as wave has two orthogonal direction of oscillation called polarization and observe that light cannot pass through two crossed polarizers.

We teach them with slides that material can be birefringent or anisotropic and light with different polarization can propagate differently. This is because birefringence causes decomposition of a wave of light into two waves (the ordinary wave and extraordinary wave) when it passes through anisotropic materials such as calcite, depending on the polarization of the light. Anisotropic materials have different refractive indices for different polarizations.

Later on they were introduced to the new demonstration of birefringence with calcite crystal. When you place a calcite crystal on the newspaper, double letters are seen as shown in Fig. 5(a). Then, students are asked to put a polarizer and realize that one of the images disappears as image with one of the polarizations is blocked by the polarizer. As students laterally rotate the polarizer the current images disappears and other image appears. Another characteristic of the wave nature of light is interference. To introduce this concept we use slides and a movie. We then explain that waves from two point sources can interact and create interference patterns. With plastic diffraction gratings as in Fig. 5(b), we demonstrate that laser beam
splits into several spots after the grating due to the diffraction. Moreover, students observe that light with different colours diffract by different amounts, red diffracts more than green.

We pass diffraction gratings and flash lights that emit white light to students and made of the plastic diffraction gratings from ‘Optics Suitcase’ provided by OSA to students\textsuperscript{10}. They shine white light through the plastic diffraction grating, and see that white light is composed of different colours. Finally, students wear glasses made of diffraction gratings and enjoy seeing various colours of light from white light sources.

### 3.3 Optical energy conversion

This session constitutes a set of four demonstrations, as listed below, explaining the conversion of energy from one form to another in various applications of light as shown in Table. 1.

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Demonstration</th>
<th>Energy conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Radiometer</td>
<td>Light energy $\rightarrow$ Heat energy $\rightarrow$ Mechanical energy</td>
</tr>
<tr>
<td>2</td>
<td>Solar cell</td>
<td>Light energy $\rightarrow$ Electrical energy $\rightarrow$ Mechanical energy</td>
</tr>
<tr>
<td>3</td>
<td>Plasma ball</td>
<td>Electrical energy $\rightarrow$ Light energy</td>
</tr>
<tr>
<td>4</td>
<td>Optical communication</td>
<td>Sound energy $\rightarrow$ Electrical energy $\rightarrow$ Light energy</td>
</tr>
<tr>
<td></td>
<td>Transmitter Receiver</td>
<td>Light energy $\rightarrow$ Electrical energy $\rightarrow$ Sound energy</td>
</tr>
</tbody>
</table>

Table. 1. Energy conversion into various forms in different experimental demonstrations.

The session starts with the demonstration of Crook’s radiometer as shown in Fig. 6(a), where a student is asked to shine a flash lamp on the wings of a radiometer and observe that the wings start rotating in the presence of light. This makes them understand that some energy is imparted to the wings in the form of heat by the light from the flash lamp, which in turn makes them rotate. Thus, showing the conversion of light energy to heat energy and then to mechanical energy. The students then proceed to experiment with solar cell as in Fig. 6(b), where the solar cell, on illumination using a flash lamp switches ON a motor connected to it. The energy conversion here is explained with the help of Einstein’s photoelectric effect.
Fig. 6. Demonstration of optical energy conversion using (a) crook's radiometer and (b) solar cell.

The Plasma ball shown in Fig. 7(a) is the most attractive part of the session. Although it was difficult for them to understand about the creation of plasma and the discharge occurring, it developed the curiosity in the students along with fun. Finally the students are introduced to the modern fiber optic communication system with the help of a home made prototype shown in Fig. 7(b), which consists of a transmitter, a fiber optic channel and a receiver. The individual parts of the system are explained and students are asked to connect the fiber channel between transmitter and receiver so that they can communicate among themselves with it. This demonstration not only explains the conversion of energy and guiding light, but also gives them an insight into the technologies they use in their daily life.

3.4 Concluding remarks

The program is concluded with a review of all the experiments demonstrated, by posing some simple questions. The students actively participated in this session by inferring interesting concepts from their observations. The organizing team of the program, shown in Fig. 8, helped the students in answering the questions. After this questions-answer session, the students are shown a video, “Careers in Optics”12. This video allows the students to experience the excitement of people working in the fascinating and rapidly expanding fields of optics and photonics, thus projecting optics as an exciting profession with a bright future and contains explanation of optics and photonics technologies, examples of its many applications, interviews
with enthusiastic and diverse individuals who work in optics. At the end we have also provided the school with an “Optics Education Directory”, which is a comprehensive guide to optics courses and degree programs offered at educational institutions around the world13,14. This helps the students to choose the best school for their higher education in the field of optics and photonics.

4. CONCLUSIONS

In conclusion we have developed an advanced version of “El día de luz” for high school students and have successfully implemented in various schools in the metropolitan area of Barcelona. This program focused on some important concepts of light illustrating ray and wave nature of light. Moreover, by means of simple experimental demonstrations, some very interesting applications show the conversion of optical energy from one form to the other. The simple demonstrations, not only explain the basic physics, but also its implementation in various applications used in our daily life. This event with active involvement of the students and teachers is very well appreciated. A video about “careers in optics” from SPIE and OSA is shown to motivate the students to pursue their further studies in optics. In addition an “Optics Education Directory” is provided to the teachers to help them in guiding the students, to choose interesting career path.

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The University for Children is a very successful event aiming to spark children’s interest in science, in this particular lecture in Optics and Photonics. It is from brain research that we know about the significant dependence of successful learning on the fun factor. Researchers in this field have shown that knowledge acquired with fun is stored for a longer time in the long-term memory and can be used both more efficiently and more creatively [1], [2]. Such an opportunity to inspire the young generation for science must not be wasted. The world of Photonics and Optics provides us with a nearly inexhaustible source of opportunities of this kind.

Keywords: 000.2060 Education, Education in Optics and Photonics

1 INTRODUCTION

Attracted by the child-friendly logo (Fig. 1) and the motivation to discover Optics and Photonics on a scientific level, more than 170 children from both sides of the Rhine (Germany and France) gathered in our University of Applied Science to be enchanted by the "Magic of Light".

To ensure the success of events of this kind and to gain the children’s acceptance, it is highly recommended to use impressive experiments and to combine these with slightly less spectacular experiments in between. Experiences like these are engraved into the children's memories, yielding a positive learning effect. Once the children understand the basic concepts and relations - the fun factor emerges and first success comes up [3].

The Children’s University - having already become tradition at the University of Applied Sciences in Offenburg - was held eight times by now (it is scheduled semiyearly, typically around July and November) by professors from our university. Topics covered by this presentation that is aimed to motivate children for science range from Physics over Chemistry to Biochemistry with a high number of interesting and inspiring experiments. In the last edition of Children’s University, I was invited to give a lecture entitled “The Magic of Light” covering the basics of optics to future researchers of age 8-12 in a motivating and child-friendly way. Myself being enthusiastic about the last visit to Frontiers in Optics in Rochester / New York where I met Charles H. Townes [4], John C. Mather, Steven Chu, Emil Wolf and many other celebrities in the field of optics, I was determined to spread this enthusiasm to the children attending the lecture.

2 PRELIMINARY DIDACTICAL PREPARATIONS FOR THE LECTURE

Among the most difficult aspects that were considered during the preparations preceding this lecture, the age group of the children – between 8 and 12 years – stands out particularly, since the children’s previous knowledge in mathematics and physics cannot be assumed. This imposes a problem since this means in particular that the children are unfamiliar
with the abstract mathematical modeling of complex processes. Certainly one also needs to adapt both the examples chosen and the language used for explanation, however trying not to lose too much information: As previously stated, we aim for an intuitive grasp of complex concepts and processes occurring in Optics. The lecture “The Magic of Light” was composed of the following topics:

- Light as an electromagnetic wave
- Light is energy
- Light has a speed
- Reflection of light
- Refraction of light
- Total internal reflection of light
- Applications of total internal reflection: optical fibers, optical communication, WDMD
- LASER
- Experiments demonstrating the functionality of the LASER
- Applications of the LASER: laser printer, optical data storage (CD, DVD, Blu Ray)
- LASERs in medicine (SPIE poster)

We used experiments that were conducted in front of the lecture hall, graphics, animations, a live-stream and PowerPoint slides. The forms of speech we employed were monologues, dialogues, and in particular the guided conversation. Luckily the children participated actively and also brought in to the lecture an unexpected amount of previous knowledge. Nonetheless they were visibly fascinated by the presented experiments.

Lectures of this kind, i.e. lectures incorporating an appreciable amount of experiments, have a very high learning effect – even if the experiments are conducted only by the lecturer. Another guarantee of success is the parallel presentation of the experiments and specifically synchronized PowerPoint-slides. This way, the slides operate like instructions for the experiments.

3 LEARNING GOALS

To guarantee for the success of the lecture, a correct and precise definition of the learning goals [5] that should be achieved is necessary. Once more, we have to stress the importance of the proper adaptation of the lecture to the listeners’ age group of 8-12 years.

The most important learning goal we set up for the lecture was to convey fascination for science (physics in general and optics in particular) and technology to the young audience, since the curiosity and thirst for knowledge of children in this age group is enormous. We point out that the knowledge children in this age achieve with fun is knowledge they can use for their whole life – furthermore, knowledge that has been achieved with fun can also be used creatively later on. This presents an outstanding premise for the potential scientists of tomorrow.

Considering the taxonomy of learning goals proposed by Bloom [6] – [11], we can claim that the learning goals we imposed on the lecture reached level K4:
- Knowledge (K1): Precise (if not literal) reproduction of information
- Understanding (K2): Ability of applying sense-preserving transformations to knowledge, ability of paraphrasing knowledge in own words and finding examples;
- Application (K3): Ability of applying abstractions, rules, methods, algorithms etc. in concrete situations;
- Analysis (K4): Ability of decomposing ideas and problem settings into its elements and comparing problems, spotting differences;
- Synthesis (K5): Composition of individual elements to a whole;
- Evaluation (K6)

The most important goal of this lecture is to spread enthusiasm for physics and especially for optics to the children. We were aiming at an age-adapted understanding of fundamental concepts such as reflection and also tried to enable the children to reproduce the ideas of refraction and total internal reflection. Furthermore we presented interesting applications of optics such as the optical fiber, the laser - and in turn their applications.

4 FIGURES, GRAPHICS, ANIMATIONS AND LIVE-BROADCAST

When striving for a sensible variety of learning media, it is necessary to reach all channels of information flow. However, one must pay attention not to overdose the information input: when overwhelming the audience, it is rather unlikely that much information reaches the intended recipients.

Pictures tell more than thousand words: By the help of suitable figures and posters that were partly provided by the SPIE and OSA, the children were exposed to new views of the world. Combining these figures with animations, one can achieve even more of the learning goals previously described: Animations convey functional interdependencies better than static images. The young audience was obviously fascinated by the images and animations. Quite often we noticed during the lecture that precise questions concerning further applications and relationships to other areas were asked.

4.1 Graphics

The usage of figures is of great importance for the success of the lecture. We should not forget that “a picture tells more than thousand words”. The self-made images were complemented by images excerpted from learned journals such as Nature and the German magazine “Der Spiegel”. The OSA [12] and SPIE [13] also offered a multitude of graphical learning material that was used successfully. For describing semiconductor lasers, the SPIE poster reproduced in Fig. 19 was used, and for presenting the applications of lasers in medicine, we used the SPIE poster in Fig. 20. Furthermore, we used the poster series “Optical Phenomena” by the OSA outside the lecture hall, so that the children were able to contemplate the “Beauty of Optics” before the lecture started.

4.2 Animations

The animations were introduced in order to polarize the interest of the young audience. Since children usually like cartoon animations, we assumed a natural affinity for scientific animations. We used animations to demonstrate the functionality of optic fibers and the WDMD. A good animation has to be self-explanatory, should impress and should also be memorable since we want the children to remember the information conveyed by the animation later on in order to use it creatively. If a picture tells more than thousand words, an animation can tell more than thousand pictures [3]. Some animations have been prepared in PowerPoint and accompanied the conducted experiments like instructions.

4.3 Film Sequences

The film sequences were used in order to facilitate the understanding of complex processes and applications. In addition, they could be used as a change of pace and last but not least provided for the lecturer’s recreation. Film sequences have to be chosen carefully with respect to the topic covered and should not span a too large time frame. For a seamless transi-
tion from lecture to sequence, we embedded the sequences into the PowerPoint presentation. The video material we chose originated from documentary movies, OSA movies, self-created movies and even two on-the-fly recordings captured during the lecture. In total, we used 8 sequences with a total length of about 11 minutes.

1. Experiment with fire department, Fig. 3 and Fig. 6 275 s Live broadcast
2. Optical fiber 60 s Documentary movie
3. Production of fibers and functionality of DWDM 89 s Documentary movie
4. Functionality of a laser printer 46 s Documentary movie
5. Functionality of CD- / DVD-ROM 83 s Documentary movie, OSA
6. Functionality of a laser, analogy with mouse traps 76 s Live broadcast
7. Functionality of a laser, analogy with mouse traps, Fig. 14 - Fig. 15 16 s Self recorded footage
8. Apollo, Earth-Moon distance measurements 26 s Documentary movie, OSA

4.4 Live Broadcasting

The live broadcasting was integrated into the lecture in order to make the previously described outdoor experiment possible. Furthermore, the young audience was able to observe the experiment from two different angles thanks to a split-screen installation. The success of the experiment could not have been guaranteed without the usage of this split-screen. Furthermore, we established a bidirectional audio connection with the lecture hall. This enabled us to react to the children’s wishes and repeat the experiment three times in total.

5 THE PHILOSOPHY OF OPTICS FORMULATED CLEARLY IN WELL-UNDERSTANDABLE EXPERIMENTS

In this part we want to stress some experiments and applications that should yield a visual understanding of optics.

5.1 The nature of light: Light is an electromagnetic wave

Figure 4 shows a part of the slide we showed to the children when teaching them that light is an electromagnetic wave and that especially light is composed of the colors one can observe in a rainbow. While showing this slide, a white light beam was decomposed into the color spectrum using a prism at the optical panel. The picture under the caption "experiment", seen at the right side of the slide, depicts the outcome of the experiment - this is exactly what the children were able to observe. Many among them already knew that white light is composed of the rainbow colors.

5.2 Light is Energy

It surely is not easy to communicate to young listeners that light means energy – but one can visualize it efficiently by means of a simple yet impressive experiment. This experiment included a Tesla transformer, a so-called plasma lamp. The children were impressed by the effects of the plasma lamp and perceived that its discharges were influenced by hand
movements. All these changes were induced by the change of the electromagnetic field surrounding the plasma lamp (Tesla coil). A part of this electric energy was then transformed into light by means of a neon tube. (Fig. 5)

Figure 4: Experiment – Light is an electromagnetic wave

Figure 5: Experimental setup using a Tesla coil to demonstrate that light is energy

5.3 Light has a speed

As is well-known, we look into the past when contemplating the starry sky. In a dialogue we conducted with the children, we found out that some among them already knew that light has a speed amounting to about 300,000 kilometers per second. Some of them even explained this speed as “fast enough to travel eight times around earth in one second”. Given this previous knowledge, we could explain together with the children why we see the past images of stars in the sky: Light needs a certain time to cover the distance to Earth. We wanted to impart this knowledge to all participants and in a guided dialogue we found out that we can compare traveling light with a water beam. It was very interesting to find out who would be best suited for an experiment involving water rays. It didn’t take long for their answer to occur: “Of course! The fire department!” Naturally, the children were highly surprised when a fire engine stood in front of our door, ready for our experiment (Fig. 6). This didactic measure was obviously intended and created a great amazement. To guarantee the success of learning, the experiment was broadcasted into the lecture hall by means of a video transmission. For a better visualization and understanding, we recorded the experiment from two different angles: frontal and perpendicular to the water jet. This experiment caused a big delight, forcing us to repeat it two times and to play the recorded footage.

Figure 6: Performed experiment using the analogy between light rays and water rays
5.4 Reflection, refraction and total internal reflection

In the first part of the lecture we focused on the foundations of geometric optic. First, we deduced the law of reflection experimentally and helped the children to formulate it in their own manner (Fig. 7).

Since we assumed that a deduction of the law of refraction is not possible for children in the age of 8-12 years, we only presented an example (Fig. 8) and stated that the light ray is subject to a break and that this effect can appear only when light passes the border between two optical media that have different optical densities [14].

When presenting total internal reflection (Fig. 9), we showed that this effect appears only when light passes from an optically dense medium to a medium with lower optical density, that there exists a critical angle for this phenomenon and especially that the angle of incidence equals the exit angle – as previously stated for the reflection.

To improve the learning success, the experiments were conducted under accompaniment of a dynamic PowerPoint slide providing more theoretical background.

5.5 Optical fiber and optical communication

To demonstrate the functionality of an optical fiber, a previous definition of total internal reflection is necessary. To reach this goal, we firstly presented a laser beam that was "trapped" in a water jet - a simple yet quite impressive experiment.

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Figure 7: Experiment for explaining reflection

Figure 8: Experiment for explaining refraction

Figure 9: Experiment for explaining total internal reflection

Figure 10: Model of light propagation in an optical fiber
An easy way to describe the propagation of light through an optical fiber is an experimental setup including a laser beam between two parallel mirrors, as seen in Fig. 10. The reflection of the beam at both mirrors represents the total internal reflection between the core and the cladding of the optical fiber [15]–[17].

Another very beautiful experiment that describes the propagation of light in optical fibers very clearly is the “laser beam in gelatin”. The advantage of this experiment lies in the fact that it becomes possible to show how light propagates in curved areas and coupled optical fibers (Fig. 11). The children were able to apply the previously obtained knowledge of total internal reflection and furthermore suggested their own examples and were able to explain the reason why light can propagate through an optical fiber although this fiber might be bent and wound. Then we proved this using the experiment setup described in Fig. 11.

Equipped with these new insights, the young audience was able to understand the way in which messages are transmitted in optical communications. Since digitally coded information can be represented as a string containing only zeros and ones, the children understood that a "one" can be translated to "light" and a "zero" to "no light". In order to deepen this understanding, we used an animation whose final frame is reproduced in figure 12. The model optical fiber was equipped with a sender that emitted light pulses and a receiver that registered the pulses. The light pulses propagate from sender to receiver as shown in the animation while the transmitted bits are represented in green.

A further learning effect was achieved when presenting the possibilities of transferring acoustic signals by optical media. The effect reached its maximum when the children found out that the signal transmission is interrupted when the light beam is interrupted e.g. by a hand. An interesting remark concerning this experiment was the question whether it would be dangerous to hold a hand in the laser beam. This proves the achievement of a higher K value in the learning goal hierarchy. The children were amazed when finding out that e.g. in the automotive industry there exist lasers that can cut off a hand instantly. The technology used to pass optical fibers was presented in a movie sequence of about 90 seconds' length taken from a documentary movie. Furthermore, we used a movie of about 3 minutes' length to summarize the fabrication of optical fibers. Finally, the enormous amount of data that can be transmitted with an optical fiber (1.5 TB) was emphasized.

Next we presented the Wavelength Division Multiplexing and Demultiplexing WDMD method [15] that decomposes light into its "color components" and enables further use of the single color channels. To reach this goal, the drawing reproduced in figure 13 was used. By means of a suitable animation the children were able to see the way in which the pulses of colored light originating from the individual light sources mix up in the optical fiber and are subsequently de-
coupled in order to transmit them to the individual receivers. This drawing additionally showed the increase in transmission rates and provided an overview of the optical fiber-based networking in Europe [18].

5.6 Laser

One of the most challenging parts of the lecture was to explain the functionality of the laser to the young audience. After explaining the term “laser” as an acronym of “Light Amplification by Stimulated Emission of Radiation”, we included another surprise experiment after long consideration. In this experiment, we modeled the concept of a chain reaction adapted to the nature of light and also described the limits of the experiment to the children.

The experiment consists of about 30-40 mouse traps that have been wound up and on which a table tennis ball was placed. The complete setup was surrounded by a Perspex box, as depicted in Fig. 14. We firstly explained to the children that every mouse trap corresponds to one atom and that the table tennis ball represents a photon emitted by the atom. An additional ball (corresponding to the initial photon) was dropped into the box through an opening. This caused a rapid triggering of the mouse traps that in turn made the balls in the box bounce (Fig. 15). Unfortunately, the analogy here reaches its limits. We explained to the children that in a laser the photons represented by table tennis balls reflect from the two mirrors of the gain medium (in our case represented by the box). One of the two mirrors is slightly transparent and allows photons to pass when they have achieved the necessary intensity by sufficiently many reflections.

Although this experiment is quite beautiful, its success is not very obvious. On the one hand, it might be possible that the children don’t understand the analogy and on the other hand, the mouse traps could be triggered by the slightest vibration. The latter happened during the preparations directly preceding the lecture – but thanks to the aptitude of our assistants we were able to reconstruct the setup just in time for the lecture. To minimize the first risk stated we recorded the experiment during the lecture and showed slow motion footage of it while simultaneously explaining the events step by step. We finally once more emphasized the limits of the analogy underlying the experiment.

Figure 13: The working principle of the WDMD, © Der Spiegel, [18]
5.7 Laser Applications

To show some applications of the laser in everyday life, we first explained the functionality of CD-ROMS, DVD-ROMs and Blu-Ray discs by a movie sequence produced by the OSA [12]. Additionally, the future optical storage media which will be able to store data by the two photon technology were presented.

The enormous amount of data that can be captured by these optical storage media was compared to the capacity of today's media. In numbers: A WORM could store the amount of data that would otherwise require 15,600 CD-ROMs, 2100 DVDs or 230 Blu Ray discs. These amounts of media would pile up to 23.5m, 3.2m or 65cm respectively. Another application we presented was the laser printer, whose functionality was explained by a movie sequence and a dismantled laser printer. The last application we presented was the measurement of distances by means of lasers and the resulting possibility of measuring the distance between Earth and Moon with errors in the dimension of a few centimeters.

A good diversion was provided by the Optical Phenomena Poster Series by the OSA. Impressed by the beautiful pictures of optics, the children's curiosity reached an even higher level.

www.osa.org or http://www.opticsforkids.org/teachersparents/outreach/
www.spie.org
http://spie.org/x31474.xml

Figure 16: Slide - Laser Application in optical data storage, comparison between CD-ROM, DVD-ROM, Blu Ray and the next generation two photon storage media WORM [19]

Figure 17: OSA's Optical Phenomena Poster Series in our University (exhibited in the corridor).
6 OSA AND SPIE EDUCATIONAL MATERIAL

Figure 18: OSA - Optical Phenomena Poster Series [12] © OSA

Figure 19: SPIE poster - Semiconductor lasers [13] © SPIE

Figure 20: SPIE poster - Applications of lasers in medicine [13] © SPIE
7 CONCLUSION

As a general conclusion, we can claim that the children had very much fun during the lecture. This was emphasized by repeated applauses and calls for encore. In the lecturer’s point of view, the learning goals have been achieved and – in some situations – even exceeded by the children’s unexpected collaboration and previous knowledge that they applied successfully. Furthermore, we are quite convinced that the experiments will stay in the children’s minds.

Last but not least the children were positively surprised by the events.

Together with colleagues from the Laboratoire des Systemes Photoniques from the University of Strasbourg, we intend to translate the courses to make them available to a French audience.

Acknowledgements

It is common practice to welcome the participants of the Children's University with a small present. By the kind support of the Thorlabs Company, we were able to offer to each participant a ball pen with an impressive integrated LED illumination. We once more want to thank Dr. Angelika Küng, manager at Thorlabs who ordered the LED ballpens directly from the USA for us.

![Figure 21: Present for the participants](image)

Thanks also to the OSA and the SPIE for their kind support with the excellent learning aids (posters, movies) published on their web sites. Thanks to Nature and VDE for the provided figures.

We also want to thank the organization team of the E-Day (San Jose/California 2007 and Rochester/New York 2008) in the annual Frontiers in Optics conference that created a platform for many interesting discussions with other people teaching optics.

For their involvement in the lecture "The Magic of Light" we also want to thank the Fire Department Offenburg. Without their help, one substantial experiment could not have been presented so impressively.

REFERENCES


KINDERGARTEN’ OPTICS

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ABSTRACT

The introduction to our school’ students of the wonders of light and optics and its understanding can and should be made as extensively as possible. As soon as at kindergarten level!

A hands-on approach leading the students to observe experiment and discover themselves in a critical committed and active way the different aspects of light and optics should be employed at all school levels and must be the main driving pedagogical practice of all learning process of science and technology.

In this communication we present a series of experiments and support material designed in this hands-on perspective to be used to introduce the study of optics to kindergarten and early basic school students. A critical evaluation of the first results of the application of these material with students aged 4 to 10 years will be presented.

1. Introduction

Young children are always eager to learn to see new things but also to know and to understand the world that surround them.

With reduced “pre-knowledge” usually, there are no previously acquired misconceptions or even prejudices. Also there no exams to study for… “just” the innate survival need to know. However, since they were born a permanent learning process take place at an extremely fast pace.
Children learn from the environment from what they feel from what they live. As we could see when contacting children in this age range, 4 to 10 years old, a constant reference to their every day life and previous experiences is made.

Hands-on activities are fundamental and the “natural” approach for these young students.

The first concern of the educator should be, with this clear perspective in mind, to show… or better… to let the children to “see”, to observe, to confront themselves with new objects processes and situations.

Time is fundamental and should be generously given to the young students. Of course some “pressure” can be useful… in due time… respecting each ones pace. From early kindergarten years the children should “learn”, should be lead to work in group to interact and cooperate with peers towards a common goal.

Care however should be taken by the educator in order to ensure that each student will have, in these group activities, the needed time to establish their own “knowledge” while guarantying that no children, apparently “faster”, feels uncomfortable “waiting” for the others. No sense of superiority, or inferiority, or even of condescendence, in this competition process that always appears in these situations at these ages, should be rewarded. Yet fundamental it is that the each child understands, step by step, the importance of “cooperation”, of listening the other letting the others to know of our findings, helping and accepting to be helped in the sake of a common goal.

How to do that?… a Portuguese popular saying (certainly with equivalents throughout the word!) “words are silver, silence is gold”… be patient give time to the students, and to your self…, open widely your eyes and lead the way smoothly affirmatively and discreetly. Words might be made of silver but it is fundamental that the child is able to verbalise coherently their feelings their findings their opinions. Hands-on should be complemented with a constructivist approach and others like construcionism and conceptual learning.

“Always” hands-on but not blind/mechanically… “… do this and then that and that and…” Learning is discovering… by the student… himself… actively and reflexively.

2. Light and optics at the kindergarten

Being related to one of our main senses, being the eyes a major gateway to the world that surround us, light related phenomena are rather appealing to young children. Young students readily realize the importance of seeing and the role of their eyes and of light sources. They are
particularly attracted to the colour phenomena, to reflection and transparency, to shade and changes in luminosity…

Below we present a set of simple experiments that we designed for 4 to 10 years old students and that may serve as basis for teachers and educators to use in their classrooms and in informal activities [7].

We divided the experiments in three parts. A first one intends to introduce the role of the eye and … we need light to see objects. At the second part we intend to show using a simple model how the eye works. Finally the third part deals with light and colours and is by the most attractive one for our young scientists.

3. Light and optics experiments in the kindergarten and elementary schools

3.1 Part 1.

The main concept behind this first set of experiments was: we need light to see objects.

The experiments were design to show that:

• We see an object because the light from the object enters the eye through the pupil. Constriction of the pupil limits the amount of light entering the eye, and dilating of the pupil allows more light to enter the eye. So, in bright light, the pupil constricts, and in darkness, the pupil dilates. (Experiment 1)

• There are objects that emit light (ie, light sources) and others that reflect light. (Experiment 2)

• Light is reflected from the surface of objects. Dark objects reflect little light while white objects reflect more light (Experiments 3 and 4. Figure 1.).

Experiment n° 1. Pupil observation

Background: The light enters the eye through the pupil. The pupil has to adapt to different light intensities.

Method: The children are divided into groups of 2 or 3. The room light is dimmed and penlights are distributed to each group. It is asked to one of the children to illuminate his/her eyes while the others observe the pupil closing down.

Experiment n° 2. Luminous and non-luminous objects
Background: There are objects that emit light and others that reflect light.

Method: The room is dimmed. Light emitting objects (of different types) and non-luminous objects are available and are shown. The similarities and differences between the various types of light sources and objects are discussed.

Experiment nº 3. Brighter and darker objects

Background: The light is reflected from the surface of the objects. The dark objects reflect little light while white objects reflect more light.

Method: Several objects of different colours are placed in a black box with the front face open. The room light is dimmed leaving only a small lamp behind the box. The position of the lamp is gradually changed to allow some light to reach the objects inside the box. As the inside of the box becomes more illuminated the darker objects become progressively more visible.

Experiment nº 4. Light reflected by objects

Background: The light is reflected from the surface of objects. The dark objects reflect little light while white objects reflect more light.

Method: In a very dark room, each child place him self in front of a mirror. One hand holds a penlight on one side of the face in order to lighten the nose. The child is asked to observe his/her face in the mirror (figure 1.).

Figure 1 - The light reflected by the objects’ experiment.
The experiment is repeated by holding a white cardboard with the other hand, parallel to the side not illuminated. The procedure is then repeated by replacing the white cardboard by a black one and then by cardboards of different colours. Finally the student replace the card a by a second mirror. Children record and discuss what they saw happening on the non-illuminated part of their face when using the different colours or the second mirror.

3.2 Part 2.

The main goal of these set of experiments is to illustrate how our eye work.

The experiments were design to show that:

- How the image of an object is focused on the retina. (Experiment 1)
- What is accommodation. (Experiment 2)
- Seeing “bad”… What is myopia and hyperopia. (Experiment 3)

These set of experiments were performed with a model of the human eye (figure 2.).

Figure 2- How the eye works experiments
Experiment nº 1. Using a bright light source (a candle may be used under teachers supervision), images can be focused on the model's retina simulating the human eye imaging mechanism.

Experiment nº 2. To demonstrate the accommodation the lens can turn thicker or flatter to focus the image on the retina. The lens is a chamber constructed of optically clear silicone elastomer connected by tubing to a water-filled syringe. Water forced into the lens increases its thickness and curvature; withdrawal flattens the profile of the lens, changing its focus.

Experiment nº 3. The eye model can simulate refractive problems (that some children may suffer from). Myopia and hyperopia can be simulated by changing the eyes' shape (length). It is also possible to use corrective lenses. Whenever there is a child using spectacles it may be used to illustrate the correction effect (if the teacher/educator is not confident enough with the process, is probably better to skip this step unless some students points it out (which often happens… fortunately…).

3.3 Part 3.

Colour is the main concept addressed at this last set of experiments.

The experiments were design to show that:

• It is easy to separate white light' colours (Experiments 1 and 2).
• We get white light by adding green, red and blue light (Experiment 3).
• Getting yellow, magenta or cyan colours (Experiment 4).
• Object’ colour depends on the light reflected from them (Experiment 5).

Experiment nº. 1. White light decomposition 1.

Background: White light is “composed” of all the colours in the rainbow.

Method: Using a bright white light source (placing a slit in front may help), a beam of white light is projected onto a white smooth surface (target). With a diffraction grating and, or, a prism, the light is decomposed, projecting the light spectrum on the target (it may not be easy to get all colours clearly visible… children must learn to be patient and resilient). Colour filters are placed in front the beam and, as always…, discussed.

Experiment nº. 2. White light decomposition 2.
Background: White light is “composed” of all the colours in the rainbow.

Method: CDs are distributed to the children. They observe the decomposition of sunlight (the ceiling lamp or even the light emitted by a computer screen) into the rainbow. The experiment is then repeated with a pocket spectrometer.

Experiment nº. 3. and 4. Mixing light with different colours.

Background: Adding green red and blue light allows us to get white light.

Method: Three light sources are used - one red, one green and one blue (simple flashlights with colour filter – the teacher must check ahead how red is the red, how green is the green…). The three beams are directed to one point of a smooth, not polished, white wall or board.

Children are also asked to make shadows with their hands (figure 3.) and notice all the colours observed. The experiment is repeated with only two lamps connected at a time. The concept of subtractive colour missing may also be addressed.

Figure 3 – Colour shadows.

Experiment nº. 5.

Background: The colour of objects depends on the light reflected from them.
Method: This experiment is done using the same light sources used before and at the same positions. Several cardboard pictures of different colours (the cardboard should not be shiny) are placed on a black board (figure 3). Those colour cards are illuminated with one of the lamps and repeated with each one of the other lamps and combinations of them. At the end the three lamps are switched on. (Especially for these two last experiments it is necessary to dim significantly room lights).

4. Brief discussion and conclusion

We decided to invite a group of elementary school students (ages 6 to 10 years old) to the university in order to perform these sets of experiments.

The activity was rather successful pleasing to students and teachers. Although stating their clear preference that the colour experiments were the most pleasant ones, the results were in general very positive, during the execution itself and in the follow-up activities undertaken back at the school.

Figure 4. Demonstrations and visits to museums and science fairs might be very useful if a follow up work is prepared by the educator and conducted in classroom context.

Follow-up, in fact, should always be considered very important. These non-formal or informal activities (visits to labs, museums, science fairs or lectures, figure 4.) should always be followed of work sessions in the classroom exploring the motivation achieved and developing and or
strengthening the knowledge transmitted/acquired. At the end of our activity a series of enquiries and quizzes were delivered to the teachers and asked to be returned for analysis and statistical treatment. Furthermore we distributed to the students material and short guidelines to build, on their own, a kaleidoscope and a simple pinhole camera (a muffin aluminum cup, a rubber band and a soft translucent paper sheet is enough…).

Being clear for us that the students easily and correctly are able to understand the importance of the eye in the process of seeing, we decided to explore a little bit the vision process. We used a simple model of the eye with a pupil, a rubber lens that could be inflated using a water syringe and a retina like displaceable target, which can be easily built. We expected the students to have difficulties in understanding the process or even accepting it … we were inside the eye…! In fact only older students, 9 to 10 years old, were able to deal with it.

![Figure 5. Shapes and colours.](image)

The age span covered, 4 to 10 years old, is rather large (especially as dealing with children). One must carefully cope with the differences… being flexible but always observing child’s’ reactions.

From very early ages young children are strongly attracted to colours, in particular to bright principal colours, are fascinated by the wonders of colour mixing and they seem more attracted to additive mixing opposite to what happens with school students that before being presented to the issue had previous experience in mixing ink for paintings (the subtractive process). The hands-on manipulation of colour cards (especially if being part of games) is particularly effective (figure 5.).
In general the basic concept covered by these experiments (specially part 1 and 3) are readily understood by the young children that immediately after realizing the concept present a series of examples related to their own experience (… when electricity failed and lights went off I was afraid my mama leave me alone in the dinner table…). This type of reaction happens quite often (normally older students are more “careful” expressing their feelings and ideas and restrain them selves) and is a good indication that some level of understanding of the concept was achieved.

References


Guided Poster Sessions: a way to introduce Optical Technology in a primary-secondary school

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ABSTRACT

There are few Optics contents along the primary and secondary studies in Spain. So, the relation between Optics and Technology is usually poorly known by the students. As a consequence, the number of students in Physics in general, and Optics in particular is low. In this paper we explain a project to show some topics in Optics Technology in a primary-secondary school. This project involves some Optics teachers in the Autonomous University of Barcelona (UAB) and a group of teachers and students of a primary-secondary school also in Barcelona (I.E.S. Costa i Llobera). Several Optics posters (made by the SPIE) were shown during one week. More than 200 students from 8 to 17 years old visited the Optics exhibition during this week. A group of 4 students (17 years old) were trained to show the posters to younger students. For this study we chose three age levels. For each level, a 50% of the students attended the exhibition and the rest didn’t attend the poster session. So, it was possible to realize a survey to check whether some knowledge differences appeared between the two groups. A questionnaire was fulfilled by these groups. The results of this survey show that a significant new knowledge in Optics was learned by the students.

1. INTRODUCTION

The programs of Science (and in particular Physics) along the primary and secondary studies in Spain usually cover a small number of topics in Optics. In general, Mechanics and Electromagnetism are much better covered during these studies. Usually, some Optics contents are introduced in the two last years of the secondary school. Nevertheless, due to time restrictions, only general concepts about Waves, and also Geometrical Optics are treated. So, it is not strange that the relation between Optics and advanced Technology is unknown to the students, and as a consequence, few of them are motivated to study Optics in the future.

Fig. 1. View of the panels with the posters (left) and the audience (right).
The Costa i Llobera school is a primary-secondary school (covering ages from 3 to 18 years) in Barcelona. It is celebrating its 50 anniversary this year. So, different activities were programmed. The Science department of the school decided to celebrate a “week of Science”. We choose to work on 4 topics (Water, the Antarctic continent, Darwin, Optics), creating a posters zone in the school (see Fig. 1). In the case of Optics, 12 SPIE Optics posters were used (these posters are freely distributed in http://spie.org/x31474.xml). In this work we explain a joint project between some Optics teachers (J.C. Escalera, M.J. Yzuel) in the Autonomous University of Barcelona (UAB) and a group of teachers and students (J.C. Escalera and the other co-authors) of the Costa i Llobera school (see Fig. 2 and 3). One of the members of the science department has a Ph.D. in Optics and is also a professor in the UAB. He trained 4 students to be capable of helping the students to understand the posters. The topics covered in the posters were very different: electromagnetic spectrum and its applications (x-rays, infrared commands, radio emissions, etc), optics devices and its applications (lasers, sensors, etc), biomedical optics and photonics. More than 200 students from 8 to 17 years old visited the Optics exhibition during this week. Usually, the groups were of about 15-30 students and they received information by one teacher or a trained student for a period of time between 20 and 60 minutes.

To analyze the usefulness of the method, a comprehension test was fulfilled by some groups. This questionnaire was designed by the four trained students. A comparative study was done to check whether there were real differences in the comprehension of Optics applications. In three levels (each with two groups of 20-30 students), we decided that one group would attend the poster session, and the other one wouldn’t attend it. The comprehension test was fulfilled by both groups, and we studied the differences between them.
In sections 2-6 we show some of the posters that were shown and the questions related to these posters. In each section we will study the results of the answers of the students to the questionnaire. We will mainly analyze two parameters: age of the students and attendance to the poster session. Finally, in section 7 we summarize the work.

2. THE HIDDEN WORLD OF LIGHT

The first poster in the exhibition is “the hidden world of light” (see Fig. 4). It shows that other types of electromagnetic waves, apart from visible light, exist. It divides the spectrum in 7 parts, showing in each case one application (see table 1).

<table>
<thead>
<tr>
<th>Light</th>
<th>Gamma Rays</th>
<th>X-Rays</th>
<th>Ultraviolet</th>
<th>visible</th>
<th>Infrared</th>
<th>microwave</th>
<th>radiowaves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>Detecting black-holes</td>
<td>X-ray medical photograph</td>
<td>Sunglasses</td>
<td>Colors</td>
<td>Infrared command</td>
<td>Mobile phone</td>
<td>Radio antenna</td>
</tr>
</tbody>
</table>

Table 1: topics studied in “the hidden world of light” poster.

The Question 1 was: “are there different types of lights (electromagnetic waves) apart from the visible light? Give some examples”.

The results of the survey in the groups that didn’t attend and attended the poster session are shown in tables 2 and 3 respectively.

<table>
<thead>
<tr>
<th>Age group</th>
<th>1st most answered</th>
<th>2nd most answered</th>
<th>3rd most answered</th>
<th>Others</th>
<th>Wrong answers</th>
<th>Blank answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(6)</td>
<td>(20)</td>
</tr>
<tr>
<td>12 years</td>
<td>Ultraviolet (1)</td>
<td>Infrared (1)</td>
<td>Gamma rays (1)</td>
<td></td>
<td></td>
<td>(21)</td>
</tr>
<tr>
<td>16 years</td>
<td>Ultraviolet (11)</td>
<td>Infrared (4)</td>
<td></td>
<td>(10)</td>
<td></td>
<td>(6)</td>
</tr>
</tbody>
</table>

Table 2: results of the survey (question 1) on the groups that didn’t attend the poster session.
Table 3: results of the survey (question 1) on the groups that attended the poster session.

<table>
<thead>
<tr>
<th>Age group</th>
<th>1st most answered</th>
<th>2nd most answered</th>
<th>3rd most answered</th>
<th>Others</th>
<th>Wrong answers</th>
<th>Blank answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 years</td>
<td>Ultraviolet (7)</td>
<td>Infrared (5)</td>
<td>TV-command (4)</td>
<td>(11)</td>
<td>(5)</td>
<td>(3)</td>
</tr>
<tr>
<td>12 years</td>
<td>Ultraviolet (7)</td>
<td>Infrared (4)</td>
<td>X-rays (1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(8)</td>
</tr>
<tr>
<td>16 years</td>
<td>Ultraviolet (9)</td>
<td>X-rays (8)</td>
<td>Infrared (5)</td>
<td>(8)</td>
<td>(3)</td>
<td>(2)</td>
</tr>
</tbody>
</table>

On the groups that didn’t attend the poster session, it can be seen (table 2) that there is a low knowledge of non-visible radiation. It changes with the age, and it becomes a little better for the 16 year group. In that case, the ultraviolet radiation is frequently mentioned, probably because of the advertising of solar protection creams.

On the contrary, the groups that attended the poster session (table 3) show a clear increase of correct answers in this topic. Interestingly, the results are very consistent with all the ages. In all the cases, several students can remember (after 3 weeks of the poster session) ultraviolet, infrared and x-ray radiations. There were very nice discussions around this poster. Figure 5 shows one of these moments. One very young girl is asking whether the x-ray photograph can show a cut in the cheek. The x-ray photograph (head) in the poster clearly shows that only bones (and bones fractures) can be seen in that type of photograph.

Fig. 5. Some discussions with the students.

3. OPTICS AND MEDICINE

There were several posters related with applications of Optics in Medicine. We focused in three of them: “Optics and Photonics” (see Fig. 6), “Optics, beyond eyeglasses..., way beyond eyeglasses!” (see Fig. 7) and “Biomedical Optics and Biophotonics, light for Health”, “Biophotonics, Light for cancer” (see fig. 8). They treat very different aspects: using Optics to obtain biomedical information, applications in surgery, etc.

It also appears some interesting projects for the future, like the possibility of using nanostructures to medical applications (see fig. 6). Young students were enthusiastic about this project, and it provoked a lot of questions.
The next three questions in our survey were the following:

Question 2: Can Optics help Medicine? How?

The results of the survey in the groups that didn’t attend and attended the poster session are shown in tables 4 and 5 respectively.

<table>
<thead>
<tr>
<th>Age group</th>
<th>1(^{st}) most answered</th>
<th>2(^{nd}) most answered</th>
<th>3(^{rd}) most answered</th>
<th>Others</th>
<th>Wrong answers</th>
<th>Blank answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 years</td>
<td>Glasses (6)</td>
<td>Electromagnetic waves (4)</td>
<td>(1)</td>
<td>(1)</td>
<td>(15)</td>
<td></td>
</tr>
<tr>
<td>12 years</td>
<td>X-Ray photographs (5)</td>
<td>See inside the body without surgery (2)</td>
<td>Glasses (1)</td>
<td>(1)</td>
<td>(13)</td>
<td></td>
</tr>
<tr>
<td>16 years</td>
<td>X-Ray photographs (5)</td>
<td>Laser surgery (5)</td>
<td>Yes (non specific answer) (5)</td>
<td>(5)</td>
<td>(7)</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: results of the survey (question 2) on the groups that didn’t attend the poster session.

<table>
<thead>
<tr>
<th>Age group</th>
<th>1(^{st}) most answered</th>
<th>2(^{nd}) most answered</th>
<th>3(^{rd}) most answered</th>
<th>Others</th>
<th>Wrong answers</th>
<th>Blank answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 years</td>
<td>Laser surgery (3)</td>
<td>Devices for blind people (2)</td>
<td>X-Ray photographs (1)</td>
<td>(1)</td>
<td>(3)</td>
<td>(11)</td>
</tr>
<tr>
<td>12 years</td>
<td>Correcting myopia, etc (12)</td>
<td>Seeing inside of the body (9)</td>
<td>Laser surgery (2)</td>
<td>(4)</td>
<td>(9)</td>
<td></td>
</tr>
<tr>
<td>16 years</td>
<td>Seeing inside of the body (10)</td>
<td>Correcting myopia, etc (8)</td>
<td>Burning cancers (2)</td>
<td>(4)</td>
<td>(1)</td>
<td>(4)</td>
</tr>
</tbody>
</table>

Table 5: results of the survey (question 3) on the groups that attended the poster session.

Table 4 shows that students without specific training tended to focus the importance of Optics in Medicine in two aspects: X-Ray photographs and glasses. It is probably related to personal experiences. The number of blank answers is very high, but the knowledge is increasing with age. Table 5 shows that the poster session produces new answers, specifically “laser surgery” (including myopia laser correction), “seeing inside of the
body" (different techniques were mentioned in the poster talk), and “burning cancers”. We can see that blank answers are reduced almost to a half, after the poster session.

Figure 7 shows some contents of the poster “Optics, beyond eyeglasses...” Most of the students were shocked when it was suggested that Optics may help in the future to enable blind people to see.

![Fig. 7. “Optics, Beyond Eyeglasses...”](image)

Question 3: Do you know some diseases that can be treated with the help of Optics?

The results of the survey in the groups that didn’t attend and attended the poster session are shown in tables 6 and 7 respectively.

<table>
<thead>
<tr>
<th>Age group</th>
<th>1st most answered</th>
<th>2nd most answered</th>
<th>3rd most answered</th>
<th>Others</th>
<th>Wrong answers</th>
<th>Blank answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 years</td>
<td>Cancer (1)</td>
<td>Eye cataracts</td>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(22)</td>
</tr>
<tr>
<td>12 years</td>
<td>Laser surgery</td>
<td>myopia (1)</td>
<td>Eye cataracts</td>
<td>(3)</td>
<td>(22)</td>
<td></td>
</tr>
<tr>
<td>16 years</td>
<td>Cancer (9)</td>
<td>myopia (2)</td>
<td>None (6)</td>
<td>(1)</td>
<td>(9)</td>
<td></td>
</tr>
</tbody>
</table>

Table 6: results of the survey (question 3) on the groups that didn’t attend the poster session.

<table>
<thead>
<tr>
<th>Age group</th>
<th>1st most answered</th>
<th>2nd most answered</th>
<th>3rd most answered</th>
<th>Others</th>
<th>Wrong answers</th>
<th>Blank answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 years</td>
<td>Eyes’ problems</td>
<td>Cancer (3)</td>
<td></td>
<td>(4)</td>
<td>(11)</td>
<td></td>
</tr>
<tr>
<td>12 years</td>
<td>Eyes’ problems</td>
<td>blindness (8)</td>
<td></td>
<td>(2)</td>
<td>(11)</td>
<td></td>
</tr>
<tr>
<td>16 years</td>
<td>Eyes’ problems</td>
<td>Cancer (6)</td>
<td></td>
<td>(1)</td>
<td>(6)</td>
<td></td>
</tr>
</tbody>
</table>

Table 7: results of the survey (question 3) on the groups that attended the poster session.

Table 6 shows that the use of Optics for treating diseases is poorly known in the 9 and 12 years group (22 blank answers). It is better in the 16 years group, where they relate the Optics applications in Medicine to cancer and myopia treatments. The groups that attended the poster sessions highly increase in their knowledge (11 blank answers). There is some concern about one aspect, maybe they thought that the cure for blindness was in a near future.
There were two very nice posters that explain applications of Optics in Medicine (see fig. 8). We focused in the importance of obtaining non invasive information (images) of the body. We also explained different laser techniques used in Medicine, in particular myopia correction. It is evident from table 7, that this possibility interested the audience.

![Fig. 8. “Biomedical Optics and Biophotonics”](image)

Question 4: Can we see inside the body by using light?

The results of the survey in the groups that didn’t attend and attended the poster session are shown in tables 8 and 9 respectively.

<table>
<thead>
<tr>
<th>Age group</th>
<th>1st most answered</th>
<th>2nd most answered</th>
<th>3rd most answered</th>
<th>Others</th>
<th>Wrong answers</th>
<th>Blank answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 years</td>
<td>Yes, using X-rays (15)</td>
<td></td>
<td></td>
<td>(5)</td>
<td>(3)</td>
<td>(3)</td>
</tr>
<tr>
<td>12 years</td>
<td>Yes, using X-rays (19)</td>
<td>Yes (3)</td>
<td></td>
<td>(1)</td>
<td></td>
<td>(6)</td>
</tr>
<tr>
<td>16 years</td>
<td>Yes, using X-rays (18)</td>
<td>Yes (5)</td>
<td></td>
<td>(9)</td>
<td></td>
<td>(5)</td>
</tr>
</tbody>
</table>

Table 8: results of the survey (question 4) on the groups that didn’t attend the poster session.

<table>
<thead>
<tr>
<th>Age group</th>
<th>1st most answered</th>
<th>2nd most answered</th>
<th>3rd most answered</th>
<th>Others</th>
<th>Wrong answers</th>
<th>Blank answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 years</td>
<td>Yes, using X-rays (2)</td>
<td>bones (2)</td>
<td>Cancer (1)</td>
<td>(2)</td>
<td>(5)</td>
<td>(7)</td>
</tr>
<tr>
<td>12 years</td>
<td>Yes, using X-rays (17)</td>
<td></td>
<td></td>
<td></td>
<td>(4)</td>
<td>(4)</td>
</tr>
<tr>
<td>16 years</td>
<td>Yes, using X-rays (8)</td>
<td>Seeing into your body with a video camera (6)</td>
<td>Detecting a contrast liquid in the veins with some method (2)</td>
<td>(1)</td>
<td>(2)</td>
<td>(1)</td>
</tr>
</tbody>
</table>

Table 9: results of the survey (question 4) on the groups that attended the poster session.
Table 8 shows that the use of X-ray photograph is very well known in all the ages. Interestingly, the 9 year group that attended the poster session seemed a little disoriented after the session (see table 9). Though there are more different answers, it also appears more wrong and blank answers. Maybe the explanation was not correctly prepared for that age. On the contrary, the older groups seemed to take more profit, specially the 16 years group. They consistently learned that it was possible to introduce a camera to film the digestive system and different techniques using contrasts and radioactive elements to obtain information of blood movement.

4. MACRO, MICRO, NANO

This poster shows the different scales that can be observed with different types of microscopes (see Fig. 9, 10).

![Fig. 9. “Macro, Micro, Nano” and “Optics, way beyond eyeglasses”.](image)

![Fig. 10. “Macro, Micro, Nano”.](image)

Question 5: Give some examples of small things that can be seen with the help of Optics but we cannot see with the naked eye.

<table>
<thead>
<tr>
<th>Age group</th>
<th>1st most answered</th>
<th>2nd most answered</th>
<th>3rd most answered</th>
<th>Others</th>
<th>Wrong answers</th>
<th>Blank answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 years</td>
<td>Microorganisms (14)</td>
<td>Animals (5)</td>
<td></td>
<td></td>
<td>(2)</td>
<td>(5)</td>
</tr>
<tr>
<td>12 years</td>
<td>Microbial (14)</td>
<td>cells (7)</td>
<td>atoms (5)</td>
<td>(7)</td>
<td></td>
<td>(2)</td>
</tr>
<tr>
<td>16 years</td>
<td>cells (17)</td>
<td>Microorganisms (8)</td>
<td>Bacteria (7)</td>
<td>(13)</td>
<td></td>
<td>(1)</td>
</tr>
</tbody>
</table>

Table 10: results of the survey (question 5) on the groups that didn’t attend the poster session.
Table 11: results of the survey (question 5) on the groups that attended the poster session.

Table 10 shows that all the students that answered the quiz have previous knowledge of the use of microscopes to see microorganisms. It seems that the 12 years group had learned recently the concept of “atom”. That knowledge is reinforced with the poster session, as table 11 shows. Some new answers (fleas, molecular structures) appear.

5. SATELLITES, TELESCOPES

Figure 11 shows several posters that were related with astronomy and remote sensing. Different types of telescopes (visible telescopes, radio-telescopes) were shown in the poster session.

Question 6: Give some examples of distant objects that can be seen with the help of Optics but we cannot see with the naked eye.

The results of the survey in the groups that didn’t attend and attended the poster session are shown in tables 12 and 13 respectively.

Table 12: results of the survey (question 6) on the groups that didn’t attend the poster session.
Table 13: results of the survey (question 6) on the groups that attended the poster session.

<table>
<thead>
<tr>
<th>Age group</th>
<th>1st most answered</th>
<th>2nd most answered</th>
<th>3rd most answered</th>
<th>Others</th>
<th>Wrong answers</th>
<th>Blank answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 years</td>
<td>planets (1)</td>
<td>stars (1)</td>
<td>Meteorites (1)</td>
<td>(2)</td>
<td>(16)</td>
<td></td>
</tr>
<tr>
<td>12 years</td>
<td>planets (13)</td>
<td>stars (13)</td>
<td>Distant objects (7)</td>
<td>(8)</td>
<td>(7)</td>
<td></td>
</tr>
<tr>
<td>16 years</td>
<td>planets (13)</td>
<td>galaxies (12)</td>
<td>Infrared (5)</td>
<td>(3)</td>
<td>(1)</td>
<td>(2)</td>
</tr>
</tbody>
</table>

Table 12 shows that the use of telescopes is well known, specially for older children. Table 13 shows that the 9 years group was a little disoriented by the information they received. The 12 and 16 year group reinforced their previous knowledge, with some new concepts (infrared telescopes, distant objects – probably galaxies).

6. WOMEN IN OPTICS

Figure 12 shows the posters about “Women in Optics”. In general, the students didn’t know that women have not been present in Science (and in Optics in particular) until quite recently.

![Fig. 12. “Women in Optics”](image)

Question 7: In the world of Optics, there are working:

a) More women than men.
b) More men than women.
c) Approximately the same number of men and women.

Table 14: results of the survey (question 7) on the groups that didn’t attend the poster session.

<table>
<thead>
<tr>
<th>Age group</th>
<th>More women than men</th>
<th>More men than women</th>
<th>The same</th>
<th>Blank answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 years</td>
<td>14</td>
<td>6</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>12 years</td>
<td>14</td>
<td>5</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>16 years</td>
<td>12</td>
<td>8</td>
<td>9</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 15: results of the survey (question 7) on the groups that attended the poster session.

Table 14 shows that in all the age groups that did not attend the posters, they think that there are more women than men working in Optics. They think that the field Optics is related with Optometry, and they usually find more women than men when they go to buy glasses or sunglasses. This opinion changes in the groups that attended the poster session. The 9 and 12 year groups tend to think that the presence of men and women in Optics is similar. Only the 16 year group changed their opinion in this subject, and they feel that it is more difficult for women to work in Optics Research and Technology.

7. SUMMARY

We have described a simple (and cheap) method to introduce Optics for young students. The SPIE posters are attractive and they not only show a relation between Science and Optics, but also very significant real world applications of Optics. The students involved in learning and teaching really enjoyed the process, and the knowledge in Optics increased for the students that attended the posters presentation.

ACKNOWLEDGMENTS

The authors acknowledge financial support from the Spanish Ministerio de Educación y Ciencia (grant FIS2006-13037-C02-01). The authors thank the students of the I.E.S. Costa i Llobera for attending the poster sessions with a positive spirit and for filling in the questionnaires. We are also grateful to the Costa i Llobera direction, Science Department and other teachers of the I.E.S. Costa i Llobera for helping us to develop this project. We also want to thank the SPIE for designing and producing the posters and their enthusiastic activities in order to support a better knowledge of Optics and its applications.
Optics history as effective instrument for education in optics and photonics

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ABSTRACT

The education problem in optics and photonics is to draw young generation on the side of light, optical science and technology. The main goal is to prove the slogan that “physics is a small part of optics”: during the thousand years optics formulated the clear worldview for humanity. In fact optics is itself presents multidisciplinary collection of independent scientific arias from one hand and was a generator of new fields of knowledge from the other hand. Optics and photonics are the regions where the fundamental problems of our reality have to be solved. The mentioned functions belonged to optics during the period of civilizations development. This is a basic idea of books serial by S. Stafeev and M. Tomilin “Five Millennium of Optics” including 3 volumes. The first volume devoted to optics prehistory was edit in 2006 in Russian. Its main chapters devoted to relations between Sun and Life, the beginnings of human intelligence, megalithic viewfinders, gnomons and ancient temples orientation, archaic optical materials and elements. It also consist the optical riddles of that period. The volume II is devoted to Greek and Roman antiquity and is in the process of publishing. It consist the chapters on the beginning of optics, mathematical fundaments and applied optics evolution. Volume III would be devoted to Medieval and Renaissance optics history. The materials are used at our university in a course “The Modern Natural Science Conceptions” for students and graduate students. In our paper the possibilities of optics history as effective instrument for education in optics and photonics are discussed.

Keywords: optics prehistory; medieval and renaissance optics; ancient images, megalithic viewfinders, gnomons and temples orientation; optical theory, materials and elements; eye and vision.

1. INTRODUCTION

Optics and photonics have exciting history closely tied with modern science. For receiving the harmonious education in this field it is necessary to trace the development of optics from early beginning up to current state. Such panorama of optics development arise deep interest of pupils to the subject of investigation and give fundamental knowledge. Sun light as main source of energy and basis of life was the most important object of investigation during the whole period of civilization evolution. Vision as the main source of information about the surrounded world determined the evolution of human intellect. The direct sky objects observation during thousand years helped to predict nature cycle changes and to fix man in time and space. Control of Sun, Moon and planets trajectories gave the calendar to many nations. Many megalithic facilities and observatories were built for this and religious purposes. Viewfinder as one of the first optical instrument was created as the result of ancient visual observations. Other ancient optical elements such as mirrors, lenses and magic spheres were the result of handicraft activity in metallurgy and jeweler’s art. Transparent crystals processing and glass-making create the basis of ancient optical materials.

During the prehistoric period optics had a syncretic stage with ancient philosophy and religion and had a magic context. Greek and Roman antiquity was characterized by serious interest to nature of light and mechanisms of vision. The famous Greek thinkers founded the basis of geometric optics, catoptrics, dioptrics and meteors. The contribution of outstanding scientists Euclid, Archimedes and Ptolemy to optics produced a strong influence on following ages. The main achievement of middle ages was the invention of glasses, while
the main achievement of Renaissance was the development of perspective theory, demonstrating the optical knowledge penetration into fine arts technology.

In our paper the general context with selected illustrations of two our books is presented to give the common impression of collected information on civilizations history seen by optician eyes.

# 2. FIVE MILLENIUM OF OPTICS: PREHISTORY

| Introduction                                      | 12 |
| Chapter 1. Sun and Life                          | 17 |
| 1.1. Sun messenger                               | 17 |
| 1.2. Beginnings of life                          | 19 |
| 1.3. Light, eye and brain                        | 25 |
| 1.4. Sun-earth interconnections                  | 35 |

Chapter 2. The cradle of intellect

| 2.1. Myths, legends and symbols (fig.1)           | 46 |

2.2. Horr eye (fig.2)

Fig.1. Sun symbols of different nations and times

Fig.2. Horr eye and its interpretation as fractions

2.3. Images and letters
2.4. Sky cycles and calendars (fig.3)

Chapter 3. Megalithic viewfinders
3.1. Megalithic civilization and stone viewfinders (fig.4)
3.2. Linear backing. Menhirs, leis and stone ranges
3.3. Viewfinders with seculated aperture. Dolmen and dromoses
3.4. Cromlechs and horizon observatories

Chapter 4. Gnomons and ancient temples orientation
4.1. Gnomons as elements of reversal backing (fig.5)
4.2. Sacred symbols of ancient viewfinders
4.3. Temple complexes orientation in Europe and Asia
4.4. Temples and complexes of New World

Chapter 5. Archaic optics: materials and elements
5.1. Bronze mirrors (fig.6)
5.2. Magic mirrors of China and Japan (fig.7)
5.3. Natural crystals and its processing  
5.3. Lenses and spheres (fig.8)  

Fig.8. Ancient crystalline lens from Ninevia, VIII BC.

5.4. First glass  
Application. Ancient optical mysteries  
1. Mystery of megaliths  
2. Pyramids, Orion constellation and Zodiac cycles  
3. Myths of ancient Egypt and Arcaim  
4. Viewfinders for skies  
5. Ancient telescope (fig.9)  

6. Quartz sculls (fig 10).  
Conclusion  
Literature (295 pos.)
3. FIVE MILLENIUM OF OPTICS: ANTIQUITY

Introduction

Part I. Principles of antique optics

Chapter 1. Antique mythology and light metaphysics
1.1. Light and vision in mythology (fig1)
1.2. Metaphysics and natural philosophy of light
1.3. Color symbolism and antique chromatism

Chapter 2. Main stages of scientific knowledge evolution
2.1. Classification of scientific disciplines
2.2. Main stages of antique science (fig.2)
2.3. Optics among antique disciplines
2.4. Structure of antique optics

Chapter 3. Physical theories of visual perception
3.1. Extramission (fig.3)
3.2. Intramission

Fig.1. Narcissus and his reflex.
Fig.2. Plato Academy.
Fig.3. Ocular beams
3.3. Sinaugogia and sinestasis 121
3.4. Acsidensia 132
3.5. Color’s nature and color perception 136

Chapter 4. Vision physiology and psychology 148
4.1. Vision physiology. Eye models (fig.4) 150

Fig.4. Galen’s model of eye

4.2. Vision psychology. Optical illusions 165
4.3. Vision and cognition 173

Part II. Mathematical principles of optics 190

Chapter 5. Studies of direct vision 191
5.1. Optics of vision 194
5.2. Direct vision in Euclid “Optics” 201
5.3. Direct vision in Archimedes and Hero “Catoptrics” 206
5.4. Direct vision in Ptolemy “Optics” 209
5.5. Illusions of direct vision 216

Chapter 6. Catoptrics 220
6.1. Euclid’s catoptrics 222
6.2 Archimedes’ and Hero’s catoptrics 227
6.3. Catoptrics theorems in Ptolemy “Optics” 230
6.4. Multiple mirror systems and burning mirrors 241
6.5 Archimedes’ burning mirrors (fig.5) 248

Fig.5. Antique mosaic with the scene of Archimedes death
Chapter 7. Dioptrics

7.1. Ptolemy's theoretical analysis of refraction
7.2. Ptolemy experiments with light refraction
7.3 Atmosphere refraction
7.4. Localization of refractive images and their distortion

Chapter 8. Meteors

8.1. Aristotle's Meteorologica
8.2. Theory of humid meteors
8.3. Theory of circular meteors (fig.6)

8.4 Theory of visual rays for study meteors

Part III. The beginning of applied optics

Chapter 9. Optical materials, elements and technologies

9.1. Bronze and mirrors (fig.7)

9.2 Optical crystals and jewelry produces (Fig.8)
9.3. Crystal lenses (fig.9)
9.4. Schliemann lenses and Nero monocle
9.5. Crystal spheres. Antique telescope
9.6. Glasses and decoration produces
9.7 Mosaics from smalt

Chapter 10. First optical instruments

10.1. Gnomonic
We hope that brief review will give the common impression about the context of our books. The conference on education and training in optics and photonics at Technium OptIC at St. Asaph is a good opportunity to discuss possible profit of translating two volumes of “FIVE MILLENIUM OF OPTICS” into English. The authors use the study of optics history for education in optics and photonics themselves and recommend other specialist to follow their practice.
Optical aurora detectors: using natural optics to motivate education and outreach

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ABSTRACT

Natural optical phenomena enjoy a level of interest sufficiently high among a wide array of people to provide ideal education and outreach opportunities. The aurora promotes particularly high interest, perhaps because of its relative rarity in the areas of the world where most people live. A project is being conducted at Montana State University to use common interest and curiosity about auroras to motivate learning and outreach through the design and deployment of optical sensor systems that detect the presence of an auroral display and send cell phone messages to alert interested people. Project participants learn about the physics and optics of the aurora, basic principles of optical system design, radiometric calculations and calibrations, electro-optical detectors, electronics, embedded computer systems, and computer software. The project is moving into a stage where it will provide greatly expanded outreach and education opportunities as optical aurora detector kits are created and disbursed to colleges around our region.

Keywords: Aurora Borealis, aurora, atmospheric optics, optical sensors, optics education

1. INTRODUCTION

The aurora is a natural optical phenomenon that occurs primarily in high-latitude regions, created when energetic particles carried from the Sun by the solar wind collide with gas atoms and molecules in the upper levels of Earth’s atmosphere, thereby releasing energy in the form of visible light. Its relative rarity at lower latitudes makes it a subject of significant curiosity, even in high-latitude regions and certainly in higher mid-latitude regions where auroras are known to occur, but with relative rarity. In fact, the combination of knowing that an aurora can occur but not knowing when one might occur creates precisely the kind of interest that can be capitalized on to create effective opportunities for education and outreach.

When giving talks that include pictures of the Aurora Borealis (especially “local” pictures), the most common question, whether from university faculty or young school children, is something along the lines of how often an aurora can be seen where they live. Unfortunately, in nearly all cases, that question is essentially impossible to answer quantitatively. The answer certainly can begin with a geophysicist’s map of aurora probability as a function of an observer’s magnetic latitude and the 11-year sunspot cycle, but an assessment of how often those auroral displays might actually be seen also involves the probability of cloudiness for each location and the diligence of potential observers. The explanation usually goes on to address things like the Ka index and satellite-generated images of the auroral oval, which are all extremely useful indicators of what is happening now and what might happen in a few hours. Then the story often turns to describing the many late nights when a very active, expanded auroral oval have encouraged us to stay up late, only to see the oval retreat northward just as it is about to reach our location. Nevertheless, the story always includes pictures from nights when the reward for diligence was a display in the sky that ranges from a pale green glow on the northern horizon to a swirling red and green display dancing overhead.

A desire to eliminate missed aurora observing opportunities led to the idea of an automated way to detect when an aurora is occurring and notify ourselves and other interested persons of the viewing opportunity. In 1982 Knight published a design for an optical aurora detector based on a photomultiplier tube (PMT) detector

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and a 10-nm-wide interference filter centered on the 557.7 nm oxygen emission line that generates the most common green aurora. The PMT signal was detected and processed with analog circuitry that generated an audible alarm when an aurora was sensed. A chart recorder was used to record uncalibrated signal levels. In 1996, Haun\(^6\) presented a digital upgrade to Knight’s system using functionally identical optical components but upgrading the electronics to include a microprocessor for intelligent alarm detection. Alarm levels and dynamic gains were set in the microprocessor software and data could be recorded with a personal computer.

Recently, we developed an optical aurora detector that builds on these prior designs by adding a radiometric calibration to measure aurora brightness in addition to presence and to send out cell-phone text messages to a subscriber list of interested observers. This system uses an updated microcontroller and further reduces the amount of analog circuitry, but still relies on the same approach of detecting auroras with a PMT and 10-nm-wide interference filter angle tuned so that the center of its bandpass is at 557.7 nm. The prototype of this instrument was deployed at the Poker Flat Rocket Range (PFRR)\(^7\) near Fairbanks, Alaska, for testing and calibration during March 2007. These field tests verified the operation of the instrument and helped prepare it for continuous operation at our mid-latitude location in Bozeman, Montana (45.67° N, 111.05° W).

2. OPTICAL AURORA DETECTOR

2.1 System design and construction

Figure 1 shows a block diagram layout of our prototype non-imaging optical aurora detector. In this figure, the four green blocks on the left are optical components, the blue center three blocks are analog electronic components, and the tan right four blocks are digital electronic components. Starting at the upper left corner of this diagram, light from the night sky is viewed through a 10-nm interference filter and 50-mm-diameter lens by a PMT. Rays traced from the outer edges of the PMT active area through the center of the lens determine the sensor’s full-angle field of view (FOV). A trans-impedance amplifier conditions the analog signal, which is read on an analog input (analog-to-digital converter) to a microcontroller module, which allows the user to select a temporal averaging period to produce a smoothed signal. This signal is processed with a radiometric calibration and threshold algorithm that determines if an aurora is present and, if so, uses the absolute aurora radiance to generate a notification message that is sent as a text message to the cell phones of interested observers. A simple, unfiltered photodiode detector simultaneously observes the broadband sky brightness and provides a signal that can be used, if desired, to adjust the gain and thresholds of the aurora detector signal to account for variable moonlight and light pollution. We also use the photodiode signal to determine when to open and close a shutter that keeps the PMT dark during daytime.

Fig. 1. Block diagram of the optical aurora detector system built at Montana State University in 2006-2007.
The optical subsystem is illustrated in Fig. 2. An optical interference filter, with a full-width-at-half-maximum (FWHM) bandpass of 10 nm, is tilted to tune its nominally 560-nm center wavelength to the oxygen emission line at 557.7 nm. This makes use of the sometimes-useful and sometimes-annoying shift of the transmission peak of an interference filter to shorter wavelengths as the angle of the incident light is increased. Prior to constructing the filter mount, we measured the filter’s transmission spectrum as a function of incidence angle and determined that a mounting surface tilted by 12° would place our filter’s transmission peak at 557.7 nm.

![Diagram of optical subsystem](image)

Fig. 2. Optical subsystem for the optical aurora detector. The interference filter is mounted at an angle that shifts the nominally 560-nm transmission peak to the oxygen emission wavelength of 557.7 nm.

A photograph of the prototype system mounted in a weather-tight box is shown in Fig. 3. The microcontroller and custom electronics board are mounted together on the left-hand side; the PMT module is at the lower-right, attached to a custom light-tight lens and filter mounting tube. At the top of the figure is a plexiglass window (clear) and custom shutter (black) that closes to maintain the PMT in darkness during daylight. The microcontroller signal is passed through a serial connection at the base of the box to a remote computer.

![Prototype system](image)

Fig. 3. Photograph of the optical aurora detector prototype. The microcontroller and electronics board are on the left-hand side; the PMT is the black module at the lower right, attached to a custom-machined light-tight lens and filter mounting tube (silver tube, center right). A shutter (black module, top) opens to allow the PMT to view the sky at night. [J. Shaw photo].
2.2 System testing in Alaska

In March 2007 we took the prototype optical aurora detector to Alaska to be tested in an aurora-rich environment. Fig. 4 shows the system deployed in an observation dome at the Poker Flat Research Range (PFRR) operated by the University of Alaska near Fairbanks, Alaska (PFRR is at 65.13°N, 147.48°W). During one week of testing, the system observed and detected auroras every night, ranging from just-visual wisps to bright, swirling displays.

Before deploying the system for aurora observations, we calibrated it using a standard lamp and barium sulfate reflecting screen. This calibration produced a curve relating output digital number to in-band radiance, which we convert to International Brightness Coefficient (IBC) units, which are used to classify aurora and airglow brightness in ranges from IBC1-IBC4, each separated by one decade. The IBC is determined in units of Rayleighs,8,9 which are defined at the reference wavelength of 557.7 nm as

$$1 \text{Rayleigh} = \frac{10^{10}}{4\pi} \text{photons} \cdot \text{s} \cdot \text{m}^{-2} \cdot \text{sr}.$$  \hspace{1cm} (1)

Table 1 lists the four IBC levels in Rayleighs, along with the corresponding radiance at 557.7 nm and a qualitative comparison to natural lighting situations. IBC I is subvisual to visible but below the onset of color vision, while IBC II is just beyond the human visual limit, which is only visible in dark skies with very low light pollution. IBC III and IBC IV correspond to bright, visually impressive displays. Fig. 5 is a photograph of the aurora near local midnight on 13 March 2007 at a time when the brightness approached IBC III. The photograph closely matches what was seen visually by observers at the PFRR. Fig. 6 is a time-series plot of the aurora detector signal during the nights of 13 March 2007.

<table>
<thead>
<tr>
<th>IBC Level</th>
<th>Rayleighs</th>
<th>Radiance @ 557.7 nm</th>
<th>Relative Brightness</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1 kR</td>
<td>$2.833 \times 10^{-7}$ W/(m²·sr)</td>
<td>Appears white</td>
</tr>
<tr>
<td>II</td>
<td>10 kR</td>
<td>$2.833 \times 10^{-6}$ W/(m²·sr)</td>
<td>Onset of color perception</td>
</tr>
<tr>
<td>III</td>
<td>100 kR</td>
<td>$2.833 \times 10^{-5}$ W/(m²·sr)</td>
<td>Moonlit cumulus</td>
</tr>
<tr>
<td>IV</td>
<td>1000 kR</td>
<td>$2.833 \times 10^{-4}$ W/(m²·sr)</td>
<td>Full moonlight</td>
</tr>
</tbody>
</table>

Table 1. International Brightness Coefficient (IBC) levels and corresponding radiometric values

Fig. 4. Prototype optical aurora detector (gray box at lower right) deployed to view the northern horizon from a rooftop observation dome at PFRR near Fairbanks, Alaska for testing during March 2007. [J. Shaw photo].
3. Educational opportunities for students working on the aurora detectors

A wide range of educational opportunities are provided in a natural, exciting manner for students in the process of designing, building, calibrating, and operating optical aurora detectors. For example, the topics learned by students working on this project include the following:

- Basic physics of the Aurora
- Radiometry and calculations of sensor signal-to-noise ratio
- Radiometric sensor calibration
- Aperture and field stops and geometric optics of radiometry
- Interference filter angle tuning and designing field of view to match filter bandwidth
- Mounting of optical components
- Machining of custom optical mounts
Detector parameters and selecting detector to meet specific signal-to-noise requirements
Amplifier circuits and electronic interfacing
Electronic circuit board layout and construction
Embedded microcontroller programming
Instrument thermal control
Light pollution and atmospheric scattering

In subsequent phases of this project, students have been exploring alternate instrument designs, including aurora imagers, and have been refining the thermal management and remote-control software options. Plans are being made to create student kits, so that students with not quite such sophisticated technical backgrounds can build and operate an instrument as part of an aurora detector network. Consequently, the range of opportunities to “learn by doing” has continued to expand. These developments will be discussed in more detail in future publications.

4. Conclusion

Building and operating optical aurora detectors is proving to be a highly motivational way for undergraduate engineering and science students to learn about topics ranging from optics to electronics to atmospheric physics to thermal control. In the course of their projects, students learn the required science or engineering subjects as they become necessary.

Following its successful Alaskan test, the original prototype sensor described here has been operating on the roof of the engineering building at Montana State University in Bozeman, Montana (45.67°N, 111.05°W) for over two years. However, in that time no auroras have been available for detection owing to an unusually quiet period of low solar activity. As solar activity eventually increases during the upcoming cycle, the instrument will be ready to alert all interested people when an aura can be seen in our area. Furthermore, the data we are continually collecting will provide unique insight into the statistics of the frequency of occurrence and absolute brightness of auroras in our area. As we develop a network of sensors, similar data will become available for different regions.

Acknowledgments

This is a Montana Space Grant project, funded through a NASA Space Grant Consortium education enhancement grant. We extend our deepest gratitude to the staff at the University of Alaska’s Poker Flat Research Range for providing access to the range and assistance with our calibration measurements and instrument deployment in Alaska. Specifically, we acknowledge the assistance of Mr. Brian Lawson (Optics Engineer), Mr. Greg Walker (Range Manager), and Dr. Roger Smith (Director of the Geophysical Institute). We dedicate this paper to the memory of Dr. William Hiscock, former Director of the Montana Space Grant Consortium, whose support and excitement helped make this project possible.

References

Multiple Dimensional Outreach Activities Attract Students to the Electro-Optics Program

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Indiana University of Pennsylvania
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Abstract – This paper discusses the basic formats of various outreach activities used to promote an engineering program in Electro-Optics (EO). These implemented outreach activities include school visits/classroom presentations, the on-campus EO Experience, EO Summer Camps, and Teacher & Guidance Counselor Workshops. The effectiveness of these outreach activities were evaluated.

Index Terms: outreach, engineering education

I. INTRODUCTION

There is a constant decrease in the enrollment of electronics engineering program in recent years throughout most of the United States of America, due to a reduction in interest in the study of electronics engineering from high school students. By introducing high school students to the new and emerging technologies such as electro-optics, lasers, fiber optics and telecommunication, their perception has been changed and their interest has been stimulated. Electro-optics and optoelectronics, collectively known as photonics, is an enabling technology which has revolutionized the information storage, data communication, manufacturing, diagnosis, therapy, medical surgery, solid state lighting, display, space, defense and transportation in the past 40 years. As these advances surround our culture, it is vital to develop an educational program in electro-optics to train highly-qualified professionals for research organizations and private sectors, as well as to raise public awareness of the vast career opportunities in this cutting-edge discipline.

In 2002, Indiana University of Pennsylvania (IUP) launched an innovative degree program in Electro-Optics (EO) which offers two training options from associate’s degrees to bachelor’s degrees [1, 2]. In this paper, the extensive, multi-dimensional outreach activities are discussed that have been implemented successfully to attract students to the EO program [3-7]. The paper is organized as follows: Section I: Introduction; Section II: Electro-Optics Educational Pathway for High School Students; Section III: Outreach & Recruitment Efforts; Section IV: Challenges of the Electro-Optics Program; Section V: Electro-Optics Program Evaluation; and Section VI: Summary.

II. “2+2+2” EDUCATIONAL PATHWAY

There is an immense demand for electro-optics engineers and technicians in the U.S. [8-10]. In order to meet the demand, a 2+2+2 model has been used, which provides considerable flexibility. The multiple entrance and exit points allow young people to pursue vocational training and academic education in multi-disciplinary engineering areas such as electro-optics. The first level of the 2+2+2 Program provides students the opportunity to enter the program at the beginning of their junior
year in high school. During their junior and senior year, students co-enroll in the appropriate math and science courses and four EO courses offered at a local cooperating career-technical school. Upon completion of these courses and an Advanced Placement Equivalency Course with the appropriate exam score, students can earn a certificate for the 15+ credits which can be articulated into IUP’s associate degree program in EO. The second level of the 2+2+2 Program allows students to complete the 64 credits needed for the associate degrees in EO. After earning an associate’s degree, students are prepared to move into technical positions in the EO industry. Students may exit the 2+2+2 Program at this point or continue to the third level. The third level of the 2+2 Program allows students to transfer 64 credits from their coursework from the A.S.E.O toward a Bachelor degree in Electro-Optics.

After collaboration with EO companies to understand their current staffing needs, the nine courses were developed which serve as the core courses of the EO Program. These courses provide students with the necessary technical background and hands-on skills to move into EO related positions. The nine core courses include: Computer Interfacing in Electro-Optics (EOPT 105); Geometric Optics (EOPT 110); Introduction to Electronics (EOPT 125); Wave Optics (EOPT 120); Detection and Measurement (EOPT 210); Introduction to Lasers (EOPT 220); Fiber Optics (EOPT 240); High Vacuum Technology (EOPT 250) and Industrial Applications of Lasers (EOPT 260).

Because of the rapid emergence and interdisciplinary nature of the EO field, teaching strategies give highest priority to activities that encourage creativity, critical thinking and problem-solving skills. Furthermore, since the program is introduced early during the freshman and sophomore years in the University, emphasis is placed on concept development and qualitative analysis rather than mathematical derivations. In addition, emphasis is placed on the synergy among different EO core courses, which reinforces students’ knowledge in this field.

Due to the hands-on skills necessary to succeed in the EO industry, each EO core course consists of a three-hour hands-on lab experiment in addition to two-hour lectures per week. Through these labs, students learn vital hands-on skills utilizing state-of-the art EO equipment. To complete each lab experiment, students are responsible for building the experiment without any preliminary setup. They select appropriate equipment available in the lab such as optical components (mounts and holders, etc.), light sources (light bulbs, LEDs, lasers, etc.) and measurement instruments (optical power meter, optical spectrum analyzer, etc.) to complete the experiment. After completing each lab, students are required to submit a formal lab report, documenting key concepts: objectives, basic theory, procedure, data collected, result analysis, discussion, and conclusions. In general, the lab component developed for this program reinforces the basic theory introduced during the class lecture and emphasizes: instruments and equipment used in the EO industry, basic optical experimental methods, and problem-solving skills [11-13].

Although the new “2+2+2” EO program offers the advantage of early involvement of the students and flexibility of the entrance and exit points, outreach is a powerful tool to expose students to the excitement and challenges of engineering, and to the career and educational opportunities in this emerging high-tech field. More important,
the outreach helps students to build their interests and gain the confidence necessary to pursue their interests. Also a higher retention is obtained when students make an informed decision about the best choice of major with all the necessary information provided.

III. OUTREACH EFFORTS

The various outreach activities, covering one or more components such as hands-on experience, interaction with faculty, staff, alumni and current students with the EO program, on-campus field trips, off-campus field trips, and social activities, are aiming for different groups: the students, school teachers and guidance counselors, and parents. As shown in Figure 1, a total of 4,233 local students have been reached from the fall of 2005 to the summer of 2008. On average, the outreach activities provided a direct impact to over 1,000 students every year. Table 1 provides the outreach breakdown by activity during 2006-2007. These outreach activities include school visits/classroom presentations, the on campus EO experience, career fairs, parent information sessions, the EO Summer Camp, and other outreach activities. The basic formats of different outreach activities are given in details below.

Fig. 1 Total number of students who attended outreach activities throughout fall of 2005 to summer of 2008.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005-2006</td>
<td>500</td>
</tr>
<tr>
<td>2006-2007</td>
<td>1000</td>
</tr>
<tr>
<td>2007-2008</td>
<td>1500</td>
</tr>
</tbody>
</table>

Table 1 Outreach Breakdown by Activity in 2006-2007

<table>
<thead>
<tr>
<th>Outreach Activities</th>
<th>Students Attended</th>
</tr>
</thead>
<tbody>
<tr>
<td>EO Experience On-Campus</td>
<td>147</td>
</tr>
<tr>
<td>High School Classroom Visits</td>
<td>709</td>
</tr>
<tr>
<td>High School Career Days</td>
<td>403</td>
</tr>
<tr>
<td>“Starry Night” – Astronomy Night</td>
<td>15</td>
</tr>
<tr>
<td>IUP Science Festival</td>
<td>60</td>
</tr>
<tr>
<td>EO Summer Camp</td>
<td>27</td>
</tr>
<tr>
<td>Total number of students reached</td>
<td>1361</td>
</tr>
</tbody>
</table>

A. High Schools Visits/Classroom Presentations

Classroom presentations provide an opportunity to speak to a large number of students in their sophomore and junior year. These presentations are arranged through a contact at the school, which is typically the physics or math instructor or
school guidance counselor. Presentation style and format is dependent upon the
time allotted. This can vary from 7 minutes to 1 hour in length.

Generally, the format of the presentation includes: an overview of EO engineering,
potential career paths, the educational opportunities at IUP, and hands-on activities
or demonstrations. Topics include:

- What is Electro-Optics Engineering?
- Careers and Job Outlook
- Hands-On Optics Activities
- 2+2+2 EO Program at IUP

The classroom presentation increases awareness of the EO engineering at the high-
school level. During the outreach, students learn about the specific field of
engineering, the job opportunities, and the salary information. These examples in our
daily life such as remote controls, DVD players, and digital cameras, are used to
illustrate the wide applications of the EO engineering. Electro-Optics encompasses
such technologies as: lasers, holograms, night vision and thermal imaging, and
optical communication. In addition to this discussion, students learn about the
emerging field of EO through portable hands-on activities which promote
experimental education. These might include a magic stripes kit which has a basic
polariscope that allows students to view the stress and strain of various transparent
objects through crossed polarizers; a magic patch kit which incorporates a thin liquid
crystal film with a good sensitivity at low temperatures; diffraction-grating glasses,
night-vision scopes, and Optical Take-Home Theme Packets [14]. These materials
are helpful to enhance students’ understanding of EO at a variety of age levels. For
example, by using the “Magic Patch”, students are able to observe thermal-optical
effects and gain an understanding of how liquid crystals are used in many electro-
optical devices such as calculators and flat-panel displays. Diffraction-grating
glasses are also distributed to students to view the diffraction of light as well as
measure the grating spacing using a laser pointer.

Because there are many appealing and challenging EO careers for young people, an
emphasis is placed on the importance and benefits that EO engineering brings to
both one’s quality of life and economic prosperity. A simple survey is conducted by
the end of the presentation. From the survey conducted, the names of those
students who indicated that they are interested in the EO program and would like to
know more about the program are collected for the on-campus EO experience.

B. The On-Campus Electro-Optics Experience

For these students who expressed their interests in the EO program, they are invited
to have a half day on-campus EO experience that runs approximately from 9am -
12pm. This outreach activity facilitates 30-40 high school sophomores-seniors who
may come from different schools. Through funding from the Pennsylvania
Department of Community and Economic Development (PA DCED), the bus
transportation is provided to students for their on-campus field trips, as well as the
pizza lunch.

Once there, the students are divided into two groups after a short introduction. One
group (about 20 students) tours the labs and engages in a variety of hands-on lab
activities with two instructors, one lab technician and several students currently enrolled in the EO Program. This group of students has the opportunity to participate in such activities as diffraction and the measurement of human hair diameter, fiber optics and fusing splice of two glass fiber ends, lasers and holography, spectroscopy and forensics applications, interferometry and DVD player, laser light show, etc. These topics may vary according to the background of students and requests from the school teachers such as EO applications in forensics or biology, etc. In addition to the lab component, the other group of students stays in a classroom and learns more about the principles behind each hands-on lab experiment, and further discusses about Electro-Optics and career opportunities in the field. A typical event itinerary is listed in Table 2.

Table 2 On-Campus Electro-Optics Experience

| Introduction and lab safety rules |
| Divide into two groups for breakout sessions |

**Session One:**

**Tour of labs**

Hands-on activities in IUP's state-of-the-art Electro-Optics laboratory at Northpointe learning about such concepts as:

- Computer interface and open space communication
- Diffraction Measurement of Human Hair
- Fiber Optics
- Forensics Applications
- Interferometry
- Lasers
- Spectrometry
- XY pattern generator and laser light show
- Thermal infrared technology and night vision camera

**Session Two:**

- Learn about the science of Electro-Optics, career opportunities in the field, and play an exciting game of "Optics Jeopardy"

Groups rotate (the session one and session two rotate)

Survey and wrap-up

Pizza lunch for students, participants, and teachers prior to returning to school

Every student and school teacher are surveyed to determine their opinion of the visit, interest in EO, and interest in future outreach and educational opportunities in the field. For example, a total of 147 high school students attended the on-campus EO experience in 2007. Approximately 40% of them expressed an interest in a career in Electro-Optics in the survey. The authors were impressed with the immense interest in EO after the on-campus field trip, as many had not been familiar with this field at the beginning of their visit.

C. Electro-Optics Summer Camps

For those high school students who indicated that they are interested in pursuing a career in EO, they are invited to attend a one-week day-camp free of charge during summer. The summer EO camp is also open to any students entering 10th, 11th, or 12th grade in the fall of the upcoming year. The summer camp is perhaps the most important and empowering part of the outreach programs. It unifies the various
aspects of the outreach activities and gives students an idea of the types of resources available for classes. The first EO summer camp was offered in June of 2006 with the funding from PA DCED. The students take part in daily lectures which involve such topics as the nature of light, wave optics, electronics, fiber optics, holography, infrared imaging technology, lasers, robotics and nanotechnology, given by each instructor. Students are then guided through hands-on activities related to these advanced topics. For example, in Electronics, they learn how to solder and complete a simple transmitter and receiver set. In Optics, students are introduced to activities using a grating spectrometer and an interferometer. Table 3 displays the activities organized for the summer camp in 2009.

<table>
<thead>
<tr>
<th>Time</th>
<th>Day 1 Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30 am</td>
<td>Breakfast</td>
</tr>
<tr>
<td>8:45 a.m.</td>
<td>Welcome and Introductions</td>
</tr>
<tr>
<td>9:00 a.m.</td>
<td>Camp Pre-Test</td>
</tr>
<tr>
<td>9:30 a.m.</td>
<td>Nature of Light and Color Spectra</td>
</tr>
<tr>
<td>10:00 a.m.</td>
<td>Break</td>
</tr>
<tr>
<td>10:15 a.m.</td>
<td>Wave Optics and Interference Lab Activity</td>
</tr>
<tr>
<td>12:00 p.m.</td>
<td>Lunch</td>
</tr>
<tr>
<td>12:30 p.m.</td>
<td>Forensics Applications Activity</td>
</tr>
<tr>
<td>2:15 p.m.</td>
<td>Break</td>
</tr>
<tr>
<td>2:30 p.m.</td>
<td>&quot;Green&quot; Lab</td>
</tr>
<tr>
<td>3:45 p.m.</td>
<td>Wrap-Up</td>
</tr>
<tr>
<td>4:00 p.m.</td>
<td>Dismissal</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>Day 2 Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30 am</td>
<td>Breakfast &amp; Updates</td>
</tr>
<tr>
<td>9:00 a.m.</td>
<td>Electronics Project</td>
</tr>
<tr>
<td>10:00 a.m.</td>
<td>Break</td>
</tr>
<tr>
<td>10:15 a.m.</td>
<td>Electronics Project (continued)</td>
</tr>
<tr>
<td>12:00 p.m.</td>
<td>Lunch</td>
</tr>
<tr>
<td>12:30 p.m.</td>
<td>Electronics (continued)</td>
</tr>
<tr>
<td>1:00 p.m.</td>
<td>Tour: II-VI</td>
</tr>
<tr>
<td>4:00 p.m.</td>
<td>Return to IUP Northpointe and Dismissal</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>Day 3 Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30 am</td>
<td>Breakfast &amp; Updates</td>
</tr>
<tr>
<td>8:45 a.m.</td>
<td>Adventures in Fiber Optics</td>
</tr>
<tr>
<td>10:00 a.m.</td>
<td>Break</td>
</tr>
<tr>
<td>10:15 a.m.</td>
<td>Adventures in Fiber Optics (continued)</td>
</tr>
<tr>
<td>12:00 p.m.</td>
<td>Lunch</td>
</tr>
<tr>
<td>12:30 p.m.</td>
<td>NASA Teleconference</td>
</tr>
<tr>
<td>1:45 p.m.</td>
<td>Tours: Sabeus, Dynamics Manufacturing and OSTI</td>
</tr>
<tr>
<td>4:00 p.m.</td>
<td>Return to IUP Northpointe and Dismissal</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>Day 4 Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30 am</td>
<td>Nanotechnology Activity (Breakfast during Presentation)</td>
</tr>
<tr>
<td>10:00 a.m.</td>
<td>Break</td>
</tr>
<tr>
<td>10:15 a.m.</td>
<td>Tour: Penn-State Electro-Optics Center</td>
</tr>
<tr>
<td>12:00 p.m.</td>
<td>Lunch</td>
</tr>
<tr>
<td>Time</td>
<td>Activity</td>
</tr>
<tr>
<td>----------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>12:30 p.m.</td>
<td>IR Camera Lab, Night Vision Lab, Robot and Unmanned Aerial Vehicles Lab</td>
</tr>
<tr>
<td>1:50 p.m.</td>
<td>Return to IUP Northpointe and Break</td>
</tr>
<tr>
<td>2:00 p.m.</td>
<td>Work on Poster Presentations</td>
</tr>
<tr>
<td>4:00 p.m.</td>
<td>Dismissal</td>
</tr>
</tbody>
</table>

**Day 5 Activity**

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30 am</td>
<td>Breakfast &amp; Updates</td>
</tr>
<tr>
<td>8:45 a.m.</td>
<td>Robotics</td>
</tr>
<tr>
<td>10:00 a.m.</td>
<td>Break</td>
</tr>
<tr>
<td>10:15 a.m.</td>
<td>Robotics (continued)</td>
</tr>
<tr>
<td>12:00 p.m.</td>
<td>Lunch</td>
</tr>
<tr>
<td>12:30 p.m.</td>
<td>Robotics (continued)</td>
</tr>
<tr>
<td>4:00 p.m.</td>
<td>Robotics Competition</td>
</tr>
<tr>
<td>4:30 p.m.</td>
<td>Laser Light Show and Other Demonstrations</td>
</tr>
<tr>
<td>5:00 p.m.</td>
<td>Post-Test and Survey</td>
</tr>
<tr>
<td>5:30 p.m.</td>
<td>Poster/Project Presentations</td>
</tr>
<tr>
<td>6:00 p.m.</td>
<td>Closing Banquet and Award</td>
</tr>
</tbody>
</table>

To enhance the students’ understanding of EO engineering and to gain in-depth information about the field, students are arranged to visit local Electro-Optics engineering companies and research laboratories specialized in the applications discussed. Some of the companies visited include II-VI Incorporated, world leader in CO₂ laser optics and laser crystal growth technology; L³ Communications, producer of complex electro-optical and electro-mechanical systems and instrumentation for the commercial and defense markets; Sabeus, designer/manufacturer of fiber optics components; and the Penn State Electro-Optics Center who are renowned for lasers, night vision and robotics imaging. During these visits, the local EO companies shared information about internship and career opportunities in electro-optics engineering, which included examples of current projects underway at their companies.

Guest speakers are also invited to take part in the Camp to provide further insight into the field and its applications to various fields. A highlight to Summer Camp, for example, was a video-teleconference arranged with NASA’s Jet Propulsion Laboratory in Pasadena, California, to provide insight into the significance of optical imaging. A Forensics Trooper from the PA State Police took part in Summer Camp 2008, who provided an overview of EO applications in forensics, and demonstrated alternate light sources and other techniques.

Finally, a closing dinner was held at the end of the week which invited the student-participants and parents, as well as business and educational leaders. Students presented posters of their projects on topics introduced throughout the week and competed for various prizes. The projects completed individually or in small teams give the students a sense of accomplishment for the end of the camp and make the discipline immediately accessible. Attendees were impressed with the quality of the students’ posters and had a difficult time choosing a winner. The winning posters were awarded such related prizes as Deflexion, an innovative laser board game that the students played during Camp. The informal interactions with faculty and staff during at meal time may be an additional advantage for students and parents.
These camps have displayed a steady growth of interest in Electro-Optics. Due to the large attendance at the Electro-Optics Summer Camp in 2007, two Camps were offered during the summer of 2008 to provide more individualized attention to students and possible interaction throughout the activities. In 2009, the two camps were full, plus about 16 students in the waiting list. The average scores of the camp pre-test and post-test were 42% and 85%, respectively, for the past three years. Also the students were asked to complete a survey at the end of the week. They were asked such questions as “How has this camp changed your understanding of Electro-Optics?” One student responded that it “greatly improved” his/her “understanding”. Another student wrote, “I learned a lot more and this went beyond my expectations of Electro-Optics.” Students were also asked how this Camp helped them make a decision about their future career. Some students wrote that this Camp helped them to decide on EO as their future career choice. Those students who attended the Summer Camps have formed the main pipeline for the EO program.

D. EO Workshop for Teachers and Guidance Counselors

As part of our long-term strategy, professional development activities such as workshops for local high-school personnel are also provided. Area math and science teachers and guidance counselors have been invited to take part in the “Electro-Optics Workshop” where they participate in hands-on EO activities that could be used in their classrooms. An overview of Electro-Optics, career and educational opportunities are also introduced. The workshop provides lecture components integrated with hands-on activities to gain insight into the field, as well as tours of local electro-optics companies and opportunities to meet IUP EO graduates currently working in the field. To promote further investigation, teachers/counselors also received kits with a curriculum guide to take back to their schools to teach their students about the exciting field of EO. The teacher/guidance counselor may earn Act 48 credit. Table 4 details the typical schedule of such a workshop.

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30 a.m.</td>
<td>Welcome - Continental Breakfast</td>
</tr>
<tr>
<td></td>
<td>• Introductions</td>
</tr>
<tr>
<td></td>
<td>• Act 48 sign-up</td>
</tr>
<tr>
<td>8:45 a.m.</td>
<td>Overview</td>
</tr>
<tr>
<td></td>
<td>• Electro-Optics Program</td>
</tr>
<tr>
<td></td>
<td>• Opportunities for students</td>
</tr>
<tr>
<td></td>
<td>o Classroom visits</td>
</tr>
<tr>
<td></td>
<td>o On-Campus EO Experience</td>
</tr>
<tr>
<td></td>
<td>o EO Summer Camp</td>
</tr>
<tr>
<td>9:30 a.m.</td>
<td>Electro-Optics Lab Activities</td>
</tr>
<tr>
<td></td>
<td>• LED Color Kit</td>
</tr>
<tr>
<td>10:30 a.m.</td>
<td>Break</td>
</tr>
<tr>
<td>10:45 a.m.</td>
<td>• LED Color Kit (cont’d)</td>
</tr>
<tr>
<td>12:00 p.m.</td>
<td>Lunch</td>
</tr>
<tr>
<td>12:45 p.m.</td>
<td>Electro-Optics Career Opportunities</td>
</tr>
</tbody>
</table>
The survey results from 18 participants who attended this workshop in 2006 showed that 97% were satisfied with the workshop and 15 indicated that this workshop should be offered again. In addition, the teachers are told that the advanced EO lab facilities and diagnostic equipment on-campus are open to high-school classes for lab experiments. This may be especially beneficial to local high schools with poor science facilities. As the result, local school teachers have bought their students to experience advanced topics such as laser holography and nuclear radiation lab experiments by utilizing the state-of-the-art EO laboratories on-campus.

E. Other Outreach Activities
Apart from the outreach activities provided for the students, school teachers and guidance counselors, other outreach activities are launched for parents and more general audiences, such as Information Sessions for parents and Open Houses for the public. Area parents have been invited to attend an information session on Electro-Optics and tour the teaching facility and campus. Focus groups are invited to attend special topics such as “Women in Forensics”, etc., with the hope that the number of female students in the program will increase. Overall, by holding these outreach activities, the area at large will be introduced to this emerging field and learns more about its career opportunities.

IV. EVALUATION

For each outreach activity, a survey is conducted to gain feedback from the participants. The survey results collected indicate a favorable response to the activities organized and the interests generated. A typical result is shown in Table 5, which was the evaluation survey completed in 2007 by 42 students brought in by the guidance counselor, including 24 juniors and 18 sophomores, after the on-campus Electro-Optics Experience.

<table>
<thead>
<tr>
<th>Table 5 Evaluation Example for the Electro-Optics Science Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. What was your favorite activity during the Electro-Optics Science Experience today?</strong></td>
</tr>
<tr>
<td><strong>Response</strong></td>
</tr>
<tr>
<td>Laser demonstrations/lab activities</td>
</tr>
<tr>
<td>Comments:</td>
</tr>
<tr>
<td>“The lasers show and the pulsing laser”</td>
</tr>
<tr>
<td>“Hands on experiences”</td>
</tr>
<tr>
<td>“Playing with red and green lasers”</td>
</tr>
<tr>
<td>“The sound rides with laser – if you interrupted the laser the sound stopped!”</td>
</tr>
</tbody>
</table>
Of 147 students from 7 schools who attended the on-campus Electro-Optics Experience in 2007, approximately 40% of them expressed an interest in a career in Electro-Optics engineering. From these surveys, the effectiveness of the outreach activities is evaluated, and possible changes for future improvements are made. More important, students who are interested in EO engineering are identified.

For summer camps, pre- and post-tests are administered. For the past three years, the average scores of pre-test and post-test were 43% and 87%, respectively, for a total of 118 campers (18 in 2006, 25 in 2007, 31 in 2008, and 44 in 2009). The survey statistics showed they had a valuable experience (4.78 out of 5), a better understanding of careers in science, math, and technology (4.73), and a better understanding of the field of electro-optics (4.82). However, some campers indicated in the survey that they were interested but will pursue science or engineering studies at other universities. To some degree, the increase of enrollment, the quality of students, retention, student academic performance and satisfaction can be viewed as measures of the success of the outreach activities.

V. SUMMARY

The basic formats of four outreach activities for the newly established EO program at IUP have been discussed. As the only program, to our knowledge, which offers both associate’s and bachelor’s degrees in EO, it has successfully implemented a 2+2+2 initiative that allows a wide range of students for entry into the rapidly-evolving EO workforce. In order to sustain its growth, a series of outreach activities have been offered to create an overall awareness of EO engineering in the community. The multi-dimensional approach has been carried out to achieve the short-term and long-term outreach strategies. Students, school teachers and parents are informed of the educational and career opportunities of the EO engineering field. The active and effective outreach activities have exposed the participants to the excitement of EO engineering through tours of on-campus labs, local EO engineering companies and research organizations. In addition, students experience an interesting learning process through the on-campus Electro-Optics
field trip and EO Summer Camp, and the interactions with the faculty and stuff, students currently enrolled in the program and local EO professionals.

Various outreach activities have effectively attracted students to the EO program, as indicated by the continuous growth of student enrollment, the improvement of freshman quality, success of graduates and current students involved in the program, nearly 100% graduate job placement, and positive reviews from local industrial leaders. The reported outreach activities and outcomes are both interesting and useful to engineering education in general, and one or more formats discussed can be adapted and implemented to promote engineering programs.

Acknowledgement

The authors would like to express their appreciation for the support and funding received from the Pennsylvania Department of Community and Economic Development from 2005 -2009, the outreach grants from SPIE in 2007 and 2009, the grants from NSF ATE/OP-TEC in 2008 and 2009, and support from the Office of Naval Research and the Penn State Electro-Optics Center.

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Student chapters: effective dissemination networks for informal optics and photonics education

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ABSTRACT
Professional societies sponsor student chapters in order to foster scholarship and training in photonics at the college and graduate level, but they are also an excellent resource for disseminating photonics knowledge to pre-college students and teachers. Starting in 2006, we tracked the involvement of SPIE student chapter volunteers in informal pre-college education settings. Chapter students reached 2800, 4900 and 11800 pre-college students respectively from 2006-2008 with some form of informal instruction in optics and photonics. As a case study, the EduKit, a self-contained instruction module featuring refractive and diffractive micro-optics developed by the European Network of Excellence on Micro-Optics (NEMO), was disseminated through student chapters in Argentina, Belgium, Canada, China, Colombia, India, Latvia, Mexico, Peru, Russia, Singapore, South Africa, and the United States. We tracked the movement of this material through the network, up to the student-teacher feedback stage. The student chapter network provided rapid dissemination of the material, translation of the material into the local language, and leveraged existing chapter contacts in schools to provide an audience. We describe the student chapter network and its impact on the development of the EduKit teaching module.

Keywords: Education, informal science, networks, student organization, outreach, language

1. Introduction

Engaging pre-college students in optics and photonics education is of vital importance to developing an educated research and work force that can conduct the exploration of light-based phenomena and technology. Numerous practical curriculum modules, after school experiments, and demonstrations designed to reach pre-college students have been detailed in the ETOP conference proceedings, but the developers of these programs can be stalled at the next step – getting the material into the hands of capable teachers that understand some optics and have significant student contact time. Various teacher networks, such as MESA or Project PHOTON seek to address this issue with teacher training programs, backed up by administrative and networking support. However, these teacher development and linking programs are not present in all communities, and are often absent in developing countries.

How can good materials find the wider audience and support that they need? How can like-minded people interested in this subject work together in a way that helps expose more pre-college students to optics and photonics educational materials? The purpose of this paper is to describe one way that education researchers and curriculum developers in optics and photonics can reach a wider audience of pre-college students world-
wide in a way that responds to local needs and conditions. In section 2, we will describe the SPIE network of student chapters, the characteristics that make them effective, and their involvement in outreach to date. In section 3, we will examine the EduKit project as an example of the use of this network for dissemination of educational materials.

2. Growth of the SPIE Student Chapter network

A student chapter is a campus organization of students who receive funding and networking support from a national or international professional organization. Student membership and chapter membership with SPIE—the International Society for Optics and Photonics— is targeted at undergraduate and graduate students involved in an optics and photonics program, though middle and high school; community college students are involved as well.

Student chapters have been a part of SPIE since the first chapter at California Polytechnic University at San Luis Obispo was founded in the mid-1990s. This chapter languished and the chapter program as a whole grew slowly through the late 1990s, attracting a total of only 5 chapters by the end of 2000. This first group exhibited a wide diversity in education goals – optics research powerhouse University of Central Florida, an after-school program at a Columbia, Missouri area public high school, and the technician-oriented Three Rivers Community College; and geography – with Tsinghua University (China) and the Warsaw University of Technology (Poland). While this diversity speaks to the wide impact of photonics, it also made it difficult to provide a coherent set of benefits to chapters that would satisfy all members.

In 2002, the chapter development effort received dedicated staff support and financial resources to expand. In two years, this modest investment of resources produced a strong return in program interest and new chapter formation. In 2004, SPIE launched a successful three-year student pipeline initiative as part of its strategic plan that resulted in strong growth in student membership and student chapters, as well as programs for non-member students. The goal of the initiative was to increase the visibility of optics while feeding the pipeline of students into optics/photonics education and careers. The initiative was completed at the end of 2006, and the program has continued as part of ongoing SPIE operations since then. Momentum from the program has resulted in continued growth of student programs, student members (Figure 1), student chapters (Figure 2), and the recognition of the need for an Early Career Professional (ECP) program to help support new professionals during their post-terminal degree transition years.

![Figure 1 – Total student membership in SPIE over time](image1)

![Figure 2 – Growth of SPIE student chapters over time. 145 chapters are anticipated by year-end 2009](image2)
Since the initiative launch in 2004, SPIE Student Membership has grown 72% (to 4,260) and Student Members now make up one quarter of SPIE’s total membership. Student chapters now number 139. While not all chapters are active at all times, roughly 85% of chapters participate with SPIE for at least one of their chapter benefits in the course of a year. Inactive chapters are removed from the ranks after a one year review process.

2.1 Student chapter benefits

Student Chapters enjoy a wide variety of support from the Society – a yearly activity grant that scales with the size of the chapter, an officer travel grant to attend an SPIE meeting, a workshop on leadership and professional development, support for a Visiting Lecturer to speak at their university or event, free books, and educational outreach materials such as the Hands-on-Optics kits and informational posters. Through the organization of chapter activities, students also become familiar with SPIE programs and opportunities as a whole: submitting papers, serving on governance committees, and networking with current society leadership. Non-member students receive support through our Lunch with the Experts events and professional development speakers at major SPIE meetings. Quarterly student newsletters and networking through Facebook (an online social networking forum) round out the program.

All three professional societies focused on optics and photonics (SPIE, OSA, IEEE-Photonics) support student chapter programs as part of their educational missions. Students at numerous schools have recognized this overlap, the availability of resources through the various society programs, and have formed joint chapters of the three societies. Leveraging resources across the three societies has allowed chapters to pursue ambitious outreach programs.

2.2 Chapter structure and access

The return on the program is that SPIE has gained a large number of young advocates and contacts in universities around the world. SPIE maintains contact with an ever-changing group of student leaders and chapter advisors. Chapters are typically organized with an elected student executive group (President, Vice-President, Secretary, and Treasurer) and a faculty member as chapter advisor. Most chapters observe a one year term limit for each student position. While small chapters sometimes have trouble filling all positions, large chapters often add positions to coordinate specific functions like membership rosters, web management, speaker selection, or outreach efforts. The chapter structure is flexible based on the needs of the group. Currently, 645 students and faculty hold positions within chapters, and this number has grown steadily with the chapter growth. This core leadership group of students and faculty within the chapter program is in more direct contact with SPIE staff than the general membership.

Accessing this network of students and advisors is done by going to the student chapter webpage: http://spie.org/studentchapters or sending an e-mail to students@spie.org with your message and target audience request. Individual chapters are also encouraged to maintain their own websites with expanded program information and contact information – links can be found on the individual chapter pages. The main page will soon be upgraded to provide better geographic information about chapters and more direct links to contact chapter officers via the Profiles feature on SPIE.org.

2.3 Distribution of chapters: geography, language, and economy

Regional development of chapters followed the historical relationships developed through the larger SPIE organization. Strong connections in Eastern Europe led to rapid growth of chapters in Poland, Ukraine, and Russia early in the program. Outreach by 2005 president Malgorzata Kujawinska brought connections and chapters in India. Subsequent presidents have made efforts in China and Latin America to good effect.

The wide geographic distribution of chapters has been particularly significant in providing one of the unique strengths of the program: multi-lingual ability. Although the lingua franca of science is English, outreach instruction in the local community must by nature take place in the local language. Student chapter members
are the best equipped to manage the translation between any instructional materials they might receive, their common language of instruction, and the dominant language of the region. In all, SPIE chapters work in 22 different languages.

SPIE membership costs are reduced for individuals residing in countries that are eligible for Special Economic Consideration, as selected by the World Bank³. Seventy-seven SPIE student chapters exist in countries eligible for this rate, or 55% of the total chapters. While this simple binary metric cannot reflect the diversity of the economic conditions in the various countries, it is a useful indicator.

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of Chapters</th>
<th>Language</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>2</td>
<td>Spanish</td>
</tr>
<tr>
<td>Armenia</td>
<td>1</td>
<td>Armenian, Russian</td>
</tr>
<tr>
<td>Belgium</td>
<td>1</td>
<td>Dutch, French</td>
</tr>
<tr>
<td>Brazil</td>
<td>1</td>
<td>Portuguese</td>
</tr>
<tr>
<td>Canada</td>
<td>5</td>
<td>English, French</td>
</tr>
<tr>
<td>China</td>
<td>18</td>
<td>Chinese (Mandarin 17, Cantonese 1)</td>
</tr>
<tr>
<td>Colombia</td>
<td>3</td>
<td>Spanish</td>
</tr>
<tr>
<td>Germany</td>
<td>1</td>
<td>German</td>
</tr>
<tr>
<td>India</td>
<td>9</td>
<td>Hindi, Telegu, Malayalam, Bengali</td>
</tr>
<tr>
<td>Ireland</td>
<td>1</td>
<td>English</td>
</tr>
<tr>
<td>Japan</td>
<td>2</td>
<td>Japanese</td>
</tr>
<tr>
<td>Latvia</td>
<td>1</td>
<td>Latvian</td>
</tr>
<tr>
<td>Malaysia</td>
<td>1</td>
<td>Malay</td>
</tr>
<tr>
<td>Mexico</td>
<td>7</td>
<td>Spanish</td>
</tr>
<tr>
<td>Peru</td>
<td>1</td>
<td>Spanish</td>
</tr>
<tr>
<td>Poland</td>
<td>6</td>
<td>Polish</td>
</tr>
<tr>
<td>Romania</td>
<td>1</td>
<td>Romanian</td>
</tr>
<tr>
<td>Russia</td>
<td>13</td>
<td>Russian</td>
</tr>
<tr>
<td>Singapore</td>
<td>1</td>
<td>English, Chinese</td>
</tr>
<tr>
<td>South Africa</td>
<td>1</td>
<td>English</td>
</tr>
<tr>
<td>Spain</td>
<td>1</td>
<td>Spanish</td>
</tr>
<tr>
<td>Taiwan</td>
<td>4</td>
<td>Chinese (Mandarin)</td>
</tr>
<tr>
<td>Thailand</td>
<td>1</td>
<td>Thai</td>
</tr>
<tr>
<td>Turkey</td>
<td>1</td>
<td>Turkish</td>
</tr>
<tr>
<td>Ukraine</td>
<td>8</td>
<td>Ukrainian</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>2</td>
<td>English</td>
</tr>
<tr>
<td>United States</td>
<td>44</td>
<td>English</td>
</tr>
</tbody>
</table>

Table 1 – Distribution of student chapters by country and primary language
2.4 Sustainability and development of chapters at different educational levels

Chapters naturally wax and wane in their activity over the course of their existence. While the goal is that once started, a chapter becomes self-sustaining indefinitely, the reality can be different. In addition to the human factors of enthusiasm, connection to the community, and succession of members, external factors also play a large role in whether chapters stay active. In the last five years, experience has shown that the chapters which stay active and engaged with SPIE share certain characteristics of program size, turn-over rate, and relevance. Among them, size of the host optics program has the most direct influence on the continued viability of chapters. Larger optics programs tend to have chapters that remain active and can easily be restarted if activities lapse.

High School chapters suffer the most from these factors. High school chapters have been organized around after school programs and individual technical training classes. An engaged and active chapter advisor is a necessity since often high school students lack the self-confidence and organization to act as a group. In addition to these hurdles, students only become acquainted with the math, geometry, and physics related to optics in their 3rd or 4th year of education, and optics and photonics is rarely included in the pre-college curriculum. With a small number of interested students and at best one year of familiarity with the chapter and the subject material, pre-college chapters rarely remain active from year to year. The SPIE program offerings themselves do not lend themselves well to high school chapters, the primary benefits being related to scientific conference attendance and career development. High school groups interested in optics & photonics are more successful in partnership with an active university chapter, using SPIE resources such as the optics posters as a supplemental resource.

Community college programs face similar issues of turn-over and relevance that high school chapters face. The topics of modern physics and the interaction of light with matter are typically taught as a second year university course in the United States, giving students little time to become versed in the material. Focused optics programs like that at Three Rivers Community College overcome some of this by starting students on optics content early, with hands-on experimentation techniques. Because of the rapid turnover of students, strong faculty leadership is essential to sustaining interest in the chapter in this environment.

Programs consisting primarily of undergraduates have a wider window for student involvement (less turn-over) and relevance than community college programs. Four year undergraduate programs allow students significant time to become familiar with optics and photonics content. In addition, students have the time to
become familiar with the chapter structure, enabling them to develop outreach efforts in their community. Undergraduates can often act as content experts for pre-college students or teachers and welcome the chance to develop their teaching techniques.

Most SPIE chapters consist of both undergraduate and graduate students, with graduate students tending to dominate the chapter leadership due to their optics focus, time availability, and the relevance of optics in their lives. Chapters that manage to integrate their programs so that undergraduate and graduate students work together on projects can be quite successful. Developing activities and systems that engage both the graduate and undergraduate students in chapter activities is quite challenging, and chapters have cited “engaging undergraduates in chapter activities” in surveys of the biggest challenges facing chapter leaders.

### 2.5 Variety in Outreach by chapters

When chapters have strong leadership, motivation, and access to resources, they can reach large numbers of pre-college students. Not surprisingly, the variety of outreach activities that student chapters conceive, design, and execute is quite significant. Appendix A contains a detailed listing of chapter outreach activities for the most complete years of the survey, 2006, 2007 and 2008. The following list calls out unique projects that have had a wide impact or exhibit a new pathway for reaching students with optics content:

- **The Centro de Investigaciones en Óptica Student Chapter** obtained a monthly spot on children’s public television program TV4Ninos, which is broadcast by TV Qu4tro, a state-wide broadcaster with over 3 million viewers. During the spot, CIO members perform different experiments in real time in order to explain basic scientific concepts.

- **The Instituto Nacional de Astrofísica, Óptica y Electrónica Student Chapter** created two workshops for the 2nd International Reading Fair, an event attended by 20,000 school children. The workshops involved building periscopes and kaleidoscopes in order to illustrate basic optics principles. Roughly 1,000 children built periscopes and 900 children built kaleidoscopes. Additionally, the chapter brought telescopes to downtown Mexico City for a total lunar eclipse so that people could observe the phenomenon more closely. Roughly 1,000 people participated in this activity.

- **The International School of Photonics Student Chapter** held their third annual Optics Fair on November 28-29. More than 1400 K-12 students attended the fair, where scientific experiments tailored to their age levels were demonstrated.

- **The Nicholas Copernicus Univ. Student Chapter** took part in the 8th Annual Festival of Art and Science, a city-wide science outreach effort. They designed a workshop where they presented physical experiments describing interesting natural phenomena. Their event drew almost 1,000 visitors over the course of three days.
• The Stanford Student Chapter hosted an online optics-themed photography contest for 6th-12th graders, receiving more than 50 entries. They also hosted a field trip, called Girls Go Tech 2008, for K-3rd grade girl scouts. They took the scouts to the Chabot Space and Science Center in Oakland where they did a number of hands-on optics activities with them. They expanded content for the Stanford OSA/SPIE Student Chapter YouTube channel, which features videos covering their educational outreach, academic, and networking events.

2.6 Measuring Outreach

On the first of each month, 10-15 chapter reports are due to SPIE covering the annual activities for the chapter. All chapters are expected to provide an annual report of activities whether or not they have received funding in that year. In practice, we receive reports from about 80% of all chapters. Staff provides feedback on the reports, uploads them to the chapter web page for record keeping and dissemination, and notes if there have been any outreach activities performed by the group. If there have been outreach activities during the year, we attempt to determine how many people participated in this activity. Some chapters provide their own estimates of the numbers of students at their events, and this is explicitly part of the chapter report guidelines. In cases where no numbers are provided, we either query the chapter leadership or attempt to estimate the number of participating pre-college students from any pictures of the outreach activity. While counting the number of people in the pictures is crude, it does provide a quick, rough number. Especially notable or well-attended outreach activities are highlighted in the quarterly student newsletter: Wavefront, which can be accessed on the web.

In the three years that Outreach efforts have been tracked, 2006, 2007, and 2008, SPIE student chapters reached 2800, 4900 and 11800 students with some form of optics education. Tracking was incomplete in 2006 and has not yet completed for the 2009 school year. Because of the wide variety of outreach projects performed and the uncertainty in the numbers of participants and duration of the events, we do not attempt to count contact hours per student for the events. Certainly, the type of contact varies for each event – some pre-college students take part in multi-day summer programs led by chapters, while others are involved in a series of demonstrations lasting for just an hour. This is especially apparent in 2008, when numerous student chapters undertook exceptionally large outreach events. Sophisticated presentations, such as the Vrije Universiteit Chapter’s “Fascination of Light” Science show, brought large numbers of pre-college students and teachers into contact with optics and photonics concepts. Other chapters, like the University of Arizona, worked on a week-long optical sciences camp for high school students. While the numbers of students reached are vastly different, the total contact hours for both projects would likely be approximately equal. Despite the difficulty in finding a way to track these events on a level that recognizes their differences, we believe that even a basic amount of counting helps quantify the impact of student chapters in their communities.

2.7 Face-to-face: Catalyzing the effectiveness of student chapter programs

While online networks can provide the communications infrastructure for educational outreach, face to face meetings have been essential in bringing projects to a wider audience. Annually, SPIE hosts the Student Chapter Leadership Workshop as part of the Optics & Photonics conference in San Diego. This workshop provides funding to bring a representative from all student chapters in good standing to San Diego for a day and a half program of professional development and networking. Since 2004, the Leadership workshop has hosted 50-90 chapter representatives and an additional 30-50 chapter students and veteran leaders each year (80 attendees ('05), 110 attendees ('06), 125 attendees ('07), 135 attendees ('08)).

This face to face meeting has been used effectively to provide both materials and outreach training through optional free courses. The Hands on Optics (HOO) program, a partnership of SPIE, OSA, and the National Optical Astronomy Observatory (NOAO), has hosted training programs for its optics modules at both the Optics & Photonics conference and Photonics West since 2006. In the last 3 years, the training program has focused on the Terrific Telescopes mini-kit, a portable version of the Magnificent Magnifications module. The mini-kit provides materials and instruction for an educator to assist students in constructing a small refracting
telescope and determine the properties of the lenses and structures that make up the telescope. The kits are roughly the size of a thick laptop computer case, and contain enough materials to make 5 telescopes. Throughout the program, the distribution of materials widely to chapters has proven difficult and expensive using standard post and shipping methods. Providing the kits directly to the students at the conference eliminates this issue. More importantly, the training courses get student educators to become familiar with the HOO mini-kit and hopefully to embrace the inquiry-based educational techniques of the modules. Recognizing that students have deeply rooted preconceptions of how natural phenomena like light and reflection actually work is a primary development of recent educational research and has been incorporated into the HOO modules thoroughly. Outreach training lessons serve to model the teaching experience so that student educators can take it out into the pre-college environment the best techniques.

Using the resources and timing of the Leadership workshop to disseminate optics education materials is an effective way to leverage resources. No other SPIE event in the year brings together students from such a wide variety of backgrounds with specific goals like service and outreach in mind. There is a great deal of enthusiasm for quality optics demonstrations throughout the student group, with many students building their own demonstration materials and hosting outreach events. As students work with one another, they share tips and strategies for improving the events. These meetings help students become a part of the broader network of professionals working on the problem of creating effective optics and photonics curricula.

3.0 The EduKit project

Through a grant from the European Commission, the Network of Excellence in Micro-Optics (NEMO) designed an outreach package called the EduKit. NEMO's goal for the EduKit program is to expose students to the potential of micro-optics in science and engineering applications by distributing Edukits for free. The heart of the kit is a plastic card containing diffractive and refractive optical elements. Combined with a laser, this card can produce a large range of beam patterns, from simple splitting and grid patterns to complex images and words. In addition to the diffractive optics card and the laser, the EduKit also contains a DVD with a description of the card and a lesson handbook in the following EU languages: Dutch, German, English, Finnish, French, Italian, Polish, Spanish, and Turkish. The EduKit materials have been described in various papers for this conference.

In summer 2008, the SPIE Student Chapter at the Vrije Universiteit Brussel took the initiative in disseminating the EduKit to 21 other SPIE Student Chapters located in Argentina, Canada, China, Colombia, India, Latvia, Mexico, Peru, Russia, Singapore, South Africa, and the United States. Again, the Student Chapter Leadership Workshop provided a venue to inform and solicit volunteers in the project, though no on-site training was provided. The plan was to get a first round of feedback on the kit by the end of 2008 so that the program can be reviewed and improvements made on the materials. The Vrije Universiteit Brussel chapter provided total of 700 EduKits to chapters for distribution in their local communities.

| Number of pupils at Edukit activities | 1147 |
| Number of teachers at Edukit activities | 116 |
| Number of received evaluation forms | 17 |

The evaluation forms asked for a simple response to the quality of the EduKit materials – optics and manual:

<table>
<thead>
<tr>
<th></th>
<th>Very good</th>
<th>Good</th>
<th>Sufficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual</td>
<td>35.29%</td>
<td>41.18%</td>
<td>23.53%</td>
</tr>
<tr>
<td>Optics</td>
<td>47.06%</td>
<td>47.06%</td>
<td>5.88%</td>
</tr>
</tbody>
</table>

It also surveyed which experiments / demonstrations from the manual were carried out by the chapters:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
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<td>82.35%</td>
<td>88.24%</td>
<td>88.24%</td>
<td>58.82%</td>
<td>35.29%</td>
<td>29.41%</td>
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</tbody>
</table>

The challenge of the kit is integrating it into pre-college classroom instruction. Diffractive optics can be a mind-bending topic, especially for young students who are perhaps just being introduced to simple ray-tracing
and basic geometric optics. Although teaching the principles of diffractive optics is not a primary goal of the EduKit, some understanding of the principles at work helps with the instruction and experiments contained in the kit.

Finding good ways to use the kit materials and the included lessons was the subject of the 2008 Outreach challenge that was jointly organized by SPIE and the SPIE Student Chapter at the Vrije Universiteit Brussel. Chapters participating in the first round of the kit evaluation were offered the chance to compete for $2000 in awards by producing short video demonstrations of basic principles and lessons that are possible with the kit. For the competition, videos were uploaded to the SciVee.tv website and judged by a panel of science education experts. The overall goal was to produce a supplement of materials that can expand the accessibility of the kit – essentially providing a quick start guide for teachers that may not have the benefit of on-site training. The challenge received three video lesson submissions which currently can be found on the SciVee.tv website, but will be made accessible through a more open video sharing site like YouTube or Vimeo.

Figure 4a – Student manipulating the diffractive optics card

Figure 4b – Various beam shapes are possible with the card

4.0 Conclusion - Dissemination using the SPIE Student Chapter network

The SPIE Student Chapter network proved effective in distributing both the EduKit material and collecting feedback from users. The general strengths of the network are the rapid dissemination of information and material via the leadership workshop, translation of the material into the local language when needed, and leveraging existing chapter contacts in schools to provide an audience. The importance of this last point cannot be over-emphasized. Many Student Chapters already have local connections with teachers from previous outreach contacts so a new network need not be established to test new materials. As evidence of the effectiveness of the network, dissemination of the EduKit began in mid-August 2008 at the Leadership Workshop and had reached 1147 students in the span of one academic semester.

Improvements to the system are planned primarily in two areas: group communications and post-event information sharing. Group communications for the EduKit project was still handled primarily through email, even though we used socially-based sites like SciVee.tv to store the final outreach projects. Group communications were not self-service and the interaction among chapters involved in the project was
Helping students organize and providing the tools they need to communicate about relevant topics is a primary goal of the SPIE student program. Some tools have worked well for group collaborative communications; for example, the SPIE Student Facebook group was growing numbers (587 members) and allowed threaded discussions and information sharing. Unfortunately, changes in the Facebook business model have removed much of the visibility from groups, making this tool less accessible. New collaboration and sharing tools must be found to compensate. Google sites – a wiki-based website creation tool - may provide an answer.

The post-outreach event reports are currently available in PDF format as subsections of the chapter reports stored on the individual Student Chapter pages on spie.org. However, just because they are available does not necessarily mean that they are read. Modern information sharing through a more collaborative medium like a blog or wiki dedicated to optics education could help tag and sort outreach events by size and topic. This would make it much easier for other chapters to share outreach event plans and communicate. SPIE’s information collection on these outreach events could also be improved with a dedicated feedback form for recording outreach interactions. Ideally, this would ask students to estimate contact hours and key lessons from their events.

4.1 Summary

We have described the size, organization, and key characteristics of the SPIE Student Chapter network; a collection of 139 campus organizations supported by the Society to engage in professional development programs like outreach to pre-college students. This network of students provides needed optics and photonics teaching in their local communities and reaches a very large number of students relative to the size of the chapter program. These outreach events have the advantages of being locally based and available in the native language of the community, relevant to the needs of the community, and employ modern concepts and teaching techniques. Overall, the student chapter network serves a very wide range of cultures, languages, geographies, and socio-economic standings. This network is accessible to people working on outreach curriculum and can serve as a rapid and effective point for dissemination for material. The Student Chapter Leadership Workshop at the SPIE Optics & Photonics conference is an effective venue from which to communicate and distribute material that chapters can use, as we demonstrate with NEMO’s EduKit project. We will continue to seek more collaborative and social means for chapters to share their outreach efforts so that quality events can spread throughout the world.
References:

2. http://www.nebhe.org/content/view/248/190/
5. http://www.hands-on-optics.org/home/
9. Taghizadeh, M. R., Stijns, Erik, and Hugo Thienpont, “The NEMO educational kit”, Proceedings, Ninth International Topical Meeting on Education and Training in Optics and Photonics (ETOP), Marseille, France

Acknowledgements:
This project was made possible by the efforts of the Vrijie Universiteit Brussel SPIE Student Chapter and VUB staff Nathalie Debaes and Bernadette Callebaut to distribute the EduKits. Prof. Hugo Thienpont is PI and contact for the NEMO project. DF would like to thank Marie Biondolillo for the geo-coding used to create Figure 3 and for tracking the numbers of students in Chapter Outreach events in 2007 and 2008. Teddy Parker-Renga also assisted with this effort. We would like to acknowledge the EduKit videos created by the Student Chapters from Nizhny Novgorod, Cochin University of Science and Technology, and the Samara region. Thanks are also due to video judges Prof. Judy Donnelly, Dr. Marc Nantel, and Dra. Cristina Solano for providing feedback on the video submissions.
### 2006 Outreach Activities

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Activity</th>
<th># people reached</th>
<th>Type</th>
<th>Counted (how)?</th>
</tr>
</thead>
<tbody>
<tr>
<td>BGSU</td>
<td>High school open house</td>
<td>10</td>
<td>HS student</td>
<td>est by counting ppl in pics</td>
</tr>
<tr>
<td>Brussels</td>
<td>BEST Summer School</td>
<td>20</td>
<td>10 adults</td>
<td>in report</td>
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<tr>
<td></td>
<td>NEMO Edukit proposal</td>
<td>14</td>
<td>misc children</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>NEMO Edukit training</td>
<td>10</td>
<td>Teachers</td>
<td>in report</td>
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<tr>
<td>CUSAT</td>
<td>10 day workshop for school children &quot;Physics: Scope and Awareness&quot;</td>
<td>20</td>
<td>Children</td>
<td>in report</td>
</tr>
<tr>
<td>Tec de Monterrey</td>
<td>Second Matlab workshop</td>
<td>25</td>
<td>undergrad</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>Mood patch workshop</td>
<td>50</td>
<td>Children</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>Contact thermomenter &amp; liquid crystal workshop</td>
<td>25</td>
<td>HS student</td>
<td>est by counting ppl in pics</td>
</tr>
<tr>
<td>Koç Univ.</td>
<td>Solar Race</td>
<td>24</td>
<td>children/HS</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>Science Festivals for Kids</td>
<td>10</td>
<td>Children</td>
<td>est by counting ppl in pics</td>
</tr>
<tr>
<td>Samara State Univ.</td>
<td>&quot;excursions and review lectures for schoolchildren and students in Samara Branch of the Lebedev physical Institute.&quot;</td>
<td>?</td>
<td>children/HS</td>
<td>unknown</td>
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<tr>
<td>Silesian</td>
<td>Demonstrations of physical and optical experiments</td>
<td>30</td>
<td>children/HS</td>
<td>est by counting ppl in pics</td>
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<td>St. Petersburg ITMO</td>
<td>Scientific Youth School &quot;Optics - 2006&quot;</td>
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<td>unknown</td>
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<td>U Alberta</td>
<td>SPIE Info Lunch</td>
<td>50</td>
<td>undergrad</td>
<td>in report</td>
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<td></td>
<td>Engineering Open House (Laser Maze to return in 2007)</td>
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<td>HS student</td>
<td>(estimated)</td>
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<td>Wroclaw</td>
<td>&quot;Festival of Science&quot;</td>
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<td>HS student</td>
<td>(estimated)</td>
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<td></td>
<td>&quot;Magic of Physics&quot;</td>
<td>75</td>
<td>Children</td>
<td>(estimated)</td>
</tr>
<tr>
<td>Nicolas Copernicus</td>
<td>Junior High School Presentation &quot;Electric and Magnetic Field&quot;</td>
<td>350</td>
<td>Children</td>
<td>est by counting ppl in pics</td>
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<tr>
<td>Warsaw</td>
<td>Festival of Science</td>
<td>250</td>
<td>HS student</td>
<td>(estimated)</td>
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<td>35</td>
<td>HS student</td>
<td>est by counting ppl in pics</td>
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<td></td>
<td>Science workshop for children &quot;Baños de ciencia con el GTM&quot;</td>
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<td></td>
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<td>120</td>
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<td>University/Event</td>
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<td>Method Used</td>
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<td>---------------------------------------------------------------------------------</td>
<td>-----------------------------</td>
<td>-------------------------------------------------</td>
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<td>13th national Week of Science and Technology Children's workshops</td>
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<td>est by counting ppl in pics</td>
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<tr>
<td>&quot;Baños de ciencia&quot; at &quot;Consejo puebla de lectura&quot;</td>
<td>15 Children</td>
<td>est by counting ppl in pics</td>
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<td>Lazer Maze</td>
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<td>Univ. of Dayton Outreach at Miamisburgh High School</td>
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<td>on website (reported)</td>
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<td>Grade 10 outreach in conjunction with Air Force Research Laboratory</td>
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<td>Montréal Chapter 2 Day Optics workshop</td>
<td>37 undergrad &amp; grad</td>
<td>in report</td>
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<td>CIO Hands-on Workshops for teachers Science Club for Children (4 meetings thus far) Science club participation (for Children and Teens)</td>
<td>? Teachers</td>
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<td>Notre Dame Academic seminars (invited speaker for students and faculty)</td>
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<td>MEPhl Alex Radnaev's visit to Irkutsk State Univ (ISU)</td>
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<td>Alabama A&amp;M Nobel Laureate Lecture: Frank Wilczek &quot;Senior Day&quot;: Physics Demo &amp; Physics Skit</td>
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<td>CUSAT</td>
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<td>High School</td>
<td>est. by counting ppl in pics</td>
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<td>Ctr. de Investigaciones en Óptica - Leon</td>
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<td>in report</td>
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<td></td>
<td>Science Club for Children</td>
<td>108</td>
<td>Children</td>
<td>est. by counting ppl in pics</td>
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<td></td>
<td>Visits to High Schools</td>
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<td>High School, Elementary</td>
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<td>Elm school</td>
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<td>Duke University</td>
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<td>High School</td>
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<td>Elementary School Outreach</td>
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<td>est. by counting ppl in pics</td>
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<td>Optics Demos</td>
<td>14</td>
<td>High School</td>
<td>est. by counting ppl in pics</td>
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<td>Univ. of New Mexico</td>
<td>Central NM Science &amp; Engineering Research Challenge</td>
<td>500</td>
<td>Elementary - High School</td>
<td>in report</td>
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<td>Intel Science Fair</td>
<td>30</td>
<td>High School</td>
<td>in report, 1500 attendees</td>
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<td>Vrije Universiteit Brussel</td>
<td>Fascination w/Light Exhibition</td>
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<td>Elementary-High School</td>
<td>in report</td>
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<td>High School Teachers</td>
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<td>K-12</td>
<td>in report</td>
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<tr>
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<td>Magic of Physics Presentation</td>
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<td>Elementary school</td>
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<td>Liquid Crystals Presentation</td>
<td>13</td>
<td>High School</td>
<td>est. by counting ppl in pics</td>
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<td>Ctr. de Investigaciones en Óptica - Leon</td>
<td>Hands-on Workshop for Students</td>
<td>65</td>
<td>High School</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>Science Club for Children</td>
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<td>Children</td>
<td>est. by counting ppl in pics</td>
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<td>Participant Type</td>
<td>Attendance Method</td>
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<td>Delhi College of Engg</td>
<td>Lecture for High School Students: Optics and The Internet</td>
<td>5</td>
<td>High School</td>
<td>est. by counting ppl in pics.</td>
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<td>INAOE</td>
<td>Seminar in honor of the National Week of Science and Technology</td>
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<td>High school</td>
<td>in report</td>
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<tr>
<td>PUCP</td>
<td>Workshop on Optics for High School Teachers</td>
<td>20</td>
<td>High school Instructors</td>
<td>in report</td>
</tr>
<tr>
<td>UNC Charlotte</td>
<td>Nobel Laureate Visits UNC Charlotte/Outreach Activities</td>
<td>250</td>
<td>High school</td>
<td>in report</td>
</tr>
<tr>
<td>ISP</td>
<td>Optics Fair</td>
<td>1200</td>
<td>Middle School, High School</td>
<td>in report</td>
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<td></td>
<td>Optics to School</td>
<td>71</td>
<td>Middle School, High School</td>
<td>est. by counting ppl in pics on website of event</td>
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<td>Koc Univ</td>
<td>Solar Boat Race</td>
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<td>High School</td>
<td>est. by counting ppl in pics on website of event</td>
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<td>Solar Car Race</td>
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<td>High School</td>
<td>est. by counting ppl in pics on website of event</td>
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<td>Lehigh Univ</td>
<td>Lab Tour for Local Cub Scouts</td>
<td>5</td>
<td>Children</td>
<td>est. by counting ppl in pics</td>
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<td></td>
<td>COT OPTO Camp</td>
<td>12</td>
<td>Middle School</td>
<td>in report</td>
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<tr>
<td></td>
<td>Local Middle School Optics Demo</td>
<td>75</td>
<td>Middle School</td>
<td>in report</td>
</tr>
<tr>
<td>NITT</td>
<td>Assisting local students w/computer knowledge</td>
<td>34</td>
<td>Middle School, High School</td>
<td>est. by counting ppl in pics</td>
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<tr>
<td>Silesian Univ. of Techn</td>
<td>Demos for High School Students</td>
<td>10</td>
<td>High School</td>
<td>est. by counting ppl in pics.</td>
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<td>Stanford</td>
<td>Science Educator's Day</td>
<td>75</td>
<td>(K-12 teachers)</td>
<td>in report</td>
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<tr>
<td></td>
<td>Community Day Science Demo Booths</td>
<td>198</td>
<td>Children</td>
<td>est. by counting ppl in pics</td>
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<tr>
<td>Taurida</td>
<td>Optics Demos in Classroom</td>
<td>36</td>
<td>5 - 9 yrs old</td>
<td>est. by counting ppl in pics</td>
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<tr>
<td>Univ. of Calcutta Chapter</td>
<td>Outreach at Loreta Day School</td>
<td>140</td>
<td>Children</td>
<td>in report</td>
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<tr>
<td></td>
<td>Outreach at Our Lady Queen of Missions School</td>
<td>150</td>
<td>Children</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>Outreach at Svarna School</td>
<td>50</td>
<td>Children</td>
<td>in report</td>
</tr>
<tr>
<td>UCSD</td>
<td>Holography Workshop</td>
<td>24</td>
<td>Middle School</td>
<td>in report</td>
</tr>
<tr>
<td>Univ. of New Mexico</td>
<td>organized high school SPIE chapter</td>
<td>12</td>
<td>High School</td>
<td>in report</td>
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<tr>
<td>Wroclaw Univ.</td>
<td>Festival of Science</td>
<td>25</td>
<td>K-12</td>
<td>est. by counting ppl in pics</td>
</tr>
<tr>
<td>Magic of Physics Presentation (for Elementary School Children)</td>
<td>?</td>
<td>Elementary School</td>
<td>unknown</td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
<td>---</td>
<td>-------------------</td>
<td>--------</td>
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</tr>
<tr>
<td>Liquid Crystals Presentation</td>
<td>24</td>
<td>High School</td>
<td>est. by counting ppl in pics</td>
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</tr>
<tr>
<td>MFI (Math/Science Tutorials)</td>
<td>?</td>
<td>High School</td>
<td>according to report, 10 high schools took part, but I don't know how this translates numerically</td>
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Total: 4947
## 2008 Chapter Outreach

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Activity</th>
<th># people reached</th>
<th>Type</th>
<th>Counted (how)?</th>
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<tbody>
<tr>
<td>Chulalongkorn</td>
<td>Science Fair</td>
<td>600</td>
<td></td>
<td>reported via email</td>
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<tr>
<td>Ctr. de Investigaciones en Óptica - Leon</td>
<td>Science Club for Children</td>
<td>146</td>
<td>K-12</td>
<td>est. by counting ppl in pics</td>
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<tr>
<td>CUSAT</td>
<td>10-day Workshop for Children</td>
<td>33</td>
<td>High School</td>
<td>est. by counting ppl in pics</td>
</tr>
<tr>
<td>INAOE</td>
<td>Periscope Workshop during learning fair/univ. anniversary</td>
<td>1000</td>
<td>Children</td>
<td>in report</td>
</tr>
<tr>
<td>INAOE</td>
<td>Kaleidoscope Workshop during learning fair/univ. anniversary</td>
<td>900</td>
<td>Children</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>Total Moon Eclipse Telescope Outreach</td>
<td>320</td>
<td>(people under 15)</td>
<td>in report/estimated. (See note for how)</td>
</tr>
<tr>
<td>ISP</td>
<td>Optics Fair</td>
<td>1400</td>
<td>K-12</td>
<td>in report</td>
</tr>
<tr>
<td>Ivan Franko</td>
<td>Amazing Optics Presentation</td>
<td>28</td>
<td>1rst grade</td>
<td>est. by counting ppl in pics</td>
</tr>
<tr>
<td>Latvia</td>
<td>Night of Science</td>
<td>700</td>
<td>K-12?</td>
<td>reported via email</td>
</tr>
<tr>
<td>Lehigh</td>
<td>Optics Presentations</td>
<td>52</td>
<td>Middle School</td>
<td>in report</td>
</tr>
<tr>
<td>Lomonosov</td>
<td>Moscow Science Festival</td>
<td>50</td>
<td>High School</td>
<td>in report</td>
</tr>
<tr>
<td>Montana State</td>
<td>High School Visit</td>
<td>30</td>
<td>High School</td>
<td>reported via email</td>
</tr>
<tr>
<td>Montreal Chapter</td>
<td>Electromagnetism and Optics Presentations</td>
<td>110</td>
<td>High School</td>
<td>reported via email</td>
</tr>
<tr>
<td></td>
<td>Electromagnetism and Optics Presentations</td>
<td>85</td>
<td>High School</td>
<td>reported via email</td>
</tr>
<tr>
<td>Nicholas Copernicus University</td>
<td>Lab visits by Krakow high schools</td>
<td>?</td>
<td>High School</td>
<td>unknown</td>
</tr>
<tr>
<td></td>
<td>Festival of Art and Science Workshops</td>
<td>1000</td>
<td>children, middle, high school</td>
<td>in report</td>
</tr>
<tr>
<td>NITT</td>
<td>Awareness Program on Physics Ed &amp; Res. '08</td>
<td>100</td>
<td>college level</td>
<td>in report</td>
</tr>
<tr>
<td>Penn State</td>
<td>Electrical Engineering Open House</td>
<td>200</td>
<td>High School</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>Nittany Valley Charter School Outreach</td>
<td>21</td>
<td>elementary, middle school</td>
<td>est. by counting ppl in pics</td>
</tr>
<tr>
<td></td>
<td>Kelly Elementary School Outreach</td>
<td>16</td>
<td>elementary</td>
<td>in report</td>
</tr>
<tr>
<td>Location</td>
<td>Event Description</td>
<td>Estimated Number</td>
<td>Age Group</td>
<td>Source</td>
</tr>
<tr>
<td>----------</td>
<td>-------------------</td>
<td>------------------</td>
<td>-----------</td>
<td>--------</td>
</tr>
<tr>
<td>PUCP</td>
<td>Basic Optics Presentation at all-girls school</td>
<td>50</td>
<td>High School</td>
<td>est. by counting ppl in pics</td>
</tr>
<tr>
<td>Silesian Univ. of Tech.</td>
<td>Science Festival</td>
<td>100</td>
<td>High School</td>
<td>reported via email</td>
</tr>
<tr>
<td></td>
<td>Lecture on LCD</td>
<td>50</td>
<td>High School</td>
<td>reported via email</td>
</tr>
<tr>
<td>Stanford</td>
<td>Girls Scouts Go Tech 2008</td>
<td>100</td>
<td>elementary school</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>Optics-themed Photography Contest</td>
<td>50</td>
<td>6th-12th grade</td>
<td>on website</td>
</tr>
<tr>
<td>Tec de Monterrey</td>
<td>Terrific Telescopes - used Hands On Optics Kits</td>
<td>38</td>
<td>K-10</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>Liquid Crystals/&quot;Mood Patch&quot; Outreach</td>
<td>110</td>
<td>K-12</td>
<td>in report</td>
</tr>
<tr>
<td>Three Rivers Comm. College</td>
<td>Demos on Phosphoresence, Luminescence &amp; building telescopes</td>
<td>75</td>
<td>5th grade</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>Laser Camp '08</td>
<td>30</td>
<td>High School</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>UV demo at Read Across America</td>
<td>?</td>
<td>Children</td>
<td>unknown</td>
</tr>
<tr>
<td>CUVO</td>
<td>Workshop on Optics</td>
<td>43</td>
<td>age 8-13</td>
<td>est. by counting ppl in pics</td>
</tr>
<tr>
<td>UC Berkeley</td>
<td>Girls Science Workshop</td>
<td>25</td>
<td>Middle School</td>
<td>in report</td>
</tr>
<tr>
<td>Univ. Laval</td>
<td>Girls in Science Workshop on Optics</td>
<td>12</td>
<td>High School</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>Jeux Photoniques</td>
<td>55</td>
<td>High School</td>
<td>reported via email</td>
</tr>
<tr>
<td>Univ. of Arizona</td>
<td>Science Fair Judging</td>
<td>?</td>
<td>K-12</td>
<td>unknown</td>
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<tr>
<td></td>
<td>Optical Sciences Camp</td>
<td>18</td>
<td>High School</td>
<td>in report</td>
</tr>
<tr>
<td>Univ. of Calcutta</td>
<td>Outreach Activity at Vidyasagar Study Centre</td>
<td>86</td>
<td>Middle School?</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>Scientific Demonstrations</td>
<td>415</td>
<td>Middle School, High School</td>
<td>in report</td>
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<td></td>
<td>Optics Kits Demos</td>
<td>264</td>
<td>High School</td>
<td>in report</td>
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<tr>
<td>CREOL</td>
<td>Expanding Your Horizons in Science &amp; Math (for girls)</td>
<td>200</td>
<td>Middle School</td>
<td>on website</td>
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<td></td>
<td>Optics Day</td>
<td>300</td>
<td>misc. ages</td>
<td>on website</td>
</tr>
<tr>
<td></td>
<td>Super Scientists at Partin Elementary</td>
<td>?</td>
<td>elementary school</td>
<td>unknown</td>
</tr>
<tr>
<td>Institution</td>
<td>Activity Description</td>
<td>Participants</td>
<td>Age Group</td>
<td>Notes</td>
</tr>
<tr>
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<tr>
<td>Univ. Dayton</td>
<td>Optics Demo</td>
<td>10</td>
<td>High School</td>
<td>est. by counting ppl in pics</td>
</tr>
<tr>
<td>Univ. of Guanajuato</td>
<td>Children in Science Academy</td>
<td>15</td>
<td>elementary school</td>
<td>est. by counting ppl in pics</td>
</tr>
<tr>
<td>Univ. New Mexico</td>
<td>West Mesa Chapter Lab Tour</td>
<td>10</td>
<td>High School</td>
<td>in report</td>
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<tr>
<td></td>
<td>Hands-on-Optics Kit Outreach at Kit Carson Middle School</td>
<td>60</td>
<td>Middle School</td>
<td>reported via email</td>
</tr>
<tr>
<td>UNC Charlotte</td>
<td>Outreach Tour</td>
<td>15</td>
<td>High School</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>Girl Scouts visit</td>
<td>20</td>
<td>Elementary</td>
<td>in report</td>
</tr>
<tr>
<td>Wroclaw</td>
<td>Festival of Science</td>
<td>50</td>
<td>Elementary</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>Magic of Physics</td>
<td>18</td>
<td>High School</td>
<td>est. by counting ppl in pics</td>
</tr>
<tr>
<td>Yerevan</td>
<td>Physics Olympiad</td>
<td>16</td>
<td>High School</td>
<td>reported via email</td>
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<tr>
<td>Vrije Univ. Brussel</td>
<td>Distributed Edukits (free educational optics kits)</td>
<td>1,000</td>
<td>misc. ages</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>Photonics Science Show</td>
<td>630</td>
<td>High School</td>
<td>in report</td>
</tr>
<tr>
<td>Duke Univ.</td>
<td>Optics Demonstrations and Presentation</td>
<td>30</td>
<td>Middle School</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>Outreach Visit</td>
<td>25</td>
<td>Middle School</td>
<td>est. by counting ppl in pics</td>
</tr>
<tr>
<td>INAOE</td>
<td>Week of Life and Science</td>
<td>240</td>
<td>Middle and High School</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>INAOE talks / workshops with students (16 total)</td>
<td>710</td>
<td>Middle and High School</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>Week of Science and Technology</td>
<td>380</td>
<td>misc. ages</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>Week of Science in High School</td>
<td>60</td>
<td>High School</td>
<td>in report</td>
</tr>
<tr>
<td>Nizhny Novgorod</td>
<td>Developing video to explain basics of Edukits for high school teachers and students</td>
<td>???</td>
<td>High School</td>
<td>unknown</td>
</tr>
<tr>
<td>Taras Shevchenko National Univ. of Kyiv</td>
<td>Invited high school students to exhibit and plenary session of Young Scientists conference</td>
<td>???</td>
<td>High School</td>
<td>unknown</td>
</tr>
<tr>
<td></td>
<td>Tutoring middle and high school students in physics and math one day a week</td>
<td>???</td>
<td>Middle and High School</td>
<td>Unknown</td>
</tr>
<tr>
<td>Institution</td>
<td>Event Description</td>
<td>Audience</td>
<td>Age Group</td>
<td>Source</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>----------------------------------------</td>
<td>----------</td>
<td>-------------------</td>
<td>---------</td>
</tr>
<tr>
<td>UCSD - Triton</td>
<td>Holography Workshop</td>
<td>60</td>
<td>High School</td>
<td>in report</td>
</tr>
<tr>
<td>UNC Charlotte</td>
<td>Girl Scouts visit</td>
<td>???</td>
<td>Elementary</td>
<td>Unknown</td>
</tr>
<tr>
<td>Univ. of Texas at Austin</td>
<td>&quot;Fun with Optics&quot; program, part of Explore UT open house</td>
<td>150</td>
<td>misc. ages</td>
<td>in report</td>
</tr>
<tr>
<td>Warsaw Univ. of Technology</td>
<td>Festival of Science</td>
<td>100</td>
<td>elementary school</td>
<td>in report</td>
</tr>
<tr>
<td></td>
<td>Workshops for Children</td>
<td>?</td>
<td>children</td>
<td>unknown</td>
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Total: 11827
New Optical Museum at Saint-Petersburg for education and training

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ABSTRACT

Nowadays the educational problem of teaching optics and photonics is to attract the young generation to the wonderful and magic world of light, optical science, technology and systems. The main issue is to explain that in the course of last several hundred years optics has been representing the most clear world view for humanity. In fact, the optics itself is a multidisciplinary complex of independent scientific directions, and, moreover, it has always been a generator of new fields of knowledge. Besides, optics and photonics are the fields within which the most fundamental problems of today’s reality are to be resolved.

It is absolutely necessary to encourage our scholars in getting optics and photonics education as an alternative physical basis to gaining solely computer knowledge. The main obstacle is the poor connection between program of optical education and the real optical researches, disintegration of different branches of the optical science, the demographic situation, some problems with teaching mathematics and physics at schools, and the collision between traditional educational methods and the mentality of the new generation. In Russia the Saint-Petersburg State University of Information Technologies, Mechanics and Optics offers partial solution to these problems: the organization of a real place for interactive optical science in a form of a new museum of optics, intended for education and training, seems to be the most effective way. This was the main reason for establishing such a museum in Saint-Petersburg at the end of 2008.

Keywords: optical and photonics education, optical museum, nature of light, theories of vision, physical optics, applied optics, ophthalmology, optical illusions and puzzles.

1. INTRODUCTION

The main tasks of the museum are to introduce the brilliant world of optics; to realize different educational strategies for several young generations of different ages, from kids to university students; to use the capabilities of Saint-Petersburg high cultural level to attract not only the citizens but also people from the country to optical community; to demonstrate classical optical phenomena in an interactive way using modern devises, equipment and systems.

The Optical Museum is situated in a picturesque Vasil’evsky Island, which used to be a historical and scientific center of old Saint-Petersburg. The museum occupies the ground floor of a XIX century building on the Birzhevaya line. Long before it was an apartment where the famous merchants’ Eliseev’i family lived, and later it was occupied by the department of S.I. Vavilov State Optical institute. The organization of the Optical Museum was supported by the city administration, the Russian Optical Society and several optical and IT companies.
The main museum halls include basic exponents on light and sight, holography, optical artifacts and a collection of historic books on optics; glass and optical materials, elements and light sources; microscopes and interferometers; projection and photo techniques; detectors of UV and IR spectra; various kinds of mirrors, laser diffraction systems and etc. Several halls are devoted to astronomical optics with mini-planetarium, precise equipment; laser games, such as laser weapon and chess, kaleidoscopes, mirror systems, light music. For training the on-line experiments in interference, polarization, diffraction (including fractal diffraction), 16 types of microscopes and 10 types of lasers are demonstrated. Special posters introduce the materials of life and deeds of outstanding and famous foreign and Russian scientists: academicians D.S. Rozdestvensky, S.I. Vavilov, G.T. Petrovsky, Yu.N. Denisyuk and others. The most interesting sights for children are the computer holography, Chinese magic and Greek burning mirrors, modern adaptive mirror, solar cells, laser security systems, polarizing control based on photo elasticity and night vision systems.

Lectures, seminars and conferences on optics and photonics are held at the conference hall. For example, lectures on the history of optics for students and post-graduates, based on two volumes of the book “Five Millennium of Optics” are given at the Museum. The video presentation of the Museum will be soon available in the Internet. The museum is a unique example of an educating State Optical Museum in Russia. The specialists from Saint-Petersburg State University of Informational Technologies, Mechanics and Optics and from the Russian Optical Society would be glad to invite foreign colleges and specialists in optics and photonics to visit our museum.

2. THE CONCEPTS OF MUSEUM

The main goals of the museum, which have already been realized, are:

- To combine certain historical facts, classical experiments with most modern optical stage.
- To mix illusions, optical tricks and paradoxes with serious scientific problems and explanations of optical phenomena.
- To provide a wide range of conducted activities: from surveys and educational excursions to a series of lectures with demonstrations and thematic workshops.
- To arise deep interest in many different groups of visitors by the diversity of content. The collections can attract school children of 7 to 10 grades, students of the first and second courses, master’s degree and post–graduate students, adults with technical and humanitarian education.
- To offer two different ways of functioning: for scholars and student groups, who appoint the visit in advance, and for family visits. The first case is more preferred.
- To organize a group of young guides from among the students and masters of university. The most effective way to attract new generations to science is when young people introduce science to those who are younger. Older guides are to be left mostly as a reserve or for status excursions.

When the visitors enter the museum, the first thing they notice is the cloak-room with dozens of distorting mirrors. By exploring them, one first gets interested in optical illusions, and through this in the optics itself.

3. THE FIRST HALL

We’ve decided to start our tour not with the historical chronology, but with holography, which is the most interesting from a cognitive point of view, spectacular and attractive, which helps to gradually involve the students into the magic world of optics. Today each one of us meets with hologram or holographic effects in his everyday life. Thus ordinary exhibitions of holograms, which used to be very popular 10-15 years ago, are...
of no particular surprise now. But nowadays the feeling of a “miracle” appears in the majority of those who are not yet very profound in science. And the main educational task of the first hall of the museum is to open the secret, to try to explain the conditions of formation and features of three-dimensional holographic images.

The explanation begins with demonstration of the simplest stereoscope (Fig.1). These toys belonging to the end of XIX century allow to “feel the difference” between the plane and 3D images. It is appropriate now to recall the method of parallax, by using which such illusions were created; the binocular vision, and even the way we define the direction of the sound source by ears. Depending on the age of the audience, we talk on the everyone two optical and two acoustic receivers to the right and to the left of the computer, which processes their signals - the brain. It is the brain that has the ability to compare the moments of impact of both acoustic waves on the eardrum (temporal phase) or to compare the moments of impact of both light waves of slightly different direction (spatial phase), entering the pupils.

Gradually, we bring the students to the idea that the possibility of registering 3D images is a matter of the registration of the phase of an optical signal. But before we turn to the explanation of holography creation schemes themselves, we offer our visitors to solve another well-known 3D illusion formed by a system of two parabolic mirrors (Fig.2). The projection of the real image on the surface is something trivial, but the view of an actual three-dimensional image “hanging in the air” arouses constant surprise and sincere interest: «And how does this work»? It is now the very time to talk about a full circumferential illumination of the object, about the scattering of light, the structure of the wave front and especially about peculiarities of its visual perception.

So now we can proceed to the principles of registration of the phase component of a wave front. We explain that none of the light receivers does not respond to the phase, we talk about the idea of “freezing” the phase from the object using the second so-called reference wave, very similar to the first.

We might remind the advanced students that such light beams are known as coherent, and their interaction with the strengthening or weakening of the total intensity is described in the terms of the light interference. We also remind them the ideas of Dennis Gabor on how to obtain 3D images by “photographing interference pattern”, expressed in 1948, long before the creation of lasers. Using two reticulated lids of frying pans, we demonstrate the dependence of the forms of interference lines on the phase difference of both waves (Fig.3).

The spacing between the wires constitutes about 0.5 mm, and thus, on a scale of a 1:1000, the nets become a rather successful model for the two interfering light beams. We change the “optical path difference” (or the difference between the phases) by rotating the nets against one another, and adding both narrow and broad moiré stripes, which are a good analogue of interference stripes.

Now it is the time to explore the real maquette of the holographic installation (Fig.4). We show that the laser source radiation is divided into two beams from the very start – the reference and the object beam, and that the expanded reference beam illuminates the position of a usual photographic layer - the future hologram. After lighting up the object, the second beam scatters in all directions, partly falling on the same recording layer. And this is were the interference stripes pattern, which carries the information of the wave phase features, scattered by object, is registered. We finish the explanation of hologram recording with a few words about the photo-chemical process. We surely give all those who wish an opportunity to examine a piece of a hologram under a microscope to make sure that there is no images on it, but only a miniature and extremely complex ornament of dark and light curved lines. At this point, considering a prepared audience, one can discuss the characteristics of holographic recording methods, the reliability of information storage and its degree of redundancy; discuss the “associative” nature of the holographic memory of the multi-view holograms with multiple images, recorded on one layer. We might also discuss more subtle issues: the conditions of angular illumination according to Leytz, the best intensities ratio between the object and reference waves, the requirements for grain size of the photographic plates, etc.
Then we explain of the recovery phase of holographic images. We draw special attention to the principle difference between the illumination of ordinary paintings or photographs, hanging on the walls, and the special illumination of holograms, which results in the apparent 3D images. It is necessary to indicate the direction of restoring light beams and their coherence with the orientation of a reference wave during the hologram recording. All these considerations must be immediately followed by concrete examples of artistic or technical holograms in the same room (Fig.5). The main task is to make the audience realize, that the viewed images are the result of spatial diffraction of light from the illuminating lamp with the same system of stripes, which we created while recording the hologram. And as it preserve all the phase information, the virtual images in front if replicated the 3D effect. In this sense a holography is the culmination of the wave properties of light: during the recording wee use the interference phenomena while during the reconstruction we use the diffraction.

It is obvious that this story could be greatly expanded and deepened for students with good physical and mathematical basis. Some particular exhibits of the holography collection illustrate perfectly the zero beam with violation of the Leytz conditions; the emergence of a real image, the peculiarities of diffraction on the sinusoidal gratings; the multiplication of the images, formed by the sinusoidal diffraction lattices; emergence of multiplicity of images in the form of nonlinear distortions of the lines forms, etc.

At this point you can make a short break and give the audience 5-7 minutes to take a good look of the holograms. Each visitor is offered a pocket flashlight to examine the content of a number of multi-view holograms, and even determine the right lighting conditions for the elements of a creative mosaic sculpture, composed of many small pieces of holograms. After the “entertaining” brake we may proceed with serious but highly absorbing work in the first hall. We still have to deal with the principles of obtaining color holograms and to get acquainted with the work of its inventor - Yuri Denisyuk, who worked and taught in the same building where the Museum of Optics is situated. The pages of his diary concerning his working plans, and especially the timing for them, always make a deep impression on today masters and post-graduate students, who are not that much used to work so intensely and selflessly as the older generation of scientists. This is followed by a story about the principles and visual demonstrations of the most impressive among recent achievements in the field of volume vision: the creation of computer, including iridescent, holographs of 3D objects; the dynamic holography using liquid crystal layers; holographic interferometry of ultra fast processes. The limited size of paper does not allow to give more details on the content and methodology of these sections study. Meanwhile, the total time spent by the student group in this first, holographic hall, ranges from 20 to 30 minutes.

4. THE SECOND HALL

In contrast to the first hi-tech exposition, the second hall represents the historical collections in traditional style (Fig.6). Here the exponents on the history of optics are displayed: models of ancient lamps, the first samples of transparent artifacts of crystal and glass, collection of bronze mirrors, models of various gnomon sundials, antique viewfinders. In the center of the room there are two vertical glass cases with installations dedicated to the two principal optical instruments: the telescope and the microscope. There are glass cases with exponents concerning the structure of the eye, the principles of color vision, and, of course, spectral composition of white light. The story here focuses on very basic issues – the retrospective of theories on the nature of light and color, the hypotheses on the vision mechanisms and the technology of optical measurements. The story is accompanied by demonstrations of different light sources from oil lamps to laser, light receivers from an eye to a solar battery, and some classical experiments on refraction, diffraction and interference. But let us be consecutive.
The introduction to the collections of the second hall starts with examination of a relief model of the eye in a scale of 20:1. One can disassemble and assemble two 3D models of eyeballs, as well as to examine their own eye-sight keenness (Fig.7). After brief training on a special eye-simulator, visitors may practice in examining their friend’s eyeballs using an ophthalmoscope. Finally, the constant interest is arise by the standard color table, which give each examinee an objective estimation of his own color sensitivity by four grades – from a low, which means nearly color blindness, to a high grade, that of a professional artist. The experiments on the visual color transmission logically bring the audience to the general problem of color diversity. It is no accident, that the question of light and color correlation has been one of the most difficult in the history of optics: the color palettes are based on too many varied physical effects. Students are shown the refractive nature of a rainbow, the interference colors of pellicle, absorbing coloration of natural minerals and colored glass filters. The spectrum of white light, acquired by using high power diffraction gratings, appeared to be the most striking and instructive to the audience. Projected on a piece of opal glass, it has not only allowed the visitors to see a consistent rotation of the spectral colors of visible spectra band, but also to remind them of the adjacent areas of the optical spectrum - the ultraviolet and infrared. At the end of our tour we return to a detailed study of the features of UV and infrared radiation we return route, while in the central hall it recommended to conduct another simple, yet always successful demonstration of the possibility of visualization of an infrared radiation right at home – using a cell phone with CCD-camera and a remote control of any audio or video device. The historical part of the excursion begins near the cases displaying samples of oil lamps, the light of which was used by the mankind for nearly two millennia. There are primitive clay lamps, as well as Greek terracotta samples with one or several wick spouts. The collection also contains several types of Roman lucides and early Christian bronze lucernes. And finally, several imitations of Muslim oil lamps are displayed, perhaps those by rubbing which you can call a genie. Further progress in the manufacture of light sources is represented by series of candles and candelabras, kerosene lamps, incandescent lamps, spectral lamps, plasma and gas-filled lamps. LED panels, and laser systems complete this section. The next historical plot is dedicated to the first proto-optical elements of a transparent material. Magic crystal balls possessed by the Egyptian pharaohs, crystal eye fibulas of ancient statues, healing crystal spheres of Tibetan monks are united in a coherent conversation. The transparent “Alhazen hemispheres” that rather popular in the Islamic world, are also represented. Later those evolved into medieval prototypes of magnifiers – the “reading stones”, which were an obligatory tool of any Latin monk-scribes before the first magnifier appeared. The further improvement of glass manufacturing allowed to create the first convex glass lenses “for the elderly” in the XIII century (Fig.8), and after a hundred years a concave lenses to correct nearsightedness appeared. And only after two centuries, by combining the long-focus positive lens with the short-focus negative lens the first visual pipe was invented. And with this the era of instrumental optics has begun…

As the practice has shown, the following historical demonstration of the magic mirrors of ancient China appears to be the most impressive. Generally, all historical stories relating to the bronze mirrors always enjoy success. Here are the stories of the pharaohs’ mirrors, which were buried in the tombs aside to their masters; the riddles of the Etruscan bilingual mirrors, and the imitation of inflaming effect of the Archimedean mirrors. The last experiment, of course, can not be conducted to the point of getting an open flame inside the museum hall. However, even the measurement of temperature in the focal point of the mirror parabola arouses great interest and curiosity among young students. The most representative is the museum collection of copies of the Chinese mirrors dating back to the Han period (II-VII centuries). Two of them, created with special technology were reconstituted in the Shanghai University. They display the magical effect when the light beam, reflected from the polished front surface,
reproduces the ornament from the back surface. Although the audience can see the metal casting of 5-6 millimeter width, is still gets an impression of a magic “transparent bronze”. The explanation of this ancient effect, which is based on the visualization of the invisible relief on the polished side of the mirror, combines perfectly with the further story about the distortions of reflected wave fronts, obtained by using the most advanced adaptive mirrors. In the center of the room a film mirror with a pneumatic control system is installed, which allows to show the principles of compensation of the distortions. This model of a segmented adaptive mirror changes to a convex, then flat, then concave form, creating the whole range of geometrically distorted images: from the enlarged direct virtual images to reduced real inverted ones.

Here, in the center of the room, three series of training and educational demonstrations can be carried out. The first one imitates the experiments of the great astronomer Claudius Ptolemy on the study of refraction of the partition edges of glass and water, which he conducted as early as in the 1 century, trying to get the data for recoding the atmosphere refraction. Here it is appropriate to say about the related issues, for example, the ancient theories of vision, based on a model of an eye emitting direct lines of visual rays. The demonstration of inversion of the light beam coming out of water into the air is perceived with great interest, when many visitors, along with Ptolemy, for the first time discovered the effect of total internal reflection. At this point it is necessarily to return to the modern times and say about the features of light propagation in dielectric transparent fibers, which are often believed to be simply hollow tubes with internal specular walls. We can finish the talk on the refraction and the refractive index with a curious trick, always admired not only by the kids, but by the adult visitors as well. During this trick a hundred and a half of small transparent balls disappear in the vessel filled with water. The most appropriate and affordable tools to be used for such an entertainment are the water gel balls, that are being sold in flower and interior design shops.

The second demonstration reconstructs a much younger scientific achievement: the famous “Poisson’s spots” – a phenomenon of diffraction, connected with the concentration of light energy in the center of the shadow of a round object. Depending on the time limit we can retell more or less detailed famous dialogue, which took place in the French Academy of Sciences during Fresnel’s report on the first theory of diffraction. The highlight of the demonstration is the construction of laser device, energy of which allows us to get the macroscopic picture of the Poisson’s spot within a distance of 4-5 meters and with exterior lighting, with the picture being clearly visible to all the visitors. It is worth noting that with the help of this laser installation we can hold special thematic lesson on diffraction for the advanced groups, because the total number of experiments that can be demonstrated on this setup is more than three dozens. Among those are the Fresnel’s diffraction at the apertures of different shapes, and Fraunhofer diffraction in the far zone, and experiments with diffraction gratings, with irregular structures and even the diffraction on fractal objects. After a small upgrade the installation can be also used for demonstrating the principles of Fourier optics.

The final demonstration in the center of the second hall is devoted to the practical use of interference measurements. Using the model of Mach-Zehnder dual beam interferometer we can show very clearly the possibility of precise measurement of the refractive index for gas mixtures. Then the students can examine a real device that works on this principle – the so-called pit interferometer, which has saved many lives, because it showed dangerous concentrations of methane in mines. We can also add another example to the practical value of interferometry – the detection of glaciers with high snow slide possibility by using the scheme of the Michelson. Built on the mountain tops, the laser version of the interferometer, with one its mirrors being enhanced on the glacier, can detect its motion just in a few tens of minutes. The parameters of this movement are very impressive: the glacier is considered an avalanching when its speed is 3 centimeters per year!

Near the exit from the second hall we have a thematic retrospective section – these are stands and glass cases with exponents on the history of photography. Apart from the collection of antique cameras and
magic projector-lamps there is a bust of Louis Daguerre and numerous examples of daguerreotypes and photographs dating back to the end of XIX - beginning of the XX centuries. However the focus is on the “great-grandfather” of all the optical devices - the famous camera obscure, in fact a simple box with a small pinhole. A short story is finished with a demonstration of magical features of the camera: the creation of real reduced inverted images of external objects without using any lenses. As the students can work on their own with high power lanterns during these experiments, here, over the Daguerre’s bust, there is also an element of a professional solar battery. After directing the light beams on its surface, visitors will immediately notice how the frame, connected to the battery, starts rotating. A few words about the solar energy seem to be a logical conclusion to the study of second hall.

5. THE THIRD HALL

The exposition in this hall is devoted to optical materials and elements. Some particular glass-cases contain different samples, concerning modern optics. The first one contains a collection of fiber-optic components, including those representing regular lightguides, different kinds of endoscopes, active components for fiber-optical lasers, constructive options of axicons, micro lens arrays for photolithography. The second glass case has samples of some of the first laser-activated glasses - neodymium, sapphire, IAG etc. Right in front of them there is a real neodymium laser with an amplifying unit and an external resonator. Its sectional design allows to show to trained visitor not only the solid-state laser device, but to clarify the mechanism of optical pumping and the role of confocal resonator mirrors. The third case displays elements of ancient and modern ophthalmologic instruments. The visitors can see sets of glass lenses of different time of manufacture, apparatus for determining optical properties of the eye, special laser stimulators of visual activity.

The main exponent here is the famous Abbe catalog, made in the Soviet Union in the second half of the last century. It is a collection of almost all then-existing optical glasses of different chemical compositions and brands from the lightest crones to super heavy flints. A considerable part of the collection is composed of special radiation-proof glass, designed by the orders of the military. The uniqueness of the collection is first of all the in the sizes of homogeneous glass blocks, for manufacturing which a research group under the guidance of academian G.T. Petrovsky has settled more than one dozen of the most difficult technological problems. The background of the catalog is a fresco, depicting the motives of medieval engravings and representing the main stages of glass manufacturing. Developed by legendary artists from the island of Murano, these techniques had been the main secret of the Republic of Venetian for several centuries. The catalog is mounted on a special three-tier basis, with each glass installed in a special frame and highlighted by a multi colored LED lines (Fig.9). For those who wish to explore the issues of optical materials science there is a computer kiosk with touch screen and plasma panel to visualize Abbe diagram classification right next to the collection. In classification each glass is marked by a single spot, and is accompanied by information on its refractive and dispersive properties, chemical composition and physical-mechanical parameters. As an illustration to the processes of glass manufacturing, the visitors can also see the examples of real technological equipment – ceramic crucibles and mixers. The story of the diversity of optical glasses, created by mankind, flows smoothly into a discussion of such serious problems of refractive imaging optics, as a correction of nonlinear distortions (geometric aberrations), the need to compensate the varying dispersion of rays of different wavelengths (chromatic aberration), etc. The level and duration of the discussion varies widely from a brief reference for the youngest children to mini-seminars held for specialists.

Right after the hall of glass, there are two rooms which are at the moment only being prepared to receive some relevant museum equipment. One of them will be store a collection of 16 microscopes, different
by working principles and magnifying capabilities, each of which will be available for the trainees (within reasonable limits). Reviewing the most popular micro objects in detail may be accompanied by their sketching or photographing. In the second of the rooms, that are still being designed, a kind of master class will be conducted, a visit of which is planned to be organized as a separate program. Here the fiber-optical equipment for laser engraving, a special stand for a quick hologram recording, designed by specialist from our University and possibly a computerized system for creating transparent 3D-models in the glass will be located.

6. THE FINAL PART – INTERACTIVE & GAMES ZONE

The tour described above takes about ¾ of the time spent by visitors in the Museum. The remain part of the exhibition is placed in much smaller rooms and is devoted to entertainment and cognitive rest, of course, within the frame of optical thematic.

First, the visitors enter a dim room with lasers. Here one should move carefully – otherwise the laser security system, placed at the bottom, will detect you. An acousto-optic deflector draws its laser designs on the ceiling; it can be controlled by voice or music. On the walls lines of verticals and horizontals are marked – thus the work of laser levels, laser horizons and theodolites is shown. Those who wish may shoot a laser gun or use professional laser glasses that completely block all light colors except red. In the room there are also placed lasers, emitting beams of all primary colors – red, green and even blue – and an infrared laser with a built-in nonlinear optical crystal for second harmonic generation.

The next small windowless room is an astronomy optics room with a mini-planetarium. The rotation of the stars sky is accompanied by a small video on the history of telescopes of different schemes, two of which are also represented here – a reflector and a refractor. It worth noticing that some interior design items appeared to be a good supplementary material for this section, for example four plasma light-balls, located in each corner of the room. The story about the glow of a plasma discharge is accompanied by a fascinating and totally useless attempt “to catch lightning”. In this very room visitors also have an opportunity to use night vision devices. And it is not only the visualization of passive infrared radiation which is available, but also a work in active mode with backlighting by special infrared searchlights.

Next, passing along the narrow corridor, we enter some “strange place”. There is an empty frame hanging on the wall, with a canvas which has no image on it. Next to it there is a cupboard, containing miniatures of picturesque landscapes but totally empty skies. In the dark depths of the cupboard one can see druses of crystals, some small items of matted plastics, and finally blank sheets of paper. But in a second, everything changes in a wonderful way: the normal light is turned off while the magic ultraviolet is being turned on. In the frame there appears a beautiful waterfront view of St. Petersburg; fairy-tale characters on flying carpets or Chagall’s violinists appear in the skies on the miniatures; the plastics shine with bright colors and crystals start to glow. Some secret signs, seals and even color photographs appear on the seemingly blank sheets of paper. When the first surprise passes, we start to talk about the luminescence, an effect of no equilibrium luminosity of certain substances under the action of UV radiation. Some visitors listen to the explanation with interest, others prefer to approach a special UV-emitters and search for some glowing part on themselves or to check the authenticity of their banknotes. Those who wish to draw their own pictures, glowing in the dark, are given some professional advice. We also teach how to distinguish harmless luminescent paint from the phosphorescent which is not very good for health.

Going back a little bit, we turn to the right after the guide and get to the hall of polarization. This characteristic of light has not yet been discussed, and here you need to spend some time to effectively explain the transverse of the electromagnetic waves, the operating principle of linear Polaroid films and show the blocking of light in a system with crossed polarizers. The easiest way to demonstrate the polarization effects is
to use a white light beam from overhead, with rotary frames of polarizers being fixed right on its working surface. Now anyone can place a transparent object between crossed polarizers and achieves the enlightenment of the path where the object has changed the direction of light oscillations. Among the available samples there are Iceland spar crystals, pieces of solidified resin, pressed pieces of the photoelastic plastics.

The visitors can offer their own objects for polarization examining – from the pellicle wrappers of cigarette packs to plastic glasses with deformed lenses. Not very proficient visitors are impressed by the way the objects with internal stresses look in polarized light: this visualization is the main “focus” of the polarizing room. Other experiments include the models of optical systems with special scattering prism. With their rotation one can see clearly the change in the trajectory of laser beam internal reflection, and, moreover, they can easily explain the polarization of light in the scattering from the normal (so-called Raleigh butterfly). These demonstrations, as well as the definition the full polarization angle (Brewster’s angle) or observation of the conoscopic pictures with the polarized beams interference, of course, are not included in the program of round excursions, but are offered to specially educated groups of students.

The last two rooms, on the contrary, are completely comprehensible to all visitors from small children to adults and even elderly people. They are focused on game booths basing on optics. Here are the main ones: a mirror illusion called “compound face” (two volunteers look at each other through a narrow banded system of mirrors with separating empty spaces); octagonal mirror room, in which the image of any object place inside is multiplicated; a set of kaleidoscopes of different structures, forming ornamental patterns; a laser harp (fig.10), with which it is possible to play familiar melodies; a strobe balalaika with a neck and illuminated from beneath by a rapidly flashing LED lines; laser chess and laser shooting range with a “beam weapon” and much more. The kids spend some time in these gaming rooms on their own, and then the main part of the excursion is finished. Anyone may spend extra time in any of the halls of the museum if wishes. The visitors are not only but encouraged to take photos of themselves and the exhibits.

As a conclusion, it is necessary to mention that the Museum of Optics has a small kiosk with optical souvenirs and toys, as well as a holographic studio, which works with already existing designs and also offers a service of making a holography by an individual design.

This entire educational complex based on a combination of education, research activities and games, and having a clear business plan, should become, in our view, the prototype of the centers attracting young people to science and technology, whether to optics, aerodynamics or acoustics.
Fig.3. Simple demonstration of interference

Fig.4. Model of the holographic installation

Fig.5. Part of the first hall holographic collection

Fig.6. Centre view of the second hall

Fig.7. Case with eye-models
Fig. 8. Ancient crystal balls, reading stones & glasses

Fig. 9. View of famous Abbe-catalog

Fig. 10. Laser harp as a harmony of Light & Music
ABSTRACT

The Applied Optics Group, National University of Ireland Galway is a research centre involved in programmes that cover a wide variety of topics in applied optics and imaging science, including smart optics, adaptive optics, optical scattering and propagation, and engineering optics. The Group have also developed significant outreach programmes both in Primary and Post-Primary schools. It is recognised that there is a need for innovation in Science Education in Ireland and we are committed to working extensively with schools. The main aim of these outreach programmes is to increase awareness and interest in science with students and enhance the communication skills of the researchers working in the Group. The education outreach team works closely with the relevant teachers in both Primary and Post-Primary schools to design and develop learning initiatives to match the needs of the target group of students. The learning programmes are usually delivered in the participating schools during normal class time by a team of Applied Optics specialists. We are involved in running these programmes in both Primary and Post-Primary schools where the programmes are tailored to the curriculum and concentrating on optics and light. The students may also visit the Groups research centre where presentations and laboratory tours are arranged.

The Applied Optics Group is an active member of TREO – the Third Level Research Education and Outreach Group which coordinates outreach activities nationally and supported by Science Foundation Ireland (SFI).
1. INTRODUCTION

More so than ever in this economic downturn, Ireland must produce high quality skilled graduates in Science and Technology subjects. According to a recent Irish Government Report one of the objectives for the future is to make Ireland an innovation and commercialisation hub in Europe, a country that combines the features of an attractive home for innovative Research and Development and a highly-attractive incubation environment for the best entrepreneurs in Europe and beyond. This will be the successful formula for the next phase of the development of the Irish economy and for delivering quality, well-paid jobs.

Research funding through Science Foundation Ireland (SFI), Enterprise Ireland and the Industrial Development Authority (IDA) is to be used to instil a commercialisation culture in third-level institutions alongside the now embedded teaching and research culture. The production of skilled graduates is essential in developing our Third Level Educational System in Ireland not least in the area of Research. Quality research needs to feed into quality teaching and learning at undergraduate level this in turn will ensure that we produce top quality graduates with an interest and capacity to lead future research projects. A lack of Science and Technology graduates has long been recognised in Ireland as a problem and new ways are being devised and implemented to alter this trend. Outreach programmes are one such innovation.

In the case of the Science outreach programmes discussed in this paper they are a new form of supplementary education in Irish schools. They have only been in operation for approximately five to seven years and their primary role is to support teachers in Primary and Post-Primary education in Ireland. These outreach programmes aid science education by raising students’ interest and enthusiasm in science and technology.

In order to broaden participation in science and technology subjects in Third Level Education in Ireland outreach programmes have been introduced in these institutions, the programmes help to bring additional knowledge from third level institutions to the different stakeholders such as students, teachers, schools, parents and the general public. Anecdotal evidence suggests that these programmes are accepted in a very positive light by both students and teachers and that they are helping to improve the scientific knowledge and interest of students from Primary, Post-primary and Third level education in Ireland. As Van Esbeck has stated “scientific research and an educated population are key drivers in the economic progress of a country”.

Funding and support at all levels of science education are essential to guarantee Ireland’s economic and social health. In a recent Irish Government Report it was stated that there was a need to restructure our economy so that we can take full advantage of the global recovery when it comes. One way to develop our knowledge economy is by expanding our science and technology base and working on our education policies and practices particularly for science subjects. A strong science base protects economies during a downturn and allows a quicker recovery when global conditions change.
2. EDUCATION IN IRELAND

2.1 Primary School Science Education (Ages 4-12 years)
It was not until 2003 that science as a full subject was introduced to Irish Primary schools. One of the main aims of the new Primary School Science Curriculum is to “enable the child to acquire knowledge, skills and attitudes so as to develop an informed and critical understanding of social, environmental and scientific issues”. The curriculum was designed in order that the child would develop as a responsible individual who will contribute and help to maintain our local, regional, national and global communities, caring for the environment with an appreciation of the world and its sustainable resources. These outreach programmes are one way to aid the integration of science subjects in primary schools.

In this curriculum the development of the child’s ideas is central to science education and the previously held ideas and beliefs of the child are modified in order to develop more scientific understanding. The teaching format adopted for science takes two forms of understanding: conceptual and procedural. Conceptual is concerned with the development of scientific knowledge and a deepening of fundamental scientific ideas while the use of the scientific process comes under procedural where the child works scientifically and engages in scientific enquiry. Science education is concerned with the knowledge and understanding of the biological and physical aspects of the world but it is important that the learning activities promote curiosity and enjoyment so that the pupils develop a lasting interest in science.

2.2 Post-Primary School Science Education (Ages 12-18 years)
The follow on programme from the Primary school curriculum is the Junior Certificate course. In Post-Primary education in Ireland this section of the course targets students from first year to third year usually in the age range of 12-15 years who, at the end of their third year, sit their first formal state exam. The 2003 Junior Certificate revised science syllabus was drawn up to cater for a whole range of students whose ability, aptitude and achievements may differ. It was designed to further develop the knowledge, understanding, skills and competencies acquired at Primary level. The curriculum is more activity based than the previous curriculum and is designed to build on the experiences students have had at Primary level. The development of scientific literacy skills, further builds on an appreciation of the impact that science has on our lives and environment.

The rationale of this new curriculum is that:

In an era of rapid scientific and technological change the study of science is fundamental to the development of the confidence required to deal with the opportunities and challenges that such change presents in a wide variety of personal and social contexts.

It is hoped that many students will be encouraged to study science subjects in the senior cycle as a result of this more hands on practical syllabus and even go so far as to conduct further studies or work in this area.

As a follow on from the Junior Certificate course, the Leaving Certificate Programme aims to provide continuity with and progression from the Junior Certificate programme. The emphasis is placed on preparing students for the requirements needed for further education or training. The Leaving Certificate science syllabus is designed to incorporate the principles, procedures and concepts of the subject, it is
also designed to take into account its interface with technology and social, political and the economic issues of the day. As the introduction to the Physics Science Syllabus in the Leaving Certificate states “science education in the senior cycle should reflect the changing needs of students and the growing significance of science for strategic development in Ireland.

3. OUTREACH PROGRAMMES FORMAT

Following is an outline of the delivery methods used and some of the hands-on experiments conducted with the students.

Format I - Primary School Programmes

The aim of these programmes is to further develop the student’s knowledge of science in terms of understanding, attitudes, skills, competencies and to deepen and extend their educational experiences. These programmes aid the development of the student’s personal and social skills preparing them for further study in science and supporting their transition from primary to post-primary education.

The outreach programmes usually take place in the students own classrooms in their Primary School and to date we have concentrated on the age range of 10-12 year olds. The class sizes average twenty five to thirty students with one teacher in attendance; we in turn provide a minimum of three researchers together with the outreach officer. The researchers may be either post-graduate students or post-doctoral level. The programmes comprise one visit to the school for four consecutive weeks and the duration of the class varies from sixty to ninety minutes. The format follows a pre-agreed programme, where a general introduction to the subject is given and then the students are divided into four to five groups of four-six, with each group having a researcher working with them on the specific experiment. Studying the interaction and dynamics of the children in the groups gives us an indication of their performance and the learning achieved.

Some of the subjects covered included Eye Dominance, investigation of the Blind Spot, the Visible Spectrum, Colour Vision, Rainbows, and experiments with White Light, explaining properties of light, use of mirrors, imaging and an examination of Telescopes and Microscopes. The use of discharged used disposable cameras proved most effective in comparing the similarity of the properties of the eye and the camera as the students work on their own individual cameras for this experiment.

Format II - Primary School Programmes

These students visit the University campus where an introduction to our Research Group is arranged together with presentations and visits to our various laboratories. This format gives us access to a wider audience as we can cater for larger numbers and where the researchers are available in their laboratories to give a more comprehensive view of their research. We hope to develop these school visits and will plan future programmes with a view to expanding our target population.
Format I - Post-Primary Schools Programmes

These programmes are mainly conducted on the University campus and follow a similar format to the primary school campus visits with an introduction to the Research Group followed by laboratory tours. There is a core group of research outreach officers from science research centres within NUI Galway campus who work together to run these programmes and help target relevant schools.

The students are mainly from Transition Year or fifth year. They are in the 14-16 age group. Transition year is a form of gap year, optional in some schools, which students take after the Junior Certificate exam. There are often a couple of core subjects studied during the year while the students get the opportunity to try out subjects not previously studied. At the beginning of fifth year, students choose the subjects they will study for their Leaving Certificate exam (this is equivalent to A-Levels in the United Kingdom and the Baccalaureate in Europe). One of the advantages of these tours is that students can familiarise themselves with the University campus and the research work being carried out. They can relate their subject choices for their Leaving Certificate exams to University courses and careers in science research.

Format II - Post-Primary Schools Programmes

As part of an ongoing developmental policy we have devised a programme incorporating an element of the new revised curriculum in collaboration with some post-primary science teachers. This programme is delivered to second year students, thereby aiding the teachers in their work and giving the students an insight into the scientific world that they may not have had previously. This programme proved very successful but mainly we have found that due to the vast range of subjects each student must cover there is a limit to the access we have to teachers and students. We have also participated in some Transition Year programmes on site covering areas of mutual interest in the area of Physics.

4. SAMPLE PROJECTS PRESENTED

4.1 Primary schools

As outlined in Section 3, one of the programmes we run with primary school students involves a series of sixty to ninety minute visits to the primary school over a four week period. The programme is delivered in the classroom, starting with an introduction to the material to be covered that week and then moving to smaller groups with a more hands-on approach. Here we will outline two areas covered in these programmes.

4.1.1 Parts of the eye

This project involves introducing the students to the anatomy of the eye including the function of each part. After an initial introduction is given by the outreach team, the students are encouraged to identify the parts of the eye on their own handout by completing the labels on a diagram of the eye. When the outreach team returns to the school the following week, this study is continued. We explain the similarity between the parts of the eye and the parts of a simple point-and-shoot camera. Each student is given a used disposable camera with the film removed and the internal capacitance discharged for safety (to avoid an electric shock!). The students take the camera apart piece by piece, noting the function of each
component, and then reassemble it. In this way, the students get hands-on experience of a compact imaging system.

4.1.2 Eye dominance
In this project, students are introduced to the concept of a dominant eye and investigate whether it relates to left or right handedness. The students are asked to extend one arm and form a small circular opening with the thumb and index finger, then with both eyes open view a distant object through the opening. The students then alternate closing the left and right eyes. When the object being viewed stays in the same position as with both eyes open, the eye open is the dominant eye. When the object shifts from view, the open eye is non-dominant. In this lesson, students are introduced to the concept of correlation, though it is presented in a fun, informal way: if you are right-handed, are you also right-eyed? (The answer is "no, not necessarily").

4.1.2 Blind Spot
In this exercise, students learn about the internal anatomy of the eye and the location of the ‘blind spot’. At the back of the eye, at the location of the optic nerve, there is a region with no photoreceptors (light-sensitive cells). If an image falls on this region, it will not be seen. This is the blind spot. The students are given a sheet of paper with a black cross on the left and a red circle on the right. Starting with the paper held close to the face, the students close their left eye and look at the cross with their right eye. As the paper is moved away from the face, the red circle disappears from their peripheral vision, only to reappear as the sheet is moved further away. The distances from the eye where the spot disappears and reappears are then used to calculate the size of the blind spot (or the diameter of the optic nerve).

4.2 Post-Primary schools
One programme we have developed for Post-Primary school students comprises the Junior Certificate curriculum on Light. It is run over a three week period for one class per week of one hour and fifteen minutes duration. The main aim of the programme is that at the end of the three week module the students can confidently undertake their state exam in the area of Light. Topics covered include dispersion (illustrated using a simple prism and a torch/light box), reflection (angle of reflection investigated using a plane mirror; two plane mirrors and a cardboard tube used to construct a simple periscope) and refraction (bringing an image to focus using a convex lens). The outreach team present the programme in a similar way to the Primary school format, where following an introduction to the topic, the students are encouraged to investigate set problems in a hands-on way. Each week, the outreach team assess progress with the teacher and the programme concludes with a written test at the end of the third week.

5. CONCLUSION

Our outreach programmes at both Primary and Post-Primary schools level have been outlined. They range from a three to four week programme delivered in the classroom to organised campus tours of science research centres. Thus far these programmes have been well received; they tie in with the newly introduced curriculum in Primary and Post-Primary schools and offer an alternative approach to classroom learning. The outreach team present the material in an enthusiastic and hands-on way. The Primary School programmes form part of the child’s initial introduction to science and the Post-Primary school programmes provide that vital contact between the students and the University research environment linking their school work with real career choices.
6. ACKNOWLEDGEMENTS

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7. REFERENCES


« Terre des Lasers »: The new Aquitaine Outreach and communication center in photonics

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Introduction

The competitive cluster "Route des Lasers" has been labeled by the French Government in July 2005. Its main purpose is to become:

- the reference in the development and in the outreach of innovative technologies of optics and lasers (laser systems and applications, metrology, and imaging, innovative physics) in the industrial sectors, as aeronautics, space and embedded systems, health, vision, chemistry, food industry, electronics...
- the center of excellence in research for its specialities: intense lasers, fiber lasers, ultra short lasers, ultrafast optical instrumentation...
- the leader for training on lasers and optics. In this respect, its target is to set-up in Aquitaine another major economic sector, creating jobs and becoming attractive to industrial researchers.

In this context, it has launched in September 2005, in cooperation with Commissariat à l'Energie Atomique (CEA) and Regional Council a project involving scientific exhibitions, called "Terre des Lasers ®", in order to create an exhibition and an area of communication and science discovery or a very large target (public, school, industry) in the fields of optics, lasers, optronics and imaging.

This initiative is part of the strategy of the "Route des Lasers" center which aims to promote technologies developed in the areas of photonics, targeting in particular children and teenagers and their awareness for this particular industrial and scientific topic.

The project

It consists of three steps.

- The first step is operational and accessible to the public (www.ilp.u-bordeaux1.fr/ILP). Dedicated to high-power lasers, and located in the Plasma & Laser Institute (close to the CEA center), it consists in:
  - a "scale 1" model of a line of MegaJoule Laser (LMJ) and a computer-based representation explaining the operation of a power laser and of fusion;
  - operational optical components from older power lasers or LMJ prototypes;
  - two rooms for practical and technical trainings, introducing high schools students to physics experimentations required by the Public Education Authority of Bordeaux (Rectorat de l'Académie de Bordeaux);
  - a website (in progress).
• The second step is going to start. Based on travelling exhibitions being held by professionals, it has two goals:

  • **Stimulate and educate:**
    
    • stimulate and educate the public to the world of optics and lasers, prioritizing children and schools, who would be the future actors;
    • stimulate scientific and entrepreneurial vocations, facilitate a better communication between researchers and public.
    • understanding, by experiments, the physical principles and the scientific and industrial applications in the optics areas, and in particular lasers, to:
      • a various public: families, students, scientists, industrialists, journalists,
      • a public with very different expectations and scientific knowledge,
      • an international public.

  • **Broadcast information during major events** (cultural, economical or social) in Aquitaine, in France and in some European cities, being representative of the "Route des Lasers " project.

• The third step, synchronised with the 2012 opening of LMJ, consists in the completion of the building to receive the exhibitions.

**Exhibitions:**

There will be two:

• a main exhibition of approximately 500 m2, operational in 2011, which will first be held in prestigious places in France and in Europe (Palais de la Découverte in Paris, Deutsche Museum in Munich, Kutxaespacio de la Ciencia in San Sebastian, Bordeaux ...), before its final integration into its future permanent building. In this respect, the architecture will be chosen to highlight the goals of the center.

• a travelling exhibition of approx. 150 m2:
  • consisting in part of the previous exhibition, easily transportable;
  • autonomous;
  • adapted to all kind of premises: professional shows and schools.

• a website setting up and keeping tracks of these exhibitions.

The scientific contents of the exhibitions will be defined and validated by a scientific industrial and educational committee involving French and European representatives (university, research, industry).

Our approach for the transfer of knowledge is multiform and adapted to the audience:

• **Free visits or guided tours of the exhibition:**
  • The chosen design of the scenes will aim to dive and accompany the visitor to the wonderful world of light. Guideline will be the Laser and its applications in low or high energy.
  • Will be presented all the thematic in order to understand the functioning (optics, fusion energy, inertial confinement fusion, plasmas) and the resulting applications (medicine, industrial applications, astrophysics, etc).
  • The exhibition will include an historical part, a discovery part (free-access manipulations and touch screens to experiment and go beyond the simple observation) and live experiences.
• The performance of experiments in or near schools, tailored to the educational programs and using kits. These experiments may be performed individually or by scientist.

**Present situation**

Several awareness projects have been completed or are being discussed in the scientific community:

- **existing projects**
  - the Network of Excellence NEMO (Network of Excellence on Micro Optics) of the 6th PCRD: creation of an educational kit in the field of micro-optics to educate students, from primary school until the end of the secondary, applications and the role of optics and micro-optics in everyday life or in research,
  - the travelling exhibition "Fascination of Light - Light for Schools", supported by the German Ministry of Education and Research (BMBF),
  - the "Kid’s Science Museum of Photons", with whom we signed a partnership.

- **projects being set up**:
  - "Photonics Explorer", driven by the University of Brussels, with the objective to develop a kit to develop awareness of the photonics low cost for wide broadcast in schools,
  - Completion in Barcelona of a museum dedicated to photonics.

**Collaborations requests**

We are looking for partnerships to capitalise the work already done and planned (known or unknown) in the area of photonics, targeting in particular schools.

We offer, to those who wish to be involved, to join the Scientific and Educational enlarged Committee, in order to define together the themes and tools that will be developed in the context of our project.

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Elevation of Optics and Photonics Education in Thailand

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ABSTRACT

We initiate a pilot project of photonics education outreach to Thai society in order to heighten public awareness and to inspire new generations of science and technology in photonics. Our target groups are students, teachers and public people. In our first state, we focus on students and teachers especially in the rural area. Learning-by-playing and critical-thinking-by-doing approaches are selected to nurture and reinforce students. For secondary and high school students, we provide a two-hour seminar on applications of photonics in daily life in order to motivate them to do science or engineering projects related to photonics. Specifically, our technical workshop with hands-on experiments provides a practical way for teachers to inspire their students about optics and photonics. Based on our phase I work with 1044 students from 21 primary schools, we find that 90% of them have fun and gain new asset in photonics. With our approach for secondary and high school levels, there are three projects accepted for the first round in the 2009 Young Scientist Competition. In addition, 90% of 85 teachers from 59 schools recognize and understand more about optics and photonics. In our further work, we will focus on the involvement of public people in order to create a new momentum that fulfills our mission.

KEYWORDS


1. INTRODUCTION

With the growth of science and technology (S&T) in the 21st century, Optics and Photonics (OP) has been a key player in today and future applications ranging from flat panel displays, green IT, and silicon photonics. However, OP was previously viewed as an orphan discipline because it worked behind the scene in order to make electronic systems operate effectively. This issue also leads people not to realize how OP

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impacts our everyday life and do not have motivation to learn more about it. If we consider the science core theme\(^1\) in our educational system, OP is not even emphasized and therefore our industrial sector and community lack qualified engineers and researchers who can solve specific technical issues in the production line as well as who can come up with innovative ideas and products. Hence, dissemination of OP to our community is needed.

In 2008, we established a project called “Shining Spectrum to Society”\(^2\) (SSS) in which we aimed to promote public awareness especially new generations to understand more about OP and its applications in everyday life through the combination of a hands-on teaching approach and media engineering. We also encouraged students in high schools to utilize their knowledge, learn new things, and practice their skill in order to do their science or engineering projects related to OP. Since then, several activities have been in active and some are on the way. In this paper, we summarize our Phase I achievements in motivating students and sharing skill and processes with teachers.

2. TARGETS AND STRATEGIES

2.1 Target Groups

OP Education in Thailand has been concerned by a few small groups of people who teach\(^3\) or work\(^4-7\) in OP. Therefore, it has gradually grown until the shortage of human resources qualified in this field occurs in the current industrial situation and probably for the future. To alleviate this problem at its first cause, we need to setup a proper strategy and determine the target groups in order to elevate OP education in Thailand to another level. Our target groups are students, teachers, and general publics as shown in Figure 1. The first two groups directly relate to how OP education can be accomplished while the last group plays a significant role in influencing OP in the Thai community.

![Figure 1. Our target groups in elevating OP education in Thailand.](image)

- **Students**

  For Thailand, OP definition and knowledge as well as its applications have been imperative in mind only for undergraduate and graduate students who have made contributions and have gained some experiences when they are in some universities. In the contrary, primary and secondary school students have been disregarded as the minor groups for OP learning even though they are really our new generations for our country’s development in the foreseeable future. Hence, we need to start nurturing and reinforcing them in the awareness of OP. For high schools students, we have to open their minds as well as to prepare their practical point of view and needed skill for learning basic and advanced OP issues.
• **Teachers**

![Diagram](image)

Figure 2. Our expected incorporation among teachers, local universities, and us.

Teachers are the master model of the students apart from their families. However, most science teachers in the primary and secondary schools lack proper skill and processes in teaching science. They sometimes teach science via memorizing instead of trying to engage and encourage students to learn science via scientific thinking and critical thinking processes. In addition, lack of interesting demonstrations or educational kits for teaching and hands-on learning is a key factor in making science more interesting in the class. With these issues in mind, teachers trained in OP and low-cost educational kits are needed. Figure 2 shows our scheme that networks our research institute with local universities and educational core centers in order to strengthen teachers in all levels about OP.

• **Public Persons**

Apart from teachers and students, if public people understand more about OP and its impact in everyday activity, they will play a really significant role in creating a momentum that retro-reflects to leverage OP education in Thailand to the desired level.

2.2 Strategies

• For elementary and primary school students: we exploit our learning-by-playing approach. We also utilize our photonics kit in the process of building the critical thinking about daily OP.

• For secondary and high school levels: we give students in these two levels a two-hour seminar on applications of photonics in daily life in order to motivate them to do science or engineering projects related to photonics. Soft and hard media are also included during the seminar.

• For teacher: we develop an easy-to-use photonics kit using simple tools for demonstrations. We incorporate closely with the local universities to provide one day of seminar and workshop for sharing knowledge in OP and exchange ideas especially our approach for effectively teaching OP via our educational kit.
• For general publics: we join several groups from NECTEC and NSTDA to demonstrate our photonics kit in several occasions. These include two festivals held during the National Science Day and the National Children’s Day.

3. PRIMARY ACHIEVEMENTS AND BARRIERS

In our first state, we visit 21 primary schools in every part of Thailand. Most schools involved in our activity not only their OP education stay behind others but also their budget in leveraging the quality of their education system is low. A total number of students participated in our activity is 1044 covering 1020 in the grade four to six and 24 in the secondary level. For the high school level, we give our two-hour seminar to 1078 students from 11 schools in every part of Thailand (see Figure 3).

Figure 3. Our activities with high school students

In addition, we have networked with three local Rajabhat universities in Phuket, ChaingRai, and Surindra provinces to give a workshop and a seminar to 129 teachers as shown in Figure 4.

Figure 4. Workshop and seminar with teachers
3.1 Primary successes

More than 90% of primary and secondary students have fun playing with our educational kit (see Figure 5) and understand more about OP in daily life. One year after our visit, we receive the information from one school in Payao province that 50% of participated students are planning to study in a science and mathematics program. They are specifically interested in the OP program for their future study in the undergraduate level. For high school students, there are three projects accepted for the first round in the 2009 Young Scientist Competition. Note that these three projects are from the school where the project is assigned as one of the core courses.
For teachers, 90% of 85 teachers from 59 schools recognize and understand more about optics and photonics. Most teachers appreciate our workshop and they are interested in our developed photonics kit. Note that only 85 of 129 teachers sent us their feedbacks.

3.2 Barriers

Based on our activities delivered to students, teachers, and general publics, they now realize and understand more about the impact of OP for our country’s sustainability and competency. However, there is a barrier that delays steps to improve S&T education system in Thailand. Especially, we find that policy makers in the education are not seriously taking into consideration the OP. To alleviate this problem, we steer to general publics and local media. If they realize the importance of S&T, in particular to OP, they will help us to promote OP to our society. With this approach in mind, we join two national social festivals such as the National Children’s Day and the National Science Day to demonstrate OP (see Figure 6). A correspondent from Manager Newspaper, one of the local newspapers, comes to interview us about our activities and goals.

![Figure 6. Our activities shown during the National Children’s Day at Royal Thai Government.](image)

4. CONCLUSIONS

Our Phase I work can effectively inspire a group of primary students from 21 schools. We find that 90% of them have fun and gain new knowledge in OP. With our approach for secondary and high school levels, there are three projects accepted for the first round in the 2009 Young Scientist Competition. In addition, 90% of 85 teachers from 59 schools recognize and understand more about optics and photonics. Our further work will focus on getting the involvement from the public people in order to create a new momentum that fulfills our mission.

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Development of Optics Kit for Schools in Developing Countries
– International School of Photonics Model

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ABSTRACT
In India, the pedagogy of science education is “believe what text book says”. Providing schools with appropriate teaching materials to enhance teaching has always been a challenge in a developing country like India. Generally it is not possible for a normal school in India to afford the expensive teaching materials to teach through demonstrations and experiments. Thus students are forced to believe what text book says rather than learning concepts through experiments. The International School of Photonics SPIE (International Society for Optical Engineering) student chapter came up with ‘Optics kit’ to supplement the teaching of optics in school level. ‘Optics kit’, developed with indigenously procured components, could be sold at an affordable prize for an average Indian School. The chapter is currently selling the kit for less than $20. The content of the kit is at par with many kits already available commercially in developed countries, and the price is just 10% compared to those kits.

The kit is aimed to higher secondary level students in India, where students are taught Ray optics and basics of Wave Optics. The content of the kit is developed based on this syllabus. The Optics Kit contains simple optical elements like lens, grating, polarizer, mirror, diode laser etc. The kit can be used to demonstrate optics phenomena like interference, diffraction, polarization etc.

The kit was developed based on the feedback gathered by the chapter through its outreach activities. The syllabus for the kit was developed through thorough discussion with educational experts in the field of Physics. The student community welcomed the optics kit with overwhelming enthusiasm and hence the project proved to be successful in giving an opportunity for students to “See and Believe” what they are learning.

KEY WORDS
Optics Education, Optics kit, Hand on Optics

INTRODUCTION
Education plays an important factor in the economic development of a country\(^{(1)}\). On the other hand it is difficult for economically backward country to provide sufficient infrastructure to improve the quality of education. Effect of this contradiction is evident in the quality of education that can be offered by developing countries through its government aided school, especially in the case of science education. Science education demands proper laboratory facilities for the students to perform experiments and develop analytical thinking rather than learning abstract ideas given in text books.
Last two decades witnessed tremendous growth in the field of Optical and Photonics and its application to various fields like communication, healthcare, environmental studies, astronomy, energy harvesting etc. In India, the physics syllabus in schools follows traditional contents. The traditional content does not emphasize the import of optics in today’s technology arena. Students are not aware of the development of science and technology in various fields and corresponding state of the art. Considering the economic situation of the state, it will take long time to bridge this gap and bring the education into right track.

A quick and partial solution is to seek a parallel approach. This is the reason why various organizations like International Society of Optical Engineers (SPIE)[2], Optical Society of America (OSA), United Nations Educational, Scientific and Cultural Organization (UNESCO)[3] encourages optics outreach activities in developing countries.

International School of Photonics SPIE (ISP-SPIE) student chapter in collaboration with OSA student chapter ventured the development of a simple, cost effective optics kit in order to develop interest in optics to school students. The idea is still in a developing stage. The first version of the prototype was launched in February 2008 and the second version with many modifications was launched in November 2008. This paper mainly focuses on the approach we adopted for developing this Optics Kit.

1. BACKGROUND
ISP-SPIE student chapter has been involved in optics outreach activities since the year 2005. The student chapter organized events like “Optics to School”, “Optics Fair” etc. which all aimed to address a large group of students in a couple of days. The one day “Optics to School” program caters on an average 200 students. The massive optics outreach program which is being conducted once in a year caters more than 1400 students every year. These programs mainly involved hands on experience with simple optics experiments. The responses to these events were overwhelming and the feedback showed that students had a different learning experience, which was different from their regular learning experience in schools.

In high school¹, students learn only classical ray optics. Concepts of reflection, refraction on convex and concave mirror and lenses are taught. The laboratory experiments involve experiments with lenses and mirrors since these experiments are cost effective for schools to afford. In higher secondary level students learn the basic concept of Wave optics. Phenomena like interference, diffraction, polarization are introduced to students at this level. Traditionally it is difficult to set up classical experiments like Young’s double slit experiment with broad band sources. Because of these, such experiments are performed only at college levels. In higher secondary level, students are forced to learn these phenomena as abstract ideas rather than performing experiments and getting convinced themselves.

The availability of cheap laser sources opens new opportunities to set up many optics experiments in a simple and cost effective way. Experiments to demonstrate interference, diffraction etc. can be set up easily using a cheap laser pointer which is available for less than half dollar in India. We tried to harness this opportunity to bridge the lack of experimental facilities to demonstrate concepts of wave optics in higher secondary school level by developing this optics kit which will act as a supplement to the current syllabus. The causes that lead to the beginning of this project is shown in figure 1.

¹ In Indian educational system, school education is for 12 years. 8th standard to 10th standard is referred as High school and 11th and 12th standard are referred as Higher secondary
2. DESIGN CONSIDERATIONS

At present there are similar optics kits available commercially in developed countries. But the costs of these kits are very high to be afforded by schools in India. Hence the main design consideration was to make the final product as much cost effective as possible without compromising much on the content of the kit. The feedback from the outreach activities gave a right solution for this challenge. It is not the number of components or number of experiments which is included in the kit that matters but it is the knowledge content of the kit that matters. Hence we adopted our basic approach as to choose the right set of experiments which can give maximum concept to students.

The cost of the kit had to be kept around 800 Indian Rupees (<20$) so that it will be easily affordable for schools. This price is affordable for individual students as well who are interested to explore the beauty of optics by themselves. Since this kit is also intended to be used by teachers for classroom demonstrations, we choose to include the conventional experiments in the kit. This gives the advantage that teachers can use this kit as a teaching aid without any special training.

![Diagram of cause and effect showing the background of optics kit development project](image.png)

Figure 1: Cause effect diagram showing the background of optics kit development project
3. RESOURCES

ISP – SPIE student chapter comprises of 50 student members. The group comprises of research scholars, undergraduate students who are studying course in Photonics and faculty members. This provided sufficient human resource to take this project forward. The financial needs were met by the 1300$ provided by SPIE as an outreach grant for the development of optics kit. This grant was obtained for the developing a cost effective optics kit and publicizing it.

![Diagram of the implementation of the optics kit project]

4. IMPLEMENTATION

The route map for the project was made based on the feedback received from teachers and students during the optics outreach activities. Second stage involved discussion with experts to decide about the content to be included in the kit. Discussions with experts in the field of education and optics gave clear guidance regarding the goal to be achieved by such a project.
From these feedbacks and discussions it was decided that as a starting, it is better to include classical experiments in the kit which explains concepts of interference, diffraction and polarization. Along with that

The most challenging part in this project was developing a manual for the kit and procuring components indigenously. The idea was to develop the kit in such a way that the components should readily be available so that the student member of the chapter themselves can assemble the kit and sell it to schools and individuals. The components were procured from local distributors and it was packaged in a compact manner. The students and faculty were involved in the development of the manual for this kit. On the second beta version the content of this manual is complete but it needs refinement to ensure that students get maximum out of this kit. The implementation pathway is shown in figure 2. As of now there is no proper machinery for marketing the product. This will be implemented once the product is ready for commercial marketing.

5. CONTENTS

The contents of the optics kit are listed below

- Laser pointer
- Single Slit
- Double slit
- A pair of Polaroids
- Mirror
- Lenses
- Rope and slits to explain polarization
- Microscopic slide with cello tape to demonstrate photoelasticity
- Diffraction Grating
- Diffractive optics Element
- Manual
- SPIE DVD – “Light at work”
- SPIE CD – “Careers in Optics”

All the components except diffractive optics elements were procured from local suppliers. The diffractive optics element was provided by SPIE. Figure 3 shows the photo of the final packaging of the second beta version of the kit. The SPIE DVD and CD included in the kit gives students a feel about the state of the art in the field at present, which is essential to attract the interest of students to the field of Optics and Photonics.
5.1 Manual

The content of the manual was compiled by a group of students in the chapter with the guidance of faculty advisor. The content was carefully designed to make it interesting for students who are using the kit. The introductory part of the manual has three sections. Manual starts with an introduction about Optics and Photonics, followed by a brief timeline about the development of the field of Optics. This section is followed by a brief note about how one can create interest in a field through anecdotes. This introductory part can create an interest for the user to go forward and try out the experiments involved in the kit.

![Figure 3: Packaging of beta version 2.0 of the optics kit](image)

Figure 3: (on left) Packaging of beta version 2.0 of the optics kit (on right) Optics Manual

Later part of the manual contains explanation of experiments. Each experiment aims at introducing the concept of a new phenomenon to student. The section starts with an introduction and background of the phenomena, followed by experiments that can be performed by students. The experiments are not meant to be for taking any quantitative analysis. Instead students can observe the phenomena and get a feel of it. At the same time the components are sufficient to extend the experiment that can be done with quantitative measurements.

6. Experiments

The experiments are designed to provide three types of learning experience to students. It invokes curiosity in students, it helps student to learn a new concept and some fun. Students are not meant to understand some involved concepts like photo-elasticity, diffractive optic elements etc. but it serves as a way to invoke curiosity in students.

6.1 Interference

This section aims at explaining the concept of wave nature of light through Young’s double slit experiment. Interference fringes can be made using the double slit and laser pointer provided with the kit. The formation of the fringes will be counter intuitive for a student who has been learned only ray optics. This can be a nice way introduce wave nature of light to students.
6.2 Diffraction

As an extension to the Young's double slit experiment single slit diffraction pattern can be produced using the laser and the single slit provided with the kit. Also diffraction pattern from a diffraction grating can be demonstrated using the diffraction grating provided. The diffractive optics element can be used to make different patterns just to invoke more curiosity in students.

6.3 Polarization

The transverse nature of light can be shown using experiments related to Polarization. There is a pair of slits and rope to demonstrate the mechanical analogy of polarization. This concept can be extended and demonstrated using the Polaroid sheets provided with the kit. By keeping the microscopic slide, stuck with cello tape between the Polaroid sheets, demonstration of photo-elasticity can be performed to give more opportunity for fun for students.
6.4 Dispersion

This is a more involved experiment to create a prism using water and mirror in order to create rainbow. This experiment can be used to explain concept of dispersion, refractive index etc. to students.

7. CONCLUSION

The second beta version of the kit was launched in November 2008 during the Optics Fair conducted by the student chapter. The response from students and teachers towards the kit was positive. Hence the idea of developing a cost effective optics kit with simple components and simple experiments proved to be a big success. The authors could successfully demonstrate the feasibility of this model within the given financial and practical constraints. This is a generic model which can be applied for developing low cost study aids to supplement school education in developing countries.

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Outreach in Optics for Developing Countries - International School of Photonics Model

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ABSTRACT

The education system of developing countries like India lack infrastructure for teaching science through demonstrations and experiments. The teaching of optics is generally based on factual data given in text books. Students are forced to believe natural phenomena without actually getting convinced themselves through observations. This imparts a big flaw in the way students understand and experience science. The International School of Photonics SPIE (International Society for Optical Engineering) Student chapter, in Cochin University of Science and Technology (CUSAT) in India comes up with their outreach activities, which is mainly aimed at giving hands on experience for school students with Optics. The pedagogy is completely in tune with the syllabus of Indian schools. This activity is being conducted by the students who are studying Photonics in University level. This gives the students a teaching experience as well. The outreach activity has been designed in two modes – Optics Fair & Optics to School.

Optics Fair is a massive outreach program which has being conducted yearly since 2006. The two day event attracts more than 1500 school students as well as general public every year. The event is divided into three sections; Primary, Secondary & Higher Secondary and the experiments are carefully chosen that the students will be able to appreciate them with their prior knowledge in optics. The basic idea put forward is “See and Believe”. In three years this event has become very popular attracting more and more students each year.

Optics to School is another mode of the outreach activity where the volunteers go to schools for a one day session where optics experiments are demonstrated to students in interesting and exciting way. The idea is to reach students in the schools in rural areas who are not able to take part in the Optics Fair due to economic constraints for transportation. This activity also has been running for past 3 years successfully.

The response received for these outreach activities is overwhelming. Program is successful in its mission to invoke curiosity and interest in students towards optics. Also within the given time constraint the program is able to give an insight of subject to students.

KEY WORDS

Optics Education, Optics outreach, Hand on Optics
1. INTRODUCTION

Developing countries faces fundamental limitation in developing an effective pedagogy in science at school level. The main reasons for this limitation are the lack of facility and lack of training for science teachers [1]. Even though the science education syllabus covers broad area of science, students remain ignorant about the new technological development in various fields of science as the syllabus is not getting revised duly. Motivating students at school level will result in the development of the field of science which in turn will help in the development of the economy of a country[2].

Last two decades witnessed tremendous growth in the field of Optical and Photonics and its application to various fields like communication, healthcare, environmental studies, astronomy, energy harvesting etc. In India, the physics syllabus in schools follows traditional contents. The traditional content does not emphasize the import of optics in today’s technology arena. This makes it essential to run a campaign in order to introduce the beauty of the field of optics to school students and making them aware of the state of the art in various technologies involving optics, with an objective to invoke interest in students towards optics.

The ultimate solution to this problem lies in improving the overall quality of education. It should involve due revision of syllabus to include contemporary development in the subject and giving proper training for the teachers. An important factor to improve the quality of science education is to improve the laboratory facilities in schools. It requires huge investment in order to achieve all above stated goals. Hence these goals are achievable only in a long term basis.

A quick and partial solution is to seek a parallel approach where universities and research institution use their human resource to communicate the new development happening in science to school students through outreach activities. This is the reason why various organizations like International Society of Optical Engineers (SPIE)[3], Optical Society of America (OSA), United Nations Educational, Scientific and Cultural Organization (UNESCO)[4] encourages optics outreach activities in developing countries.

International School of Photonics SPIE (ISP-SPIE) student chapter in collaboration with OSA student chapter designed its outreach programs in order to bring the message of light to school students.

2. BACKGROUND

ISP-SPIE student chapter and ISP – OSA student chapter involve a group of students consists of undergraduate, postgraduate and research students whose main focal area of study is Photonics. From first year onwards the chapter was keen in spreading the message of light through outreach activities. The outreach programs were developed in order to give students hands on experience with some basic optics experiments. The activities were mainly of two types. One in which volunteers go to school and carryout a one day long session involving presentation, hands on experiments. Second approach was to conduct a massive outreach program (“Optics Fair”) which was designed in an exhibition mode catering a large group of students in a short span of time.

The main financial backing required for these activities came from SPIE and OSA. Also we could attract local sponsorship in order to meet the financial requirements.

3. DESIGN OF CONTENT

The main design consideration of the activity was to give participants maximum knowledge in the limited time available. The learning environment should be different from usual classroom environment in order to ensure that students get maximum out of such programs. Learning through activity was the solution
we found for this challenge. Activity based teaching is a very effective mode of teaching and it ensures that student will find learning experience interesting.

The content to be included for each session varies depending on the target audience. The content of the program was designed depending on the level of knowledge in optics for the target audience. Based on this concept we categorized the target audience who are school students into three categories.

The first category included students till 7th standard. The knowledge level in optics for this category of students is very low. Optics is not introduced as a subject into their curriculum at this level. The students would have naïve ideas about phenomena like reflection, refraction etc., about which they have not studies systematically at this level. The aim of package we created for this level of students is to “fascinate” them with light and colors. To give them a visual experience of light. There were three separately designed sessions based on different themes. A session on “colors” was designed aiming at Lower Primary students. This session included activities to teach students basic concepts of colors like primary colors, mixing of colors etc. Also there were some interesting optical illusions in order to make the session more interesting. The theme for another session was “Reflection”. This session included activities like building Kaleidoscope, periscope etc. aimed to give a feel about the phenomena of reflection to students. The third session was based on “Refraction” where activities which demonstrate phenomena based on refraction were included.

The second category included students in high school. At this stage students were introduced to the field of optics in a systematic way. They would have studied ray optics and phenomena like reflection refraction etc. They would have studied action of spherical mirrors and lenses based on ray optics model and also would have introduced to some basic optical instruments like microscope, telescope etc. Even though the students had studied about basic ray optics and about basic optical instruments, they would not have used an optical instrument or seen what they have studied in action. The tagline for the package for this category of students is “believe through experiment”. The package involved simple optical experiments which can be explained using ray optics. It also included some demonstrations which can invoke inquisitiveness in students to explore more about the field of optics.

The third category consisted of students in higher secondary level. This is the stage when students are introduced to concept of wave optics. At this stage students might be doing some ray optics based experiments. But normally there would not be any wave optics based experiment included in the curriculum. Students are forced to learn phenomena like interference, diffraction, polarization etc. without seeing actual experiment. In contrast to the ray optics concept which is quite intuitive, concept of wave optics is hard to digest for a prejudiced mind which understands ray optics in terms of Newton’s corpuscular theory. This creates aversion in students towards the subject of optics when they are introduced to wave optics. The package designed in this category aims at demonstrating classical experiments which led to the advent of the field of wave optics. Classic wave optics experiments like Young’s double slit experiments, single slit diffraction etc. are difficult to realize using a white light source. This was the reason why these experiments were not accessible for school students. Today the availability of cheap diode laser pointers opened up new opportunity to setup such experiments easily.

Each session was designed to be for one hour for a group of 30 to 40 students. The sessions mainly involved activity. The activities did not involve any quantitative measurements. Rather students were

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1 In Indian educational system, school education is for 12 years. 8th standard to 10th standard is referred as High school and 11th and 12th standard are referred as Higher secondary
expected to experience various phenomena qualitatively which would supplement their textbook-based knowledge. The design concept for the content is summarized in figure 1.

Other than the main focal theme, activities and experiments that introduce students to the field of lasers and optical fibers were included in sessions of category 2 and 3. This helps to make students understand the important role Optics and Photonics play in our day today life. It would in turn invoke interest in students in order to learn about the development happening in the field of Optics and Photonics.

4. Experiments

This section gives complete list of experiments setup for various sections. The experiments involved in this instructional package are standard optics experiments. But the presentation method and the objective of including specific experiment in specific category added value to the whole package.

The main experiments and activities included in category 1 is given below.
• Colors
  o Newton's color disc
  o Primary colors
  o Rainbow creation
  o Optical illusions
• Reflection
  o Mirror
  o Kaleidoscope
• Refraction
  o Bending of light and illusions associated with it
  o Lens
  o Telescope

The category 2 which mainly focused on ray optics based demonstration included experiments listed below.

• Telescope
• Microscope
• Prism and dispersion
• Total internal reflection
• Scattering of light
• Eye
• Light and lasers
• Tyndall experiment for wave guiding

The list of experiments included in category 3 is given below.

• Interference – Young’s double slit experiment
• Diffraction
  o Single slit diffraction
  o Diffraction grating
5. OPTICS TO SCHOOL

This program is designed to run as a whole day program in a school. A group involving 20 to 30 volunteers would go to the school and setup the experiments mentioned in the previous section, depending on the target audience. The program starts with a presentation in order to introduce the students to the objective of this program. Also students would be shows presentation of various fascinating development happening in the field of optics and Photonics at present.

Figure 2: Photos of Optics to School program
This session would be followed by activity session where one or two volunteers would be assigned to a particular experiment. A group of four to seven students will spend 15 minutes on a particular experiment. They would get opportunity to get hands on experience with each demonstration and the volunteers would be explaining the experiment to students. Thus in a single session which last one to one and a half hour, students would be going through four to five experiments and they would be given enough time to clarify the doubts arising while going through these activities.

The presentation mode was kept deliberately informal in order for students to give a completely stress free learning experience. This helped in invoking inquisitiveness in students.

The program gained very enthusiastic and positive response for past four years. Students showed enthusiasm to get involved in the activities included in the demonstration session and they actively participated in the discussions. Students came up with interesting doubt which is the proof that the program was successful in invoking the inquisitiveness in students. The feedback obtained from teachers was also overwhelming. They considered this program as a way to sharpen their knowledge. Also this activity based instructional package acted as a supplement to the standard textbook which made further teaching easier.

Figure 3: Photos from Optics fair 2007
6. **Optics Fair**

Optics to school program proved to be a big success. But due to practical limitation of time, it was possible to conduct this event only for a limited number of schools in one academic year. In order to cater more number of students in a short span of time, idea of a massive outreach program named as “Optics Fair” was mooted. Achieving this idea demanded more organizational skills and more human efforts. The challenge was to setup all experiments under one roof for two days and cater maximum number of students possible in these two days.

This ambitious task was achieved in 2006 for the first time which was proved to be a big success followed by greater success in year 2007 and 2008. Every year this two day event catered more than 1400 students in three categories.

Other than the activity sessions, which ran similar to that in Optics to School, there were poster exhibitions. The poster exhibition on life and work of Prof. C. V. Raman was a special attraction of the event. Also there was screening of scientific documentaries. As a whole participants got a festive experience. They were living a day with optics. The event proved to be a great success for past three years with more positive responses each year.

7. **Conclusion**

A model for outreach activities was developed and successfully tested for four years. The content of the activity was carefully designed so that this program would act as a supplement to the regular curriculum for school students. But this content aimed to bridge the gap in the knowledge in optics due to the unrevised curriculum. The feedback obtained from students and teachers clearly shows that the approach adopted in designing the content of the program is appropriate. This is a generic model which could be adopted in countries where large numbers of students have to be addressed with limited resources in terms of time and trained manpower.

**REFERENCES**


Use of hybrid online course for retraining employed technicians

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Indian Hills Community College

ABSTRACT
The National Center for Optics and Photonics Education (OP-TEC) is dedicated to meeting the U.S.’s demand for photonics technicians. A key to meeting this demand is assisting two-year colleges in providing flexible and effective means for preparing these technicians. To this end, OP-TEC has developed a hybrid online course that can be used for multiple purposes, including faculty development, student enrichment, and employee retraining. The online delivery mode and multipurpose capability of this course provide two-year colleges an educational delivery platform that can reach well beyond their local service areas and provide undergraduate students and already employed technicians an opportunity to engage in this technical area. This paper will focus on the use of this course as a tool for retraining technicians who are already employed (“incumbent workers”) by photonics and photonics-related companies. It will explain why these workers are important to meeting the technician demand of U.S photonics employers, present the structure of the course and its components, and describe a recent implementation of the course by Indian Hills Community College, Ottumwa, Iowa, in retraining employees at Mound Laser and Photonics Center in Miamisburg, Ohio.

KEYWORDS: Lasers, optics, photonics, fiber optics, OP-TEC, Indian Hills Community College, online hybrid, Blackboard

1. DEMAND EXCEEDS SUPPLY

The main source for providing skilled technicians for U.S. photonics companies is the community and technical college system. However, although several community and technical colleges have excellent photonics programs, the total output of program completers is far below employer demand, according to two studies conducted by OP-TEC.

1.1 Supply
The purpose of the first study was to determine the capacity of U.S. colleges to produce photonics technicians.¹ To collect this information, the study used both Internet searches and telephone surveys. The Internet searches identified postsecondary institutions in the U.S. that offer photonics instruction (from single courses to full programs) that can contribute to the training and education of photonics technicians. The telephone surveys confirmed that the identified colleges still offer this instruction and determined the number of students enrolled and the number of program completers. All the institutions that contributed to the final results of the survey indicated that they have active photonics instructional offerings (at least one course in photonics, optics, and/or laser technology) and that their former students are employed in the optics/photonics industry as a result of their participation in that instruction. The results of the survey indicated that 600–700 students are enrolled in programs that are capable of leading to technician-level employment in the photonics industry. However, only 250–300 are completing their programs each year and are available to fill industry positions.
1.2 Demand
To determine the demand side, OP-TEC commissioned the University of North Texas (UNT) Survey Research Center to canvass industrial companies around the U.S. that perform R&D with optics, lasers, and photonics technology or are original equipment manufacturers for photonics R&D companies to determine how many photonics technicians they currently have in their employment, the additional number they will need in 2009, and the number they will need in the next five years. Using both the Laurins Publishing Company Photonics Directory (2008) and OP-TEC databases, the researchers identified a total of 3989 U.S. photonics companies. The researchers contacted over 600 companies and generated a representative sample of 300 that employed photonics technicians. Besides employment data, the survey collected information on the educational levels of employed photonics technicians, the employers’ preferences with respect to the levels of education those technicians should have, and the types of jobs photonics employers are seeking to fill. After a statistical analysis of this sample-based survey, a final report was issued. In summary, the report stated that over 19,000 photonics technicians are currently employed in the U.S., that over 2100 additional photonics technicians will be needed next year, and that approximately 5900 will be needed over the next five years (2010–2014).

When the supply and demand results are compared, it is clear that for the U.S. to meet its demand for these workers, community and technical colleges must substantially increase the numbers of their graduates and program completers. For example, let’s assume that in 2010 U.S. colleges can add 300 new technicians to the pool of photonics workers. This will fall far short of the 2100 workers needed. Helping to close the gap between supply and demand is one of OP-TEC’s primary challenges. To meet this challenge it must empower colleges to increase enrollments in their existing photonics and photonics-related programs and to implement new programs.

Although these two options—implementing new programs and enhancing existing programs—are viable, experience has shown that colleges are not amenable to making quick changes. Changes at the program level require gaining local and state approvals, purchasing laboratory equipment, establishing advisory committees, and performing many other preliminary tasks—a process that can take years. So OP-TEC sought a quicker way to meet the high demand for photonics technicians. One option was to provide specialized training for incumbent workers in photonics-enabled technologies such as manufacturing, biomedicine, and telecommunication. The training would enhance those technicians’ ability to maintain and troubleshoot the systems with which they work.

But why did we choose incumbent workers as our other target? Why not concentrate on producing new technicians? The demand for photonics workers covers a broad spectrum of ability levels. Organizations involved in research, original equipment manufacturers, and field service companies need photonics technicians who have a detailed understanding of lasers and their operations. These technicians typically have AAS degrees in laser electro-optics, photonics, or closely related fields and represent one part of the demand identified in the UNT survey results. Another significant portion of this demand comes from companies that use photonics as an enabler of other technologies. Examples include telecommunication companies that are heavily dependent on lasers and fiber optics; manufacturing companies that use lasers for welding, cutting, and scribing; and medical groups that use lasers and fiber optics for diagnostic and therapeutic procedures. Each of these organizations employs technicians who need an understanding of photonics to fully comprehend the performance of the systems they maintain, calibrate, and/or repair. However, many of these technicians never had the opportunity during their years of formal education to learn about photonics. As a result, their employers feel this deficiency on the shop floor. To remedy this deficiency, companies could hire new technicians with a basic understanding of photonics. However, it is less expensive to provide a means for incumbent technicians to acquire these basic skills. To meet this training need, OP-TEC has created a hybrid online course that enables incumbent workers to develop basic photonics skills and knowledge using a flexible format.
2. HYBRID ONLINE COURSE CONTENT AND STRUCTURE

Technicians working in photonics-enabled fields typically have the basic skills and knowledge that photonics technicians require. They understand the theory and application of AC, DC, and electronic circuits; are well versed in metrology; have a working knowledge of basic scientific principles; and have analytical skills sufficient to solve basic problems that may involve college algebra and trigonometry. These technicians also have honed their problem solving skills and have experience working in teams. What they lack is a basic understanding of photonics and how it enables the processes they are responsible for maintaining.

To meet this need for basic photonics skills and knowledge, OPTEC has devised a course titled *Fundamentals of Light and Lasers* that covers basic concepts related to light, optics, and laser operations. Figure 1 lists the modules that make up the course.

![Figure 1 Course Content](image)

This foundational course provides incumbent technicians working in photonics-related fields a broad overview of the scientific and technological concepts required for understanding the basic operational concepts and applications of photonics devices.

As Figure 1 shows, this course covers a progressive sequence of topics that allows students to start with the basic concepts of light; learn about laser and optical lab procedures; become familiar with laser safety issues; understand how light is controlled by lenses, gratings, and other optical devices; and integrate these concepts into a study of laser operation. *Fundamentals of Light and Lasers* provides the basic skills and knowledge needed by technicians in most photonics-enabled industries and thus serves to meet a portion of the demand identified in the UNT report.

2.1 Course Structure

This course is a true online hybrid. It contains all the basic elements that are typically present in online offerings. It is a hybrid in that it requires participants to perform the laboratory exercises “on site” at educational institutions selected by their employers. This requirement was put in place because OP-TEC’s educational philosophy maintains that technicians need more than a conceptual understanding of photonics. They should also have experience in working with photonics laboratory protocols and practicing data acquisition and analysis techniques. Consequently, the hands-on component is considered an essential part of the course.

The length of the course can be adjusted to fit the employer’s need. It can be completed in five eight-hour days or expanded to any reasonable length, though we recommend that the timeframe not exceed one year. If the course extends much beyond a year, it loses its coherence and requires extensive review, which can entail larger time commitments and thus more lost work time.

The online elements of the course are shown in Figure 2 (a screen capture of the course’s homepage).
Fig 2 Online Elements of OP-TEC's Fundamentals of Light and Lasers

The buttons along in the left-hand column provide the following links:

**Instructor Notice:** This link takes students to a page where the instructor posts notices that are time sensitive or important in administering the course. This screen automatically opens when students log on to the course.

**Syllabus:** This link takes students to the course syllabus, which provides key information relating to the course.

**Weekly Schedule:** This link allows students to view assignments for a given week.

**Students and Teachers:** This link accesses the bios of the course instructor(s) and bios submitted by students.

**Lecture:** This link opens a video that provides background materials and an overview of the laboratory that can be accessed through the Lab Video link.

**Lab Video:** This link accesses a video that shows a course laboratory being conducted. The video emphasizes the equipment used, safety issues, required data, and data acquisition techniques. Students are asked to keep laboratory notebooks to record this information. (The notebooks are useful to the students during their on-campus laboratory capstone experience.) Through this link, students can also access data tables that present "live" data taken during the laboratory. Using these data, students perform specified calculations that verify equations or explain concepts investigated in the laboratory.

**Applets:** This link accesses other links that allow students to view the applets referenced in the Fundamentals of Light and Lasers text. These applets supplement instruction presented in the text.

**PE&Q Solutions:** This link accesses solutions to the assigned problems, exercises, and questions (PE&Q) compiled from the text. Course instructors can close student access to the PE&Q Solutions, requiring that the students solve the problems on their own, either independently or in groups. The answers are provided as a
means for students to check the accuracy of their work. Once students have had time to work independently on the assigned PE&Q’s, the instructor will grant them access to the solutions.

Assessment Answers: This link provides answers to assigned PE&Q’s. These answers are always available to the students.

Test: This link allows students to access graded tests. Instructors set the dates that students can access the tests.

Test Solutions: This link provides a means for students to review the solutions to graded tests. Instructors set the dates that students can access the solutions.

Discussion Board: This provides a means for students to interact with each other and their instructors. A discussion board is an asynchronous communication option that students use to exchange information on course-related matters.

Chat: This is another means for students to interact with each other and their instructors. The chat rooms are synchronous and allow students to work together in group activities. The course has at least one instructor-led chat each week for the whole class.

My Grades: This link allows students to view their grades. The link is password protected, thus ensuring confidentiality.

2.2 Laboratory Capstone Experience

As already mentioned, the Fundamentals of Light and Lasers course requires students to participate in laboratory activities. The intent of the laboratory capstone experience is to give students the opportunity to conduct the experiments contained in the text. Since all OP-TEC partner colleges have the facilities and equipment necessary to conduct the laboratories, the capstone experience can be scheduled on any of their campuses. However, in case this is inconvenient for the students or employers, OP-TEC has worked with IHCC to develop a mobile laboratory package that can be shipped to wherever the laboratories are to be conducted. The capstone experience lasts two and a half to three days and includes additional hands-on activities that are not contained in the textbook.

2.3 Course Adaptations

The architecture of the course is flexible, which allows it to be adapted for two other applications.

Faculty Development: One key to increasing the flow of students through the pipeline is to increase the number of faculty members who are qualified to teach photonics courses. The Fundamentals of Light and Lasers course can be adapted to provide faculty development in photonics. This is typically a twelve-week course with a laboratory capstone experience that includes best practices in teaching photonics.

Dual Credit: Career pathways reach back into high schools. One of their purposes is to enable students to begin exploration of their career options. This course can be adapted as a dual credit offering (students receive both high school and college credit) and become part of the curriculum supporting photonics career pathways. Because of its online format, high schools do not have to find qualified instructors and, because of the capstone experience, do not need to purchase expensive laboratory equipment. Students who take the course are exposed to the technology that underlies photonics and, through the capstone experience, get to visit a college campus and hear about career opportunities. Both these assets have positive impacts on student recruitment and the flow of students through the photonics pipeline.
3. COURSE PRESENTATION: A SUMMARY OF INDIAN HILLS COMMUNITY COLLEGE’S TECHNICIAN TRAINING OFFERING TO MOUND LASER AND PHOTONICS CENTER

3.1 Course Customization

Before OP-TEC’s *Fundamentals of Light and Lasers* could be taught at Indian Hills Community College (IHCC), it had to be customized to fit the IHCC online course format. Of the several available online formats, IHCC uses the format known as ANGEL. The OP-TEC course also required minor adjustments in content to make it an acceptable substitute for the IHCC’s LEO 101–Photonics Concepts (four semester credit hours). Once these alterations had been completed, the course was entered into the IHCC course schedule to be offered during the twelve-week spring 2009 term.

3.2 MLPC Students

Mound Laser and Photonics Center (MLPC) enrolled eight students in the course. The students were MLPC technicians, engineers, and research scientists with a broad range of credentials, from associate degrees to bachelor’s degrees in mechanical engineering, education, material science, and engineering physics. One student held a Ph.D. in physics (see the list below). The students were highly motivated and very interested in learning about lasers and photonics so they would have a better understanding of the photonics equipment they were responsible for working with. Each student had the option of taking the course for college credit (four semester hours) or completing the course as an audit with no grade assigned. All selected the audit option.

3.3 Positions and Education of MLPC Participants

<table>
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<tr>
<td>Project Manager</td>
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<tr>
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<td>Bachelor’s in Materials Science and Engineering</td>
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3.4 Plan for Delivery of the Course

The course delivery plan was to have students participate online in the theory portion of the course with weekly interactions and then to complete the laboratory capstone experience on-site at MLPC near the end of the course. The plan called for the IHCC instructor to travel to MLPC to work with students for one to three days as needed to complete the laboratory exercises. The instructor was tasked with assembling laboratory kits and shipping them to MLPC or taking them with him. OP-TEC provided every student with a copy of the *Fundamentals of Light and Lasers* textbook.

3.5 Course Delivery

The course began on Monday, February 23, 2009, with a GoToMeeting.com activity arranged through OP-TEC. (GoToMeeting.com is an online meeting service that allows computer screen sharing along with live, interactive audio and video delivery to all participating locations.) The participating MLPC employees (students), Dr. John Souders of OP-TEC, and Bill Gray and Greg Kepner of IHCC all participated in the kick-off activity. Instructor Bill Gray used a webcam while introducing himself and discussing the course content and online delivery system. Bill explained how the online course worked and gave instructions on how to access the course content and submit assignments. Students were able to ask questions as Bill
demonstrated the features of the online course system. With all questions answered and the demonstration complete, the students were ready to begin the course.

The course was composed of eleven lessons or units of instruction. Each lesson was composed of pre-quiz focus questions, mini-lectures, discussion forums, assignments, quizzes, and a unit exam. Each lesson was open and available to students online for a period of one week. All of the students’ written work was submitted online through the course system. Multiple-choice or true-false quizzes and exams were automatically graded by the system and feedback was automatically provided online to the students. Short-answer questions and other essay-type answers were graded manually by the instructor, who provided feedback online.

The students read the textbook and worked through the online course content weekly. Students whose schedules allowed met for one hour each week during work time to discuss the course content and how it related to their work at MLPC. All of the student-instructor communication about course content took place online. Group questions and comments were emailed to the instructor through the online course feature. The instructor responded to each inquiry or comment as needed.

Students read the applicable textbook chapters weekly and then typically spent two to three hours online completing the questions, assignments, quizzes, and exams. Online PowerPoint slideshows with video voiceovers covered the course content for each lesson. Occasional technical difficulties in synchronizing the video and voice occurred, but this problem has been corrected.

3.6 Laboratory Kits
For the lab kits, instructor Bill Gray selected components and equipment that would be mobile and fit easily into 6” x 17” x 23” plastic storage containers. Each kit included an optical breadboard, a diode laser, four lenses, four mounted mirrors, translation stages, a variety of optical mounting hardware, a diffraction grating, colored filters, slit apertures, concave mirrors, convex mirrors, a power meter, an LED flashlight, a protractor, a tape measure, a ruler, paper, and a pencil. Relatively inexpensive equipment was selected from a variety of vendors that could be transported easily and could be effectively and conveniently used in most classrooms or laboratories. (A list of laboratory equipment is provided as an appendix.) The Fundamentals of Light and Lasers text sometimes calls for very precise measurements that require more sophisticated equipment, but IHCC’s kits were adequate to accomplish the main laboratory objectives.

3.7 Capstone Laboratory Activity
The IHCC instructor traveled to MLPC on the weekend of May 1–2, 2009, and brought the laboratory kits with him. The students were well prepared to perform the laboratory exercises. Each student had read through the laboratory exercises in advance and had a good understanding of their goals and objectives. Working in pairs, the students began setting up laboratory equipment early on Friday morning. Because the students had excellent and diverse educational backgrounds plus relevant work experience, they were able to work through the laboratory exercises very efficiently and had completed their work by late Friday afternoon. The instructor worked with the students to ensure that the labs were correctly set up and that the appropriate techniques and safety precautions were followed. He answered questions and discussed laboratory data after the laboratory activities were completed. Due to the advanced student preparation and the efficiency of the students’ work on the laboratory exercises, the second day of the laboratory was not needed.

3.8 Student Feedback
The overall student response for the class was very positive. Students felt that they had learned valuable and practical skills and knowledge and that their time was well spent. Considering the excellent educational backgrounds and industry experience of the students, this was good news. In an e-mail to the IHCC instructor, MLPC R&D Research Specialist Sarah Bertke wrote, “Before we started, we thought we knew
everything there was to know about lasers but we were wrong. We are very happy with what we learned in your class.”

Ms. Bertke also had this to say:

Several months ago there were a few samples at MLPC that we noticed exhibited diffraction-grating-like characteristics after we scanned a laser across their surfaces. When you move the sample around, the light would reflect in different colors depending on the angle at which you looked at the surface. We had since set these samples aside.

When Bill came to our company in May with the LEO 101 lab kits, we were performing Lab1-5B, and one of our employees remembered our samples with the mysterious diffraction characteristics and brought one of the samples down to the conference room where we were performing the lab. We shined one of the lasers in Bill’s lab kits onto our sample and sure enough, a diffraction pattern appeared on the wall. So, we repeated Lab 1-5B with our sample, except instead of calculating the laser’s wavelength (which we already knew), we used the same equation to instead calculate the diffraction grating spacing, “a,” of our sample. We intend to repeat this procedure on our other samples with this characteristic to see if we can find any patterns between the spacings, “a,” and the laser parameters which were used to create them.

It was so poetic that a professor of a lasers course showed us, employees at a lasers company, how to use this laser-induced phenomenon to solve a dilemma that was caused by other lasers. You learn something new every day!

4. FUTURE PLANS

Based on the success of this pilot course offering and the need for incumbent worker training in the photonics industry, IHCC plans to continue to offer LEO 101 Photonics Concepts online. IHCC will also continue to utilize OP-TEC’s Fundamentals of Light and Lasers textbook in the course.

OP-TEC will continue to expand the use of this course in training incumbent workers and will make the course available to any educational institution that has the faculty and laboratory equipment necessary to deliver it. OP-TEC will also work with educational institutions in helping them train faculty, identify equipment, build advisory boards, develop curriculum, and supply instructional materials. This course is one of several means OP-TEC uses to accomplish its mission of increasing the supply of well-educated photonics technicians by building and strengthening the capacity and quality of photonics education in U.S. two-year colleges. To learn of other means OP-TEC uses in accomplishing this mission, visit www.op-tec.org.

REFERENCES


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<td>AX73961</td>
<td>1&quot; round glass polarizers</td>
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<td>Thorlabs</td>
</tr>
<tr>
<td>1</td>
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</tr>
<tr>
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<td>Primary/Secondary Color sheets</td>
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<td>LED-100</td>
<td>X-LIGHT</td>
<td>Educational Innovations</td>
</tr>
<tr>
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<td>Metric ruler</td>
<td>Arbor Scientific</td>
</tr>
<tr>
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<td>P2-7145</td>
<td>2&quot; diam, Concave/convex mirrors 6 mirrors</td>
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<tr>
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<tr>
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<td>P2-7680</td>
<td>Light source, multi colored flash light</td>
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</tr>
<tr>
<td>1</td>
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<td>3030979</td>
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<td>Edmund Scientifics</td>
</tr>
<tr>
<td>1</td>
<td>3081424</td>
<td>Rainbow window holographic prism</td>
<td>Edmund Scientifics</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>Candle</td>
<td>Walmart</td>
</tr>
</tbody>
</table>
Efforts of the National Center for Optics and Photonics Education (OP-TEC) to prepare the technician workforce for photonics industries

Dan Hull
Executive Director, OP-TEC

John Souders
Associate Director, OP-TEC

ABSTRACT

The mission of the National Center for Optics and Photonics Education (OP-TEC) is to create a secondary-to-postsecondary “pipeline” of highly qualified and strongly motivated students and to empower high schools and community colleges to meet the urgent need for technicians in optics and photonics. This paper describes the methodologies and processes OP-TEC has developed to carry out that mission. A recently completed assessment of the need for optics and photonics technicians in American industry concluded that U.S. colleges lack the capacity to produce an adequate supply. OP-TEC’s challenge is to close the gap between the supply of and demand for photonics technicians. To help increase college capacity, OP-TEC has developed and implemented a recruitment process for initiating photonics programs in U.S. colleges. This paper describes the recruitment process and its results, along with the relevant support services provided by OP-TEC. In support of its mission, OP-TEC has developed curriculum and instructional materials that prepare students for the photonics workforce. To help ensure that completers of U.S. photonics programs are workforce ready, OP-TEC uses a skill-standards-based process for developing curriculum and instructional materials. This paper reviews the foundational skill standards and explains the process for integrating them into the materials development process. The curriculum and instructional materials that result from this process are also described. 1

KEYWORDS

Lasers, optics, OP-TEC, fiber optics, technical programs, photonics, National Science Foundation/ATE

1. MISSION/ORGANIZATION

The National Center for Optics and Photonics Education (OP-TEC) is a National Science Foundation (NSF) Advanced Technological Education (ATE) National Center of Excellence. OP-TEC’s mission is to create a secondary-to-postsecondary “pipeline” of highly qualified and strongly motivated students and to empower high schools and community colleges to meet the urgent need for technicians in optics and photonics. Under its current grant from NSF, OP-TEC has been awarded five million dollars over a period of four years. OP-TEC has focused its energy primarily on building the capacity of community and technical colleges to use their existing program infrastructures to train and educate photonics technicians that will meet industry’s current and future need for these specialized workers.

OP-TEC is a consortium of colleges whose efforts are coordinated and directed by its PI, Dan Hull, and four Co-PI’s: Dr. Fred Seeber, Dr. Chrys Panayiotou, Dr. Larry Grulich, and Dr. M.J. Soileau. The consortium of partner colleges comprises Camden County College, Indian River State College, Indiana University of Pennsylvania, Indian Hills Community College, Tri-County Technical College, Irvine Valley College, Central Carolina Community College, and Texas State Technical College.
2. SUPPLY AND DEMAND

A key step in the fulfillment of OP-TEC’s mission is to determine (1) the demand, now and in the future, for photonics technicians and (2) the capacity of community and technical colleges to meet that demand. In 2008, OP-TEC commissioned two studies to determine the relevant supply and demand parameters.

2.1. Supply

The purpose of the first study was to determine the capacity of U.S. colleges to produce photonics technicians. To collect this information, the study used both Internet searches and telephone surveys. The Internet searches identified postsecondary institutions in the U.S. that offer photonics instruction (from single courses to full programs) that can contribute to the training and education of photonics technicians. The telephone surveys confirmed that the identified colleges still offer this instruction and determined the number of students enrolled and the number of program completers. All the institutions that contributed to the final results of the survey indicated that they have active photonics instructional offerings (at least one course in photonics, optics, and/or laser technology) and that their former students are employed in the optics/photonics industry as a result of their participation in that instruction. The results of the survey indicated that 600–700 students are enrolled in programs that are capable of leading to technician-level employment in the photonics industry. However, only 250–300 are completing their programs each year and are available to fill industry positions.

2.2. Demand

To determine the demand side, OP-TEC commissioned the University of North Texas Survey Research Center to contact by telephone a large random sample of industrial companies throughout the U.S. that perform R&D with optics, lasers, and photonics technology or are original equipment manufacturers (OEM) for R&D companies. The goal was to determine how many photonics technicians the companies employ, the additional number they will need in 2009, and the number they will need five years from now. Using the Laurins Publishing Company Photonics Directory (2008) and OP-TEC databases, the researchers identified a total of 3989 U.S. photonics companies. The researchers contacted over 2500 of those companies before generating a representative sample of 663 companies, of which 300 employ photonics technicians. Besides employment data, the survey collected information on the educational levels of the photonics technicians currently employed; the employers’ preferences with respect to the levels of education those technicians should have; and the types of jobs photonics employers are seeking to fill. After performing a statistical analysis of the survey, the researchers issued a final report. The results showed that over 19,000 photonics technicians are employed in the U.S., that over 2100 additional photonics technicians will be needed next year, and that approximately 5900 will be needed in five years (2014).

When the supply and demand results are compared, it is clear that for the U.S. to meet its demand for these workers, community and technical colleges must substantially increase the numbers of their graduates and program completers. For example, let’s assume that in 2010 U.S colleges can add 300 new technicians to the pool of photonics workers. This will fall far short of the 2100 workers needed. Helping to close the gap between supply and demand is one of OP-TEC’s primary challenges. To meet this challenge it must empower colleges to increase enrollments in their existing photonics and photonics-related programs and to implement new programs.

In addition to the challenge of increasing college capacity, OP-TEC must work to ensure that new technicians possess the skills and knowledge necessary for success in the photonics industry. To meet this second challenge, OP-TEC must provide relevant and effective curriculum and instructional materials. The remainder of this paper addresses these two challenges and outlines OP-TEC’s response to them.
3. INCREASING THE SUPPLY

Increasing the supply of photonics technicians is directly related to expansion of the base of colleges that offer photonics education and training. Though simple in concept, expanding this base requires a systematic process for enabling colleges to implement photonics programs. OP-TEC has developed and is implementing an aggressive process for recruiting new colleges and assisting them in adding photonics content to their existing curricula. This process (outlined below) consists of five phases, as illustrated in Figure 1.

**Phase 1: Awareness.** The main purpose of this phase is to make two-year colleges (TYC), both community and technical colleges, and secondary school systems (SSS) aware of the existence of OP-TEC and its mission. In this phase, OP-TEC works to establish itself as the point-of-contact for all matters related to the education and training of photonics technicians. OP-TEC works to help the TYCs and SSSs recognize that photonics is a high-demand, high-pay technical field that is still emerging and has great growth potential.

<table>
<thead>
<tr>
<th>Phases</th>
<th>Actions</th>
<th>Allocation of Center Effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Awareness</td>
<td>• Understand needs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• OP-TEC known</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• OP-TEC’s services available</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Develop website</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Establish relationships between OP-TEC and professional societies</td>
<td>Center staff: 85%</td>
</tr>
<tr>
<td></td>
<td>• Publish articles and make presentations</td>
<td>Partner colleges: 15%</td>
</tr>
<tr>
<td></td>
<td>• Encourage faculty and staff to attend photonics education workshop</td>
<td></td>
</tr>
<tr>
<td>2. Institutional commitment</td>
<td>• Faculty and staff attend photonics education workshop</td>
<td>Center staff: 75%</td>
</tr>
<tr>
<td></td>
<td>• Follow-up with workshop attendees</td>
<td>Partner colleges: 25%</td>
</tr>
<tr>
<td></td>
<td>• Establish secondary/postsecondary partnerships</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• OP-TEC assistance requested</td>
<td></td>
</tr>
<tr>
<td>3. Assessment</td>
<td>• College/partnership determines best photonics option</td>
<td>Center staff: 30%</td>
</tr>
<tr>
<td></td>
<td>• Select photonics-enhanced technology, based on local needs</td>
<td>Partner colleges: 70%</td>
</tr>
<tr>
<td></td>
<td>• Form or expand employer advisory committee</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Obtain employer support and advice</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Design and develop curriculum</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Design labs and identify equipment</td>
<td></td>
</tr>
<tr>
<td>4. Preparation</td>
<td>• Obtain program approval and changes</td>
<td>Center staff: 15%</td>
</tr>
<tr>
<td></td>
<td>• Develop labs</td>
<td>Partner colleges: 85%</td>
</tr>
<tr>
<td></td>
<td>• Obtain equipment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Recruit students</td>
<td></td>
</tr>
<tr>
<td>5. Implementation</td>
<td>• Conduct program</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Obtain student materials</td>
<td>Center staff: 60%</td>
</tr>
<tr>
<td></td>
<td>• Teach courses</td>
<td>Partner colleges: 40%</td>
</tr>
<tr>
<td></td>
<td>• Collect data</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Evaluate and revise program</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1 OP-TEC college recruitment process

**Phase 2: Institutional commitment.** This phase has two main objectives. One is getting TYCs and SSSs to commit to an assessment of their need for photonics programs or, if the need has already been established, commit to program implementation. The other objective is to assist institutions in developing secondary/postsecondary partnerships on which to build 4+2 career pathways.
Phase 3: Assessment. The main purpose of this phase is to determine the best way to implement a photonics program in a given TYC. In this phase OP-TEC works closely with the educational organization to provide survey instruments for assessing need within its service area, to provide a list (through professional societies) of potential photonics employers in its service area, and to help the organization establish an advisory board or add members to an existing board that can provide guidance in the photonics area. The primary outcomes of this phase are to:

1. Determine the educational organization’s need for a photonics program and the type of photonics program required to meet that need.
2. Establish an advisory capacity for ensuring the proper implementation of the program and its continuous updating to meet future needs.
3. Design and develop curriculum and laboratories.
4. Identify required laboratory equipment.

To help meet these outcomes, OP-TEC provides program planning guides (PPG) that detail the requirements for adding photonics programs. The guides are designed to enable college decision makers to quickly grasp the implications of adding photonics to their program offerings. Figure 2 provides more detail about the PPGs.

<table>
<thead>
<tr>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photonics as a converging/enabling technology</td>
</tr>
<tr>
<td>Applicable skill standards</td>
</tr>
<tr>
<td>Curriculum, courses, materials</td>
</tr>
<tr>
<td>Labs and equipment</td>
</tr>
<tr>
<td>Faculty requirements and training</td>
</tr>
<tr>
<td>Building the high school pipeline</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Programs supported by PPGs completed as of May 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomedicine</td>
</tr>
<tr>
<td>Defense and Homeland Security</td>
</tr>
<tr>
<td>Manufacturing</td>
</tr>
<tr>
<td>Optoelectronics (semiconductors, MEMS, and nanotechnology)</td>
</tr>
<tr>
<td>Telecommunication</td>
</tr>
</tbody>
</table>

Fig. 2 Program planning guide content and supported programs

Phase 4: Preparation. The main purpose of this phase is to help the educational organization build the infrastructure necessary to implement the program, as outlined in phase 3 (assessment). OP-TEC provides a professional development course designed to prepare faculty to present photonics topics. OP-TEC also works with faculty to locate and procure the laboratory equipment identified in phase 3 (assessment). During this phase, OP-TEC helps the educational organization prepare to implement a photonics program by assisting the organization in gaining state and/or local program approval, developing labs, purchasing equipment, training instructors, and recruiting students.

Phase 5: Implementation. In this phase, OP-TEC and its partner colleges act as advisors to ensure the successful launch of new photonics programs. OP-TEC helps educational organizations assess the effectiveness of their programs by helping them develop means for surveying their employer bases and making program adjustments as dictated by the results of the surveys.
The process described in the preceding paragraphs is designed to achieve OP-TEC’s goal of building capacity at U.S. colleges to educate and train photonics workers. The process is also designed to amplify the assets available at OP-TEC and provide a sustainable means of expanding photonics education. The success of the process will depend heavily on close collaboration between OP-TEC and educational institutions that implement new photonics programs.

Over 200 colleges are involved in the OP-TEC recruitment process. Seventy-one are beyond phase 1 (awareness) and four have reached phase 5 (implementation). As it works with the colleges, OP-TEC leverages its resources by assigning mentors from its partner colleges. The extent of this mentorship is indicated in the right column of Figure 1 as the percentage of the overall effort contributed by the partner colleges in each of the five phases. For instance, in phase 1 (awareness) little mentorship is needed, but in phases 3 (assessment) and 4 (preparation) the extent of the mentorship needed is substantial.

3.1. Empowerment services provided by OP-TEC

In carrying out the process outlined in the previous section, OP-TEC offers several services designed to empower colleges to advance through the process. These services can be categorized in the following five broad areas:

1. Information about photonics technology and technician careers
   - Provide an overview of optics and photonics technology
   - Identify technical areas in which photonics is an enabling technology
   - Maintain up-to-date needs projections for photonics technicians
   - Post job opportunities for photonics technicians
   - Maintain a website for information exchange by members of the photonics community

2. Technical assistance in program feasibility and planning
   - Identify local employers that are involved in the photonics industry
   - Determine specific areas of concentration required by local photonics employers
   - Assist secondary and postsecondary institutions in infusing photonics into existing technical curricula

3. Technical assistance in curriculum design and development
   - Participate in organizational meetings of photonics advisory committees
   - Adapt the *National Photonics Skill Standards for Technicians* to local and/or regional needs
   - Design and develop career pathways in photonics to meet local industry requirements
   - Assist educational institutions in selecting the most effective teaching models

4. Technical assistance in designing laboratories
   - Provide guidance in configuring laboratories
   - Recommend equipment and suppliers
   - Provide cost estimates
   - Assist in selecting laboratory experiments

5. Training
   - Provide online training in the teaching of postsecondary optics and photonics principles
   - Provide online training to enhance the understanding and implementation of photonics curricula
   - Provide professional development opportunities for high school teachers to enhance their skills in presenting photonics topics
Through these services, OP-TEC empowers colleges to design photonics programs that best meet the needs of the industries in their service areas.

4. CURRICULUM AND INSTRUCTIONAL MATERIALS DEVELOPMENT

During the college recruitment process, a strategic decision must be made as to what audience(s) the college will serve and what programs should be put in place to serve them. These decisions, which are typically made by advisory committees composed of representatives of industries in the colleges’ service areas, usually focus on three options. (1) If a college’s service area is heavily represented by photonics R&D or laser OEMs, the college should consider implementing an AAS program in photonics. (2) If the college’s service area is heavily represented by companies that use photonics as an enabling technology, the college should consider infusing photonics into the technical programs from which these employers hire their technicians. (3) A third option is the advanced certificate program, a non-degree-granting program designed to upgrade and/or update the skills of photonics technicians already employed.

OP-TEC has developed curriculum for all three options. The AAS degree (Figure 3) is a benchmark 4+2 articulated program that allows effective “pipeline building” from high schools to colleges. The photonics courses listed in the postsecondary portion are supported by OP-TEC’s Laser/Electro-Optics Technology Series course materials.

<table>
<thead>
<tr>
<th>9th grade</th>
<th>10th grade</th>
<th>11th grade</th>
<th>12th grade</th>
<th>13th year</th>
<th>14th year</th>
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<tbody>
<tr>
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<td>Algebra 1</td>
<td>Geometry</td>
<td>Algebra 2</td>
<td>Precalculus</td>
<td>Calculus or other adv math</td>
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<tr>
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<td>Biology/Life Sciences</td>
<td>Chemistry</td>
<td>Physics</td>
<td>College Physics</td>
<td>Elective</td>
</tr>
<tr>
<td>English</td>
<td>English 1</td>
<td>English 2</td>
<td>English 3</td>
<td>English 4</td>
<td>Tech Comm/ Writing</td>
</tr>
<tr>
<td>Technology</td>
<td>Career Mgt Success</td>
<td>Computer Apps</td>
<td>DC/AC Electricity</td>
<td>Digital Electronics</td>
<td>Elective</td>
</tr>
<tr>
<td>Technology</td>
<td>Intro to Photonics</td>
<td>Intro to Lasers</td>
<td>Light Sources and Wave Optics</td>
<td>Laser Electronics</td>
<td>Laser Apps</td>
</tr>
<tr>
<td>Technology</td>
<td>Geometric Optics</td>
<td>Lasers/ Electro-Optic (EO) Components</td>
<td>Lasers/ EO Devices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology</td>
<td>Laser Technology</td>
<td>Lasers/EO Measurements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social Sciences, Humanities, History, Government, Health</td>
<td>Humanities, Social Sciences</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3 AAS benchmark photonics 4+2 curriculum

The advanced certificate (Figure 4) provides a means for already employed technicians to learn about photonics and its application in the technicians’ areas of specialization. Courses that are to be taught along with the photonics course in advanced certificate programs will vary according to local industry needs. Electronics was chosen for this example, since it tends to be one of the most rapidly changing technologies in most technical fields and thus requires constant update training.
### Course 1: Fundamentals of Light and Lasers
- Nature and Properties of Light
- Optical Handling and Positioning
- Light Sources and Laser Safety
- Basic Geometrical Optics
- Basic Physical Optics
- Principles of Lasers

### Course 2: Elements of Photonics
- Operational Characteristics of Lasers
- Specific Laser Types
- Optical Detectors and Human Vision

### PET Modules
- 4 in Manufacturing
- 3 in Biomedical
- 3 in Homeland Security
- 3 in Environmental Monitoring
- 2 in Optoelectronics

### Manufacturing
- Laser Welding and Surface Treatment
- Laser Material Removal: Drilling, Cutting, and Marking

### Homeland Security
- Lasers in Forensic Science and Homeland Security
- Infrared Systems for Homeland Security
- Imaging System Performance for Homeland Security Applications

### Environmental Monitoring
- Basics of Spectroscopy
- Spectroscopy and Remote Sensing
- Spectroscopy and Pollution Monitoring

### Biomedicine
- Lasers in Medicine and Surgery
- Diagnostic Applications of Lasers
- Therapeutic Applications of Lasers

### Optoelectronics
- Photonics in Nanotechnology
- Photonics Principles in Photovoltaic Cell Technology

A typical infusion curriculum is shown in Figure 7. This curriculum treats photonics as an enabling technology in manufacturing. Once again, the two courses in OP-TEC’s *Optics and Photonics Series* are embedded, thus
enabling students to learn the role of photonics in materials processing. The manufacturing modules listed are the four PET manufacturing modules listed in Figure 6.

<table>
<thead>
<tr>
<th>Grade</th>
<th>English</th>
<th>Math</th>
<th>Science</th>
<th>Technology</th>
<th>Technology</th>
<th>Other</th>
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</thead>
<tbody>
<tr>
<td>13</td>
<td>English Composition</td>
<td>College Alg &amp; Trig</td>
<td>Electronic Control Devices</td>
<td>Computer Apps Mfg</td>
<td>Principles of Machining 1</td>
<td>Eng Design</td>
</tr>
<tr>
<td>Semester 1</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Hum Elect</td>
<td>Precalculus or Math Models</td>
<td>Gen Phy 1</td>
<td>Advanced CAD</td>
<td>Materials and Mfg Processes</td>
<td>Hum Elect</td>
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<tr>
<td>Semester 2</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Tech Writing</td>
<td>Fundamentals of Light and Lasers</td>
<td>Electromech Devices</td>
<td>Statistical Process &amp; QC</td>
<td></td>
<td>Econ</td>
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<tr>
<td>Semester 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Tech Elect</td>
<td>Elements of Photonics and Mfg Modules</td>
<td>Metrology and QC</td>
<td>Automated Mfg Systems</td>
<td></td>
<td>Tech Elect</td>
</tr>
<tr>
<td>Semester 2</td>
<td></td>
<td></td>
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</tbody>
</table>

Fig. 7 Infusion curriculum for manufacturing

4.1 Instructional materials development and updating
Curriculum provides a pathway that enables students to achieve academic goals in predefined structures that enhance their learning. However, even if a curriculum meets students’ goals and helps them to learn, it is not valuable unless it uses instructional materials that are relevant to the workplace and meet the needs of employers.

The process used to develop OP-TEC’s instructional materials treats employer needs as foundational. Figure 8 depicts the development process as a pyramid.

[Diagram of instructional materials development process]

Fig. 8 OP-TEC instructional materials development process
At the base of the pyramid are industry-validated skill standards. Skill standards are employer specifications for the knowledge and skills required for success in specified technical areas. OP-TEC developed *The National Photonics Skill Standards for Technicians* in 1995. Because photonics applications have undergone rapid change in the last decade, the standards have been revised twice; the third edition was completed in 2008. The revision efforts were led by photonics industry representatives and reflect their inputs as to the current needs of the U.S. photonics industry. Updates and revisions of the skill standards are critical in maintaining the currency and relevance of the instructional materials based on the standards. All OP-TEC materials referenced in this paper are based on these standards and have been or are being updated to reflect changes made in the third edition. Figure 9 provides more detail on the structure, organization, and components of the standards. Copies can be downloaded from the OP-TEC website (www.op-tec.org).

### Photonics Skill Standards
- Specifies the knowledge and skill requirements for a variety of technicians in the photonics industry
- Provides the foundation for AAS curriculum and materials development in photonics technology
- Can be adapted by local employers for curriculum design at a particular college
- Provides benchmark (4+2) curriculum framework, infusion curriculum, and advanced certificate
- Identifies six specialty areas for photonics technicians

### Organization of the Standards
- Six specialty areas
- Critical work functions for each specialty
- Tasks
- Skills
  - Employability and
  - Technical

### Critical Work Functions
General areas of responsibility or functions that are required of a technician working in a specialty area
*Example:* Assemble various fiber-optic components and modules into subsystems and understand their function

### Tasks
Observable and measurable activities that technicians perform to accomplish a critical work function
*Example:* Integrate fiber-optic components and modules into specified systems

### Technical and Employability Skills
Basic abilities that are necessary for a technician to perform a task
*Examples:*
- Technical: Test and verify initial source output and launch angles at source/fiber interface
- Employability: Navigate the Internet to gather task-related information

**Fig. 9 Details on the structure, organization, and components of OP-TEC’s *National Photonics Skill Standards for Technicians***

### 5. SUMMARY

This paper has presented two of the major challenges facing OP-TEC: (1) increasing the capacity of U.S. colleges to produce photonics technicians and (2) developing and maintaining relevant, up-to-date curriculum and instructional materials. Through OP-TEC’s partner colleges and the generous support of the National Science Foundation, these challenges are being met. OP-TEC has developed processes for assisting colleges in implementing photonics programs and providing curriculum and instructional materials to ensure the work-readiness of program completers. These processes and instructional products are resources that can be used internationally in building the strength of the photonics technician workforce. We invite our international colleagues to review and implement these processes and give us feedback on their effectiveness. It is our hope that through this feedback we can make even greater strides in filling industry’s need for highly skilled technicians.
REFERENCES

[1] *Note on organization:* The figures that appear in this paper are also used in the ETOP 2009 presentation of the same title. It is the authors’ intent that by coordinating the paper with the presentation, they will better enable conference attendees to understand the topic and its implications.


The Laser Institute of Technology for Education and Research
At Camden County College
How it has Changed and Evolved after 20 years

Fred P. Seeber
Professor of Physics/Photonics
Co-PI OP-TEC
Camden County College
Blackwood, NJ
USA

ABSTRACT

The Laser Institute of Technology for Education and Research (LITER), nationally and internationally recognized in the field of Photonics, is a state of the art facility built in 1989 on the campus of Camden County College, Blackwood, NJ. This building consists of six high power laser labs, five low power laser labs and four fiber-optic laboratories. It also contains classrooms and research labs and the facility houses over $5,000,000 in equipment. This paper will discuss the evolution of this facility in regards to enrollment in its photonics programs, funding for new equipment purchases and maintaining and updating the facility in laser safety requirements as required by the ANSI Z-136.5 Standard for Educational Institutions. The paper will also discuss how OP-TEC (The National Center for Optics and Photonics Education) has helped to keep this Laser Institute at the cutting edge of photonics education.

The Laser Electro-Optics Technology program at Camden County College, Blackwood, New Jersey was an early pioneer in Laser Technician Education.
It was founded in 1976 with Dr. Fred P. Seeber as its coordinator. At that time, it was only the fourth such program in the United States. The program started small with limited equipment and space. The classes and labs occupied just a few rooms in one of the college's buildings. After years of success and with the explosive growth of the Photonics industry throughout the 1980's, the faculty saw the need for expansion of the programs and the facilities. In 1984 the college offered the country's first community college program in Fiber Optics. In 1989, with funding from the National Science foundation and New Jersey Higher Education, the Laser Institute of Technology and Educational Research (LITER) broke ground and two year's later the building was open to students and faculty. This facility houses cutting edge equipment in lasers, optics, and telecommunication, including optical time domain reflectometers, optical spectrum analyzers, XFP transreceivers, EZ raman spectrophotometers, farfield beam profilers, and automated interferometers, among others. LITER constantly updates its equipment and inventory through both state and federal grants such as New Jersey workforce grants and National Science Foundation equipment and program grants, along with private grants from industries that support the college’s program in photonics. Today Laser Electro-Optics and Fiber-Optic Technology programs, now Photonics Technology, serve approximately 80 students each year and are premier curricula of their kind in the nation. Graduates of the Laser Electro-Optics curriculum and the Fiber Optics option are in great demand nationwide and receive excellent salaries as a result of their intensive training in these areas. However, student enrollment has fluctuated from a high of 120 students per year to a low of about 60 students per year stabilizing at about 80 students.

The LITER building is a unique facility. Of the more than 1100 community colleges in the United States CCC is the only one having a building that is solely dedicated to Photonics education and research. In New Jersey only Princeton University and Camden County College have such facilities. The building houses 15 laboratories with industry grade equipment, study areas, a traditional classroom, and a large lecture hall/classroom. The building is designed with safety and convenience in mind. The laboratories are separated into three wings: Low-Power Wing, High-Power, and Fiber-Optic Wing. The Low-Power Wing is designed for students in courses like; Intro to Photonics, Optics and Optics Measurements etc. that work with low power lasers and optical equipment. The High-Power Wing is equipped with all types of medical and industrial high-power lasers and is generally intended for second year students with a strong Photonics safety background.
The Fiber-Optic Wing houses all fiber optic and communications equipment for both first- and second-year courses. Over the past several years the fiber optic wing has received a major upgrade including over 1 million dollars worth of state-of-the-art equipment through the New Jersey High-Tech Workforce Grant and industry equipment donations. Two new laboratories have been added specializing in optical communication system testing.

The Photonics program at Camden County College has two tracts. One being the Laser/Electro Optic Technology option with 6 laser specialty courses, 4 electronics courses, 2 physics courses and 3 math courses. This option is also divided into a non-calculus and calculus path depending on the student’s high school curriculum. The second tract is the fiber/optics option with 4 laser specialty courses, 3 fiber/optics courses, 3 electronics courses and with both options 2 computer courses. Again the students in the Fiber/Optics Option can take a calculus path if their background permits.

Various certificates in Fiber/Optics can be earned by students currently working in the field. Several on-line hybrid Photonics courses are also offered by Camden County College. The college also has several in-service courses tailored to local industry. The Photonics program at Camden County College is the only full Associate degree program in the State of New Jersey. Since the ATE/NSF OP-TEC Center started Camden County College as a partner institution has developed 2 new on-line hybrid Photonics courses with in person capstone laboratories. These courses not only benefit students at CCC but students throughout the country. This has also contributed to higher enrollment in the program. Several meetings and workshops have been held at CCC to promote the goals of OP-TEC. Various educational materials have been authored by the Photonics faculty at CCC that is now used for training. Below are the Laser Electro-Optic and Fiber-Optic technology options to the Photonics program:

## Laser/Electro-Optic Technology

**Degree:** Associate in Applied Science  
**College Code:** PHT.AAS

<table>
<thead>
<tr>
<th>Code</th>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>LFO-101</td>
<td>Introduction to Photonics &amp; Photonic Safety</td>
<td>4</td>
</tr>
<tr>
<td>MTH-125</td>
<td>College Algebra &amp; Trigonometry <strong>or</strong></td>
<td></td>
</tr>
<tr>
<td>MTH-140</td>
<td>Calculus II</td>
<td>4</td>
</tr>
<tr>
<td>ENG-101</td>
<td>English Composition I</td>
<td>3</td>
</tr>
<tr>
<td>PHY-101</td>
<td>Physics I <strong>or</strong></td>
<td></td>
</tr>
</tbody>
</table>
PHY-201  Physics III1        4
............  Humanities Elective        3

Second Semester
EET-101  Electrical/Electronic Principles        4
MTH-132  Statistics for Technology or
         MTH-150  Calculus II1        4
ENG-102  English Composition II        3
LFO-201  Photonics Materials        3
PHY-102  Physics II or
         PHY-202  Physics IV1        4

Second Year/Fir s t Semester
LFO-211  Photonic-Optic Principles & Components        4
LFO-212  Pulsed & CW Lasers        3
LFO-241  Introduction to Fiber Optics        3
EET-211  Electronics I        3
LFO-231  Photonics Measurements        3
HPE......  Health & Exercise Science Elective        1

Second Semester
LFO-292  Photonics Seminar        1
LFO-221  Photonic & Electro-Optic Devices        3
LFO-251  Laser Electronics or
EET-212  Electronics II        3
.............  Social Science Elective        3
.............  Computer Programming Elective        3
HPE......  Health & Exercise Science Elective        1

Total Minimum Credits 67

Fiber Optics Technology Option
Degree:  Associate in Applied Science
College Code:  FBR.AAS

<table>
<thead>
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<tr>
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<td>Introduction to Photonics &amp; Photonic Safety</td>
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<tr>
<td>MTH-125</td>
<td>College Algebra &amp; Trigonometry or MTH-140</td>
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<tr>
<td>ENG-101</td>
<td>English Composition I</td>
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<tr>
<td>PHY-101</td>
<td>Physics I or</td>
<td></td>
</tr>
<tr>
<td>PHY-201</td>
<td>Physics III1</td>
<td>4</td>
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</tbody>
</table>
As part of the evolution of these Photonics programs Camden County College has partnered with OP-TEC [The National Center for Optics and Photonics Education].

2. OP-TEC: The National Center for Optics and Photonics is funded by the National Science Foundation as a ATE center with the stated mission of promoting photonics education and assisting colleges around the country in developing and implementing educational programs that support expansion of this critical new technology. By providing information materials and networking opportunities colleges and universities around the country can take steps in implementing photonics programs that give their students the opportunity to work in this rapidly expanding, high-demand, high-paying field. Because the number of college degrees in Engineering is decreasing, causing fierce competition for the relatively small pool of qualified optics technicians and engineers the need for many more trained individuals in
Photonics is apparent. A recent survey of employers showed that the number of U.S. technical jobs in photonics and photonics-enabled technologies is expected to grow more than 1800 per year on average through 2009, an annual increase of more than 6 percent. OP-TEC will also develop new materials in photonics and create career pathways that will begin at the high school level and extend into post secondary degrees. Examples of these technical areas are: **Telecommunications, manufacturing, medicine, forensics and homeland security.** This consortium of two-year colleges, high schools, universities, national laboratories, industry partners, and professional societies is creating OP-TEC. These participating entities have committed to join forces in creating a secondary-to-postsecondary “pipeline” of highly qualified and strongly motivated students and empowering community colleges to meet the urgent need for technicians in optics and photonics. OP-TEC will serve primarily two types of one and two-year postsecondary programs: (1) those devoted to lasers, optics, and photonics technology; and (2) those devoted to technologies that are enabled by optics and photonics. OP-TEC will provide support through curriculum, instructional materials, assessment, faculty development, recruiting, and support for institutional reform. OP-TEC will serve as a national clearinghouse for teaching materials; encourage more schools and colleges to offer programs, courses, and career information; and help high school teachers and community and technical college faculty members develop programs and labs to teach technical content.

The project has four main goals: (1) Serve as a national resource center for optics and photonics education and training. (2) Create, assemble, align, and distribute coordinated curriculum materials designed to support optics, laser, and photonics education in high schools, two-year colleges, and retraining of adult workers. (3) Support established and new photonics education programs in high schools, community and technical colleges, universities, and professional societies. (4) Provide education and training for administrators, counselors, high school teachers, and community college faculty members to prepare them to (a) design new photonics technology programs that meet their local needs; (b) infuse photonics into programs in photonics-enabled technologies; and (c) teach optics, photonics, and lasers using curriculum materials distributed by OP-TEC.

OP-TEC will also establish a national infrastructure for developing and supporting widely disseminated educational programs in cutting-edge, high demand technologies that require photonics. That infrastructure will encompass both the secondary and postsecondary levels and will involve
collaboration between educators and industry personnel. OP-TEC will help to bridge the gap in the participation of women and minorities in technology and break down geographical socioeconomic barriers, making the study of technology more widely accessible. By providing career pathways in which students begin the pursuit of technical careers early and transition seamlessly into postsecondary programs, OP-TEC will enable students to acquire the skills necessary to compete in the global marketplace. The center’s planners project that by the end of year 4 the number of schools using OP-TEC’s materials and services will be 150+ colleges and 400+ high schools, representing collectively 700+ high school teachers and postsecondary faculty members. The net result will be a significant increase in the pool of qualified technicians in the many technologies that are enabled by photonics. These following services can and will be provided by OP-TEC:

1. Information about Photonics Technology and Technician Careers
   - Provide an overview of optics and photonics technology
   - Identify technical areas where photonics is an enabling technology
   - Maintain updated needs projections for photonics technicians
   - Post job opportunities for photonics technicians
   - Maintain a website for information exchange within the photonics community

2. Technical Assistance in Program Feasibility and Planning
   - Identify local employers that are involved in the photonics industry
   - Determine specific areas of concentration required by local photonics employers
   - Assist secondary and postsecondary institutions infusing photonics into existing technical curricula

3. Technical Assistance in Curriculum Design and Development
   - Participate in “organizational meetings” of photonics advisory committee
   - Adapt the Photonics Skill Standards to meet local/regional needs
   - Design and develop career pathways in photonics to meet local industry requirements
   - Assist educational institutions in selecting the most effective teaching models

4. Technical Assistance in Designing Laboratories
   - Provide guidance in configuring laboratories
• Recommend equipment and suppliers
• Provide cost estimates
• Assist in selecting laboratory experiments

5. Training
• Provide on-line training for teaching postsecondary optics and photonics principles
• Provide on-line training to understand and implement photonics curricula
• Provide professional development opportunities for high school teachers to enhance their skills in presenting photonics topics

This National Center for Optics and Photonics Education will bring together educational institutions, industry, employers and professional societies working for a common goal to produce for our country qualified individuals in the field of Photonics for now and in the future.

1. The American National Standard for Safe Use of Lasers in Educational Institutions Z-136.5[2009] applies the requirements of the latest revision of ANSI Z136.1[2007] to the unique environments associated with educational institutions, including teaching laboratories, classrooms, and lecture halls, science fairs as well as projects, and science museums, when they incorporate lasers into their educational process. It is intended for staff and students who use lasers as part of their academic instruction and development in the university, college, secondary, and primary educational environments. The wavelength range of interest includes the ultraviolet, visible, and infrared regions of the electromagnetic spectrum, specifically the wavelength range from 180nm to 1mm. The purpose of the Z-136.5 standard is to provide reasonable and adequate guidance for the safe use of lasers by evaluating and minimizing hazards associated with laser radiation in educational environments. The hazard evaluation procedure used in this standard is based on the classification (Class 1 through Class 4) of the laser or laser system, which is related to the ability of the laser beam to cause biological damage to the eye or skin during intended use. The beam from Class 1 lasers and laser systems are considered to be non-hazardous; Class 4 lasers and laser systems possess the highest potential hazard. Many lasers and laser systems are used in universities, colleges, secondary, and primary schools for teaching, research, laboratory experiments, demonstrations and projects/science fairs. Often large numbers of students work in laboratory
groups in confined areas, and frequently, different departments share laser systems and installations. It is common to find a variety of lasers of different classes and wavelengths in a single laboratory. Open laser cavities and unrestricted beam paths are also common in these environments. Many of the installations are capable of producing non-beam hazards such as, exposure to chemical, electrical, and optical as well as plasma radiation hazards.

3. In the typical educational institution utilizing lasers, there is often a changing number of students and faculty involved with various experiments that constantly require new configurations of the laser system and laboratory. Care must be taken to ensure that new traffic patterns and new laser set-ups are installed accordingly with safe laser practices.

4. Environments common to educational settings include:
   - Classrooms
   - High school and undergraduate teaching laser laboratories
   - Graduate teaching laser laboratories
   - Science fairs and science projects
   - Auditorium demonstrations
   - Outdoors
   - Entertainment activities

As previously stated one of the main goals of OP-TEC is to serve as a national center for photonics education and training as well as laser safety. The center will be advising hundreds of high schools and 2YR and 4YR colleges around the country about starting and infusing photonics curricula into the programs of their institutions. Guidance will also be provided for existing programs to maintain a level of excellence. This will take several forms including workshops at a college with an existing laser education program and existing laser laboratories, visits to start up educational institutions desiring to use lasers and the associated optical equipment, online hybrid training courses in photonics with in person laser capstone laboratories. An example of a college where workshops and capstone laboratories were held and will be held at Camden County College, Blackwood, NJ. Again the program at the college which started in 1976 has over 500 graduates who are working as engineers, technicians and managers throughout the photonics industry. Many are presidents and CEOs of their own companies.
OP-TEC has adopted the ANSI Z-136.5 Laser Safety Standard for Educational Institutions as its guide for advising participating high schools and colleges concerning things as:

1. Laser classification
2. Laser control measures for various grade levels
3. Personal protective equipment
4. Standard operating procedures
5. Nominal Hazard Zones
6. The importance and role of a Laser Safety Officer (LSO)
7. Suggested laser laboratory layouts

and much more. Many people feel that more accidents take place at educational institutions than any other laser application. For this reason OP-TEC is making an assertive effort to infuse good laser safety practices using the Z-136.5.

The use of lasers by the academic community continues to dramatically escalate. Academia is inundated with a profusion of lasers, each with a diverse function. Traditional departments such as Biology, Chemistry, and Physics have introduced the use of lasers as an essential element of tutelage. Even the more distinctive departments such as Cancer Research, Civil Engineering, Earth and Planetary Sciences, Plasma Fusion, Spectroscopy, and so forth, have incorporated the laser in the composition of their educational mechanism. The literature indicates most ocular accidents happen during alignment procedures, which is an everyday activity for laser educational laboratories. Also, the improper use of laser safety eye wear is a major area of concern for laser safety in educational institutions. More Class 2, 3, and 4 lasers are used in universities, colleges, laser electro-optic technical colleges and high schools than probably any other area: for teaching, research laboratory experiments, and demonstrations. Relatively large numbers of students work in laboratory groups in confined areas, with various lasers of different wavelengths in the same laboratory. Open cavity and beam paths of Class 3B and Class 4 lasers are common in these environments. Many educational institutions do not have laser safety officers or standard operating procedures.
In conclusion, the Laser Electro-Optic Programs at Camden County College in Blackwood, New Jersey started in 1976 with only a HeNe laser and some borrowed equipment from the Physics lab and little more. In the last 33 years the photonics programs and the Liter building (Laser Institute for Education and Research) has become the foremost facility at any two year county college in the northeast and the entire USA. As mentioned previously, the Laser Institute houses over $5,000,000 in equipment which includes lasers of all wavelengths, cutting edge fiber-optic equipment and all types of measurement instrumentation. Camden County College offers degrees and certificates in various options in photonics. The photonics programs at the college have become a resource for this country and abroad for specialties in Telecommunications and Laser Safety. Constant fine tuning and updating of the Photonics curricula and equipment inventories go on continuously. Enrollment in the programs has fluctuated as changes have taken place in our society and technical fields. The association with OP-TEC has provided new avenues for our students to travel as well as Camden County College becoming a regional center for professional development, especially again in the areas of telecommunications and laser safety. Laser safety is of the utmost importance for any institution using lasers as a tool in their experimentation. PHOTONICS WITH OP-TEC AT CAMDEN COUNTY COLLEGE WILL HAVE A VERY OPTIMISTIC FUTURE

References


2. Seeber, F., (2006) OP-TEC the National Center for Optics and Photonics Education, LIA TODAY, page 1 and 8


Active learning in intermediate optics through class tutorials and concept building laboratories
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ABSTRACT
We have been modifying our intermediate optics class and laboratory with a focus on improving student learning through the use of active engagement. To facilitate this process we developed a two pronged solution. For the classroom we created a series of tutorials to help the students use the mathematics and techniques of derivations, apply these solutions to other problems, and develop a stronger conceptual foundation in intermediate optics class. In the optics laboratories we developed an approach that relies upon direct confrontation of misconceptions, predictions, collection of data to support or refute the predictions, reconciliation, discussion, and leading questions rather than a series of detailed, cookbook-like instructions as might be found in a traditional laboratory. Through the class and laboratory we build conceptual understanding in subjects like image formation by lenses and mirrors, ray optics, and ultimately elliptical polarization while fostering laboratory independence and helping students erect a new paradigm for learning.

Keywords: active learning, interactive engagement, optics tutorials, optics laboratory

1. INTRODUCTION
In 2006 we embarked on a complete revision of our optics curriculum which had not been updated for over twenty years. These revisions involved changing how we teach the intermediate optics lecture and the laboratory. One consideration in these modifications is that both the class and laboratory must be challenging for senior physics students who have significant laboratory and classroom experience while not being impossible for students who have just completed the introductory physics sequence.

The optics class and laboratory modifications follow in the wake of significant revisions of our introductory physics classes and laboratories. In the introductory classroom we make significant use of a teaching approach known as interactive engagement\textsuperscript{1} and peer teaching\textsuperscript{2, 3} rather than simple lecturing. Given the measurable success of this approach at improving student understanding of the material\textsuperscript{1} and considerable change in student attitude to learning, we felt it would be appropriate to adopt interactive engagement for the lecture component of our intermediate optics class. However, there are difficulties with implementing interactive engagement at an intermediate level.

2. WHAT ARE ACTIVE LEARNING AND INTERACTIVE ENGAGEMENT?
Active learning and interactive engagement (IE) means different things to different people. Active learning is an educational technique that developed over time. It is an approach in which students are involved in, and responsible for their own learning process. Active learning uses various methods such as interactive lecture demonstrations\textsuperscript{4} and peer instruction\textsuperscript{5} to aid students in understanding the material under deliberation. Adoption of this approach tends to have wider implications on the students’ learning methodology (knowledge acquisition vs. knowledge construction, answer making vs. sense making) than simply the material under consideration. Active learning requires the development of a habit of mind for both instructor and student. In

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comparison, a traditional lecture class is dominated by student passivity (sitting in class and listening to lecture) followed (hopefully) by independent active learning through homework (if properly designed) and text reading (if the students do it). In a traditional lecture class there is no need for students to mentally engage with the material while in class.

The term interactive engagement encompasses any and all of the variety of active learning approaches and venues, whether in the laboratory, lecture, studio or recitation format. IE classes can be characterized as a "minds-on, hands-on" approach; the students are mentally engaged with the material in the classroom and they must do the work in the class. The students actively discover the material and its intricacies in class. IE has been used extensively at the introductory physics level with great success in improving student understanding and retention of knowledge.

An IE class is dependent upon the communication process. The instructor must be engaged in a conversation with the whole class (not with a single questioner) and as such discovers misconceptions held by the students. This enables the instructor to contrive situations to directly confront those misconceptions. The instructor’s role is to set the scenario that the students investigate or consider; to determine the problem they have to solve and then allow the students to discuss the problem in small groups. Once a group consensus is formed, the instructor moderates a class discussion leading to a class consensus. The instructor may direct the conversation with particular questions, but the instructor is not the source of information. Rather, it is the class discussion that is the source of information.

3. CHALLENGES

In a traditional intermediate physics class, a significant amount of class time is devoted to the instructor showing the students derivations of key results. These results are then applied to a variety of physical situations. Similarly, in a traditional laboratory phenomena and classic investigations are generally demonstrated. Unfortunately, too many students do not or cannot connect the derivation to physics, they cannot follow the logical methodology applied through the derivation, and they are unable to apply laboratory results and techniques to other physical situations or investigations. For example, do students know under what situations the derivation results are valid? Can they apply the derivation techniques to different problems? Are the students learning effectively in the laboratory if they are only following directions to complete a demonstration?

We turned to IE in an attempt to improve learning in intermediate classes, but there are many issues. The lack of information available regarding student misconceptions of intermediate and advanced undergraduate topics makes this task more difficult than introductory courses. Furthermore, the nature of these courses simply makes it harder to implement IE. Some of the problems include: 1) the concepts become more challenging; 2) the mathematics is more challenging; 3) the students must become adept at interpreting the mathematics physically and relating the results to reality; 4) a traditional (and important) reliance on derivations; 5) the laboratory investigations become more technologically and conceptually complex; and 6) these classes build upon earlier classes and any misconceptions not allayed in those classes will cause difficulties in these.

Not to be dismayed, we have developed techniques to facilitate the use of IE in the intermediate optics venue. Our solution has been to develop a series of tutorials for the lecture portion of the class and to completely redesign the laboratories to engage the students. Our basic philosophy is that the students must discover the physics. These tutorials and laboratories are available on our web page: http://users.ipfw.edu/masters/Optics_ccli_project.htm.

It is important for an instructor to recognize that adopting IE in a class or laboratory may make progress through the materials more slow than in the case of traditional lecturing. As a result, the students will have a better mastery of the materials, improved learning skills, and better investigative skills. Regardless, we have to reduce some of the topics often considered in lecture and in laboratory due to time constraints.
4. THE LECTURE COMPONENT OF INTERMEDIATE OPTICS

The intermediate optics course has two components: geometric optics and physical optics. These basic optics models then provide a strong foundation for more advanced courses. Additionally, we try to help the students become more sophisticated in their use of mathematics, to expand their ability to interpret mathematics physically and improve their conceptual understanding of light. Rather than lecturing or showing this material, we let the student discover the physics through tutorials.

Course outline

I. Nature and models of light
   a. Basic ray model
   b. Basic wave model (what is a wave)
   c. Photonic model

II. Geometric optics
   a. Point and extended sources
   b. Ray-tracing
   c. Images
   d. Optical systems
   e. Aberrations
   f. Mathematical formalism

III. Physical optics
   a. Mathematical wave formalism for light and Maxwell’s equations
   b. Polarization (polarizer concepts and matrix methods)
   c. Interference and diffraction

The purpose of a tutorial is to help initiate the discussions. A tutorial is a document designed to lead a student to a solution and were inspired by Lillian McDermott’s *Tutorials in Introductory Physics* and Alan van Heuvelen’s *Active Learning Problem Sets*. There are three classes of tutorials: introductory tutorials which should be a review and deal directly with misconceptions; guided derivation tutorials in which the students are helped through a derivation of some particular result; and application problems.

Typically, a class will use the sequence: 1) the students work in small groups on the tutorial while the instructor circulates and asks additional questions to various groups of students (based on where they encounter difficulties), 2) the class discusses the results, 3) resolution. Occasionally, a tutorial might be assigned for the students to complete at home for discussion in the subsequent class.

Models of light

In geometric optics we stress use and interpretation of ray diagrams. Often, the value of ray diagrams is not apparent to students since in class it is often rapidly replaced with equations in introductory physics. However, ray diagrams contain a wealth of information about images, locations where images can be seen, etc. that is not available through pure calculation. But to understand ray diagrams, the students must first construct an idea of what is meant by a ray of light. We ask questions to guide these discussions such as: “What is a light ray?” “What information about light does a single ray indicate? A collection of rays indicate?” “Using a ray diagram how would one indicate that one light beam has twice the power of another?” “How could you indicate irradiance using a ray diagram?”

Waves are a source of confusion for students. Typically students confound the amplitude of a wave with the spatial extent or physical size of the wave. Other commonly held beliefs of light-wave misconceptions: “light travels in waves,” “light is composed of particles that are following a wave path,” and “the static wave diagram represents the path followed by light.” These misconceptions are also addressed through discussions.

Students are often confuse the amplitude of a wave in a diagram as indicating the spatial size of a wave. To address the spatial extent of a wave as relative to its spatial size, we consider a longitudinal wave. In figure 1, the students are asked to plot the wave – which consists only of counting particles in a box. If we double
the height of the boxes making the wave’s spatial extent larger, do we change the amplitude of the wave? If we double the amplitude of the wave, what has to change with the number of particles in each box?

Figures 1 – Tutorial fragment to assist students in understanding the wave representation and also wavelength, frequency and how they are related. The divisions on each grid are every 5 cm. The boxes are 5 cm wide by 10 cm high by 1 cm deep (into page). A) Plot the wave form on the supplied grid. B) The same wave but a short time later. Determine the speed, wavelength and frequency of the wave. C) Suppose you were to double the amplitude of the wave in A, make a graph and fill in the corresponding number of particles in each box. D) Suppose the volume of each box were doubled. What would change about the graphical representation? Would the physical dimensions (size or spatial extent) of the wave change?

The ray and wave models of light are commonly treated as independent. However, they share some common information which is worth exploring. Consider the question posed in Figure 2A and answered in Figure 2B.

Figures 2 – A) The wave diagram of a beam of light passing through an optical element placed at the dashed line. Construct a ray diagram that contains some of the same information and determine, as specifically as possible, the type of optical element. B) the solution.
Ray tracing

Once the idea of a ray diagram has been established the class works on imaging through ray tracing. Figure 3 is used to develop ray tracing formalism for a thin mirror. The students already have discussed ray diagrams and the law of reflection as found through Fermat’s principle.

![Figure 3 - Tutorial fragment showing the beginning of ray-tracing images for curved mirrors. The diagram showing the bundles of parallel rays serves several purposes. First, it forces the students to recognize that not all of these rays cross at the “focal point.” Second it is a refresher that the bundle of parallel rays constitutes light from a distant point source. Third, distant point sources will have parallel bundles of rays that intercept the optic at different angles with respect to the optic axis.](image)

Making the students work with ray tracing is important so that they develop an appreciation of what they can determine using this technique. In Figure 4 are two examples in which simple numerical calculations of image location and a lack of understanding of ray diagrams would make the questions unanswerable. (Figure 4 B based on techniques developed by Professor David P. Maloney)

![Figure 4 - A) Describe what each of the observers (1-4) see. B) The three ray segments shown are part of the different principle rays used for ray tracing. Based on this diagram, specify the type of lens, its focal length, image and object locations. Observer 1 can only see the bottom of the object. Observer 2 can see the whole object. Estimate the size of the lens.](image)

Derivations

An important aspect of any intermediate class is the derivation. Rather than the instructor simply showing the students the derivations on the board and having the students copy it to their notes, we require the students work through the derivations in peer groups. For example, in Figure 5, the beginning of a tutorial intended to lead the students to apply the appropriate geometric construction and approximations to find the “thin mirror” equation and to determine the location of the “focal point” is shown. After the students have been given time to complete the tutorial, the class reconvenes and a discussion of the results of the derivation proceed, with the instructor asking questions about various details of the derivation. Other derivation tutorials have been developed that investigate spherical refracting surfaces, double refracting surfaces, aberrations, frustrated internal reflection, the eye, wave equations, interference and polarization.
**Intermediate Optics: Reflection from curved surfaces.**

Our goal is to determine the location of the image of a point source based upon the point source's distance from the mirror surface and the radius of curvature of the mirror.

Useful information: small angle approximation $\tan \phi \approx \sin \phi \approx \phi$, $\cos \phi \approx 1$

Consider a point source located a distance "s" away from the surface of a convex spherical mirror of radius R. This is shown in the diagram above. Imagine a light ray that makes an angle $\alpha$ from the horizontal axis and hits the mirror some height "h" above the horizontal axis.

How would you determine where the image of the point source is formed? What is the distance of that image from the surface of the mirror?

Is the image real or virtual?

Can you relate the angles $\alpha$, $\alpha'$, and $\theta$ together?

Can you relate the angles $\alpha$, $\theta$, and $\phi$ together?

**Figure 5** – Beginning of the derivation tutorial of the thin-mirror equation. Students have to work through the mathematics and then interpret the results.

**Application**

Application tutorials require the students to use the relations and concepts that they have discussed and derived. They are not asked to simply plug in numbers, but to synthesize various techniques, methods and concepts into a whole. Figure 4B is an example of an application tutorial in which the students have to work with ray tracing. Another example is given in Figure 6.

**Tutorial results**

These tutorials serve several purposes. First, the instructor becomes apprised of the student’s misconceptions and mathematical skills; information an instructor could not as easily obtain via lecturing. Secondly, the students leave the class with clear notes in the form of the completed tutorial rather than the haphazard collection of copied information. Furthermore, the critical discussion that takes place at the end of class forces the students to put the material in their own knowledge framework. We believe (and our observations support this) that after this class format, the majority of students have better retention of the optics concepts and develop better mathematical skills and seem to enjoy the collaborative nature of the classroom.
5. LABORATORY

In the United States, the laboratory often has goals of "showing" phenomena to students, "familiarizing" students with classic or traditional investigations, to "teach" students about the nature of scientific investigations, to "teach" students about data acquisition and analysis, and/or to "demonstrate" to the students what they have learned in class. With these goals, students can easily become overwhelmed because they are confronted with new apparatus, new phenomena, new physical concepts, and new analysis techniques in almost every laboratory. What is learned in the first laboratory investigation may not apply to laboratory investigation eight! All this newness results in the students exclaiming "Tell me what I need to do, how to do it and what it means!" A request with which all too many instructors are willing to comply by providing detailed directions. This is much as Robert Millikan lamented "modern laboratory work in Physics often degenerates into a servile following of directions ...". Fortunately, intermediate optics laboratory typically consists of conceptually limited topics. The problem is how to avoid developing simply the "skill in manipulation" Millikan talks about and assist the students grasp the principles or the concepts.

For intermediate optics students, we set two outcomes: developing laboratory independence, and developing an understanding of optics such that they could design their own optical experiments. Success of achieving each of these goals can be directly measured by providing a task for students in which we provide no guidance; we only observe their work and behavior. Independence can be monitored by observing how they set up an optical system (do they construct a reasonable optical system using appropriate mounts or do they...
To perform a reasonably complex optical experiment, we identified certain basic skills and concepts as listed below. However, not all investigations lend themselves to this approach; we had to select certain key topics (in particular we excluded interferometry as it always seems more demonstration based than experiment based).

**Concepts in the laboratory**
- Point and extended sources
- What is an image?
- Virtual and real images
- Image location (are virtual images really there?)
- Does a real image require a screen?
- Point to point correspondence between image and object.
- All rays do not pass through the focal points
- Why use curved mirrors?
- Polarization: what are linear, circular and elliptical polarization
- Understanding linear, ½ wave and ¼ wave polarizers

**Skills acquired in the laboratory**
- Optics handling skills
- Use of Lenses
- Imaging systems
- Use of mirrors for alignment
- Maintaining polarization through reflection
- Use of polarizers and waveplates

Our academic semester consists of 16 weeks with a 3 hour laboratory activity each week. Every laboratory investigation consists of four parts: a pre-laboratory assignment; class discussion about this assignment, the laboratory activity, and a final task. The pre-laboratory assignment is completed and turned in prior to the laboratory session and serves the following purposes: 1) to give the students a chance to think about key topics for the upcoming activity; 2) to provide a topic of discussion for the beginning of the laboratory; and 3) to give us (the instructors) insight into the students' understanding.

The first 11 laboratory investigations consist of conceptual and skill building activities set up so that students must make predictions about certain situations, collect empirical evidence to support or refute these predictions, and reconcile the observations with their predictions. Leading questions within the activity help bring resolution to the activity. Throughout the sequence, later activities are dependent upon the results of earlier activities. The laboratory sequence is listed below. At the end of a laboratory period, the students are required to complete a “final task” in which they are asked to predict the outcome of a new scenario not covered in laboratory, and then test their prediction.
Laboratory Sequence

Week 1. Point and extended sources – adapted from Tutorials in Physics
Week 2. Refraction (planar refraction) [virtual images and location]
Week 3. Image formation (curved surface refraction – using beakers) [real and virtual images]
Week 4. Single thin lens – real images and image location using webcam
Week 5. Single thin lens – meaning of focal point
Week 6. Real and virtual images formed with lenses
Week 7. Plane mirrors, images and optical alignment skills
Week 8. Spherical mirrors and image locations
Week 9. Polarization – linear, half-wave plate [learning to use polarizers and what polarization means]
Week 10. Polarization – quarter-wave plate [is circularly polarized light the same as unpolarized light?]
Week 11. Polarization and reflection [maintaining polarization through reflection]
Week 12-16 - The remaining 5 weeks are spent on the optics project. Projects have been, static Fourier transform spectrometers, frustrated total internal reflection, optical activity of corn syrup, and the construction of a spectrograph.17

The investigations are performed by small groups (three students per group) and the students must come to a group consensus on any answer. These groups are assigned by the faculty and change three times through the semester. Initially, academically weaker students are paired with academically stronger students. The students are informed that they must be able to work independently and cannot rely solely upon their classmates for performing certain tasks. They are individually responsible for their own knowledge/skills. The last groupings pair students with the same academic level. This means that there always is that one group consisting entirely of students who do not seem to have been contributed significantly to their previous groups. We have found that at least one of those students greatly improves in this environment.

Webcam

Because the laboratory requires the students collect empirical evidence of their observations, in particular for locations of image and orientation of the image, we make extensive use of web cameras. Some of these cameras have the lens removed. These are used either to image directly upon the sensor, or replace the lens with a 50 mm FL lens (fixed in position relative to the sensor). The 50 mm FL lens gives the camera a fairly small depth of field and allows it to serve the purpose determining the location of an image – even a virtual image.

Sample activities

Figure 7 is a laboratory fragment that elicits student ideas on the issue of all of the light rays passing through a focal point. Once they have made predictions, they have to test the situation and see if they were correct. This type of situation provides the students with a “low-stakes” opportunity for failure, which is one of the most critical learning tools. Once students learn about lenses, they often see no use for those silly concave and convex mirrors. The problem is that students often do not see any reason that they should make use of curved mirrors. In this activity chromatic aberration becomes very apparent as the location of the image, depending upon color changes visibly for the lens, but does not change at all for the mirror. Of course, the mirror introduces aberration due to its use off axis. A laboratory fragment is shown for students to explore curved mirrors is shown in Figure 8,
Lenses Part II
This section explores the nature of a focal point in regard to the rays that form an image. This section also explores the effects on an image as a result of forcing all the rays to pass through a small hole.

Set up the light source, 200mm focal length lens, and a ruled screen on an optical rail. Adjust the distances between the screen, lens, and source so that a clear image appears on the screen. Place the webcam on the optical rail and get the image to appear on the monitor screen.

Consider what would happen if we add an iris to this set-up and remove the cm ruled screen. A student suggests that an iris will have a minimal effect if it is placed at the focal point of the 200mm lens (see the sketch shown below). The student explains that this works because all the rays must pass through the focal point. Do you agree or disagree with this students reasoning? EXPLAIN YOUR THOUGHTS.

![Sketch of lens setup](image)

Figure 7 – Fragment of a laboratory having the students reconsider through experimentation their ideas of image formation and ray paths.

Set up the following. Use the point source and the 50mm diameter, 200mm focal length lens.

Adjust the lens and record the distance from the lens to the camera for each of the color lenses. Make sure you readjust the focus each time. Note: you may have to adjust the shutter speed of the camera so that it doesn’t saturate.

Are all of the image distances the same? Should they be? Explain.

Now set up the following using a 200mm focal length concave spherical mirror. Try to keep the angle $\phi$ as small as possible. Adjust the mirror, camera distance for each color filter.

![Sketch of mirror setup](image)

Figure 8 – A laboratory fragment in which the students discover a reason for using curved mirrors rather than lenses.
Students generally believe the sole test for polarization is rotation of a linear polarizer indicating no preferential polarization angle. Unfortunately, under this criteria, circularly polarized light qualifies as "unpolarized" light. In this investigation, the students explore unpolarized light from a light bulb and then circularly polarized light created using a quarter waveplate. In the former case, the students cannot change the polarization to linear using a quarter waveplate. While in the latter, they are able to do so, making this discovery valuable in persuading them that unpolarized light is not the same as circularly polarized light. In Figure 9, a fragment of this investigation is shown.

By only rotating the quarter-wave plate and linear polarizer, try to minimize the light reaching the photometer detector. Was there a significant decrease in light power at a particular polarizer angle compared to other angles? Quantify your answer using data.

Remove the quarter-wave plate and the linear polarizer without changing the position of the photometer. What does the photometer meter now read? What is the ratio of the light power reaching the detector with the quarter-wave plate and linear polarizer (minimizing the light) compared to the light power without them?

Is the light from the quartz-halogen lamp “unpolarized”?

How does the quartz-halogen light compare with your expectations of “unpolarized” light?

Connect a second λ/4 – plate to a plate rotator. Attach a piece of tape to this mount (NOT ON THE OPTICS) so that you can distinguish this quarter-wave plate from the first. Set up the equipment as shown below.

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**Laboratory Conclusions**

These laboratories provide a strong background for the students to learn, not only how to use optics, but also how optics work. The eliciting of their thoughts in a low-stakes scenario, and providing the opportunity to acquire empirical evidence with which to refute their predictions enables them to gain a mastery which they might not have been afforded had they simply been following explicit directions. This is the meaning of active learning.
6. OVERALL CONCLUSIONS

These tutorials and laboratories are designed to help the students actively work with the material. However, they cannot be used effectively without instructor to question and lead and they are not intended to be used as such. They are meant to spur discussion between the students, to help the students discover optical phenomena and physics and build an understanding of the same. These tutorials and laboratories are available at [http://users.ipfw.edu/masters/Optics CCLI Project/optics_ccli_project.htm](http://users.ipfw.edu/masters/Optics CCLI Project/optics_ccli_project.htm)

7. ACKNOWLEDGMENTS

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REFERENCES


Active and Interactive Teaching Based on Exploring Forefront Topics in Information Optics

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ABSTRACT

Information Optics (i.e. Fourier Optics) is a compulsory professional course in the teaching program for juniors in the field of applied physics at Beijing University of Technology. Various methods are applied to information optics teaching in order to obtain satisfying teaching effect. Active and interactive teaching method based on exploring forefront topics was proposed and put into practice, especially for teaching “holography and holographic technology application” section of the course in which the teaching activity was not restricted to classroom any more. A visiting to the exhibit of forefront production of holographic display was introduced as an episode in the teaching. The process of teaching was designed elaborately to an interactive activity between the teacher and students, and to stimulate students to cooperate. The teaching practice proves that the active and interactive teaching method is much favorable by students and successful in information optics teaching.

Key Words: undergraduate teaching, information optics, active and interactive teaching method

1. INTRODUCTION

Fourier analysis is a ubiquitous tool that has found application to diverse areas of physics and engineering\(^{[1]}\). Information Optics is a course that applies the Fourier analysis tool to optics for dealing with the problems of diffraction, imaging, optical data processing, and holography. And the course is also named Fourier optics popularly. Information Optics (i.e. Fourier Optics) is a compulsory professional course in the teaching program for juniors in the field of applied physics at Beijing University of Technology. The Applied Physics program at Beijing University of Technology is designed to nurture innovative talent in modern applied physics, providing students both solid theoretical grounding and training for practical scientific research skills by offering 4-year BS degree\(^{[2]}\). Teaching and studying of professional courses play an important role in the
process of nurturing student’s innovative talent. The course content of information Optics including necessary mathematics, linear systems theory, diffraction theory as well as the application of those theories, which are more difficult for students to understand and use freely. Therefore, it is very important to pay attention to teaching methods for stimulating students’ interest in learning and help them to establish a clear physical picture.

Various methods are applied to information optics teaching in order to obtain satisfying teaching effect. Such as use PowerPoint and Matlab software to visualize teaching in classroom [3], introduce and simplify our advanced scientific research result to the professional experiments for students [4] and so on, Active and interactive teaching method based on exploring forefront topics is proposed and put into practice, especially for teaching "holography and holographic technology application" section of the course in which the teaching activity is not restricted to classroom any more. A visiting to the exhibit of forefront production of holographic display is introduced as an episode in the teaching. The process of teaching is designed elaborately to an interactive activity between the teacher and students, and to stimulate students to cooperate. The teaching practice proves that the active and interactive teaching method is much favorable by students and successful in information optics teaching. Active and interactive teaching method is described in the paper in details.

2. CHARACTERISTICS OF THE COURSE CONTENT

We focus on teaching both the basis and forefront content of information optics. The details of information optics course content are shown in Table.1. The basis mainly reflected in the teaching of theories. Through comprehensive analysis of the course content, three foundations supported the entire curriculum are determined to teach: (a) Mathematics; (b) linear system theory, which is a combination of point between communications theory and optics; (c) scalar diffraction theory, which is the basic physical foundation, introducing Fourier analysis methods to the traditional wave optics. We believe that the three basic theories are very important for students, which help them learning to built appropriate mathematical model for a more complex optical problem, on the other hand, learning how to use spectral analysis (that is, Fourier analysis) method to deal with the problems, that is, to deal with problems in a different perspective of space and frequency domain. The students will benefit from such a broad perspective in their life-long learning.

The forefront mainly reflected in the teaching of the application of Fourier optics theories. We focus on teaching the application of information optical technology in several major fields, including: (a) the frequency characteristics of optical imaging systems; (b) optical holography; (c) spatial filtering and optical information processing. This part of contents are fresh, lively and advancing with the times, we are not limited to those materials in book, but using the latest
cutting-edge research results as teaching examples.

### Table. 1 Compose of Teaching Content of Information Optics

<table>
<thead>
<tr>
<th>Fundamentals of Information Optics</th>
<th>Mathematics</th>
<th>Linear System Theory</th>
<th>Scalar Diffraction Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematics</td>
<td>Step, Signum, Rectangle, Triangle, Sinc, Gaussian, Circular Function, $\delta$-Function, Convolution, Correlation, 2-D Fourier Transform</td>
<td>Linear Shift-Invariant System; Analysis of 2-Dimensional Linear Systems; Two-dimensional Sampling Theory</td>
<td>Mathematical description of optical wave; The Kirchhoff Formulation of diffraction; Angle-Spectrum of plane wave; Fresnel and Fraunhofer diffraction; Diffractive gratings</td>
</tr>
<tr>
<td>Frequency Properties of Optical Imaging Systems</td>
<td>Phase-Transform Function of Lenses; Fourier Transform Property of Lenses; Imaging Analysis of Diffraction-limited Systems under Coherent and incoherent Illumination; Coherent Transfer Function; Optical Transfer Function</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optical holography and application of holographic technology</td>
<td>the basic principles of holography; a plane hologram; Fourier transform holography; volume hologram, holograms with white light retrieved, applications of holography</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optical information processing</td>
<td>the basic principles of coherence filter; the simple amplitude and phase filtering; applications of grating filter and complex filters</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 3. AN OVERVIEW OF TEACHING METHODS

Students have studied calculus and physical optics which are necessary basis for this course before they start to learn "Information Optics". Most of students come from the capital city of Beijing, having active thought and sensitive to modern information technology. They have strong thirst for knowledge while they are in the more competitive employment environment. We strive to help students, through the "Information Optics" course teaching and studying, to master optical information processing basic theory and methods, technology. Through the "Information Optics" teaching activities to develop and improve the students’ ability of analyzing and solving
problems, especially ability of innovating. So that students can become more competitive among the contemporary in modern society.

For the teaching of basic theory, we focus on enabling students to master that knowledge at different level. We pay more attention that key and difficult knowledge to explain in detail in class, and require students to do more exercises, so that they can receive basic training. In order to increase the perceptions of students and to develop their ability of practice, we have also designed the classic content to demonstration experiments allowing students to participate actively in the preparation in spare time and presentation in the class.

For the teaching on application of information optical theories and technology, a large number of fresh examples are introduced. For examples, when teaching distinguished ability of grating, dense wavelength division multiplexing technology is introduced. When teaching frequency response of imaging systems, the current model of the human eye and performance evaluation of digital cameras are introduced. These new materials not only have clear physical concepts, reflect the latest developments, but have a substantial nature. Our results of original research also introduce into the teaching timely. Teaching practice shows that those materials with our original idea are very helpful for students to nurture their creative thinking and ability.

4. ACTIVE AND INTERACTIVE TEACHING AND LEARNING

4.1 Various forms of interactive teaching

In accordance with the characteristics of the students and teaching content, various methods of interactive teaching are put into practice. We encourage students to participate in teaching and learning actively.

At the beginning of every lesson, there is "questions and fast answer" in order to review the learned content in last time and transition to the new content. "Questions and fast answer" is lively forms to stimulate students learn actively.

Some phenomenon of diffraction, Fourier transforms of lens, spatial filtering and other classic contents are designed as classroom demonstration experiments. Volunteers are recruited in the class. The volunteers prepare after class and implement their own demonstration experiments in class. The teacher offer proper guide and suggestion.

In order to strengthen the communication between the teaching and learning, a questionnaire survey usually be done after the teaching last for about five weeks. According to the feedback of the questionnaire, we can improve our teaching and offer different help for Individual students to develop in accordance with their personality.

Through a variety of audio-visual teaching, we give students a more comprehensive training,
Such as introducing appropriate video of principles of holography and white display hologram in English. We especially pay more attention to link theory and practice. For the teaching of holography and its application, all students are organized to visit holographic display technology and its applications in order to increase the student's perceptual knowledge and to develop their interest in learning.

**4.2 Teaching process for the content of optical holography**

The teaching content of optical holography section consists of the basic holography theory, recording material, and application of holographic technique, which is characterized by times and advancement. The teaching is designed elaborately and implemented smoothly in the process of teaching. Major steps in the implementation of teaching process are as follows:

1. **Confirming the teaching target** Students can master the basic principle and application of holography, and understand the importance position of holography in information optics. Meanwhile, students’ innovation awareness, cooperation and research capability ought to be cultured and improved through the teaching and learning.

2. **Teachers’ lecturing:** the teacher always takes two hours to explain the basic holography theory and holography classification, which can make students grasp the correlative concept based on comprehension. The heuristic and discoverable method is applied to help students learn new knowledge.

3. **Determining the activity topic and learning groups:** Some reference topics are given (as the following Table 2). Students are demanded to learn the content of holography display and application by themselves in combination with network resources, teacher’s courseware and other reference materials. And every student is required to choose an interested topic to finish their term paper. Learning groups are divided according to their term paper topic and the collective research subject and sub-subject for each member are confirmed. With the exploring issues, all of students are organized to visit the internal top-ranking productions of holography display in Beijing University of Posts and Telecommunications, and some key knowledge are expounded on the visiting spot. The perceptual cognition is enhanced, which can lead them to combine the theory and practice.

4. **Active cooperation and communication:** Each group needs to investigate a mass of materials including internet resources, obtain help from teachers, and discuss problems together in their spare time, and finally fulfill the learning products. The potential latent of students is inspired by this kind of teaching and learning process.

5. **Showing learning production by Oral Presentation in class:** Each group elects one
student to show their production by multimedia in class. So that the learning productions can
be exchanged with each other. All the students will benefit more from the exchange,
discussion, self-comment and mutual-evaluation. Any question or query to each study
production is proposed energetically, and the advantages and shortcomings are deliberated
earnestly. Eventually, the excellent achievement is voted by teachers and students to express
a full affirmation to the intelligent labor outcomes. Meanwhile, the attitude of active
participation is also encouraged and praised adequately.

Table 2. Details of Reference Topics of Term paper and Learning Groups

<table>
<thead>
<tr>
<th>Reference Topics</th>
<th>Student Number who select the topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 The theory and development of Rainbow hologram</td>
<td>1113 1116 1128 1207 1228 1230</td>
</tr>
<tr>
<td>2 Principles and development of holography with white light retrieved</td>
<td>1123 1111 1119 1213 1218 1208</td>
</tr>
<tr>
<td>3 Holographic anti-counterfeiting technology</td>
<td>1101 1124 1107 1222 1225 1224</td>
</tr>
<tr>
<td>4 Principles and status of high-density large-capacity optical storage technology</td>
<td>1108 1132 1118 1226 1204 1206</td>
</tr>
<tr>
<td>5 Volume holographic grating devices and their development</td>
<td>1117 1106 1232 1212 1211</td>
</tr>
<tr>
<td>6 Principles and status of three-dimensional holographic display and movies</td>
<td>1129 1127 1103 1210 1220 1227</td>
</tr>
<tr>
<td>7 The classification of holographic recording material, recording mechanism,</td>
<td>1126 1215 1223 1202</td>
</tr>
<tr>
<td>characteristics and application</td>
<td></td>
</tr>
<tr>
<td>8 Application of digital holography in the biological cells imaging</td>
<td>2127 113 1121 1214 1219 1221</td>
</tr>
<tr>
<td>9 Application of digital holography in of three-dimensional measurement</td>
<td>1105</td>
</tr>
<tr>
<td>10 The principle of computer-generated hologram and its application</td>
<td>1114 1112 1209 1216</td>
</tr>
<tr>
<td>11 principle of Dynamic synthesis hologram and its development</td>
<td>1115 1104 1125 1217</td>
</tr>
<tr>
<td>12 Optional subject you interested in</td>
<td>1102</td>
</tr>
</tbody>
</table>
5. TEACHING EFFECT AND EVALUATION OF STUDENTS

Active and interactive teaching methods are favorable by students. They express their thought in the following words:

“This kind of teaching method enhanced the class attractiveness and accelerated my study interest”. “The products about holography display widen my visual field, and made me more interested in holography technology”. “Study force and enthusiasm were inspired by this kind of teaching approach”. “The visit in Beijing University of Posts and Telecommunications not only increased my interest to this curriculum, but also made me learn the scientific attitude and faith”. All of the aforementioned aspirations from students demonstrate the active and exploring teaching pattern has produced a favorable instructional effect.

After teaching reform and practice for several years, information Optics in our school curriculum has been formed teaching modes with its own distinct characteristics, and has achieved good teaching results. The teaching effect and learning outcomes of students are reflected in the professional design of experiments, graduate and postgraduate study. During the teaching and learning process, a certain amount of scientific training are offered which is very helpful to nurture students’ ability of innovative practice. Each year, a large number of outstanding students in the field of applied physics choose to major in optics as their postgraduate study.

As far as teaching of this course in future, we will continue to strengthen and improve the innovative modes of teaching, focus on the basis while the innovative practice of the students abilities, so that students learn not only knowledge, but also improve the ability to learn methods for their life-long learning. Through our teaching activities, the basic tasks of undergraduate education can be effectively completed, namely: for students (1) making a good theory foundation and attain the ability of lifelong studying when graduating; (2) Increase the competitiveness of engage in practical work after graduation (3 ) to do some preparation for continuing to study as a post-graduate student.

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References
Holography as a tool for advanced learning of optics and photonics

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ABSTRACT

Laboratory works on holograms recording, reconstruction and interpretation are useful for two reasons. Firstly, holography is widely used in science and engineering. Secondly, training labs in holography require complex applying of knowledge on interference, diffraction, coherency and other domains of optics.

Educational kit and methodological instructions for optical experiments were presented in the previous paper 1. The desktop holographic camera described in this paper is one of the additional functional units of the kit. The desktop holographic camera does not require additional protection against vibrations even if the exposure time is several minutes. This is a compact holographic installation for recording Denisyuk holograms.

Two experiments are described in the paper to illustrate the usefulness of holographic laboratory works. The first one is a recording and reconstruction of a Denisyuk hologram. The second one is a recording and interpretation of a double-exposure interferogram when the holoplate is sagged due to loading between exposures.

Also included in the paper are holographic setup and laboratory works on digital holography. These experiments require, in addition, complex applying of knowledge on photo receivers, CCD and other domains of photonics.

Keywords: educational kit, training labs, holography, desktop holographic camera, Denisyuk hologram, double-exposure interferogram, digital holography.

1. INTRODUCTION

The educational kit “UMOG” and its methodological instructions have been presented in previous papers 1,2. Methodological instructions provided with this set include the list of demonstrations and laboratory works as well as links between various experiments and phenomena. Methodological instructions give recommendations for more than 50 demonstrations and practical works in various domains: light diffraction, interference of light, holography, geometric optics, Fourier optics, polarization effects, optics of spectra, fiber optics, as well as a combination of the effects.

A picture of the set is shown in fig.1.

The desktop holographic camera (fig. 2) is one of the additional functional units of the kit.

Laboratory works on holograms recording, reconstruction and interpretation are useful for two reasons. Firstly, holography is widely used in science and engineering. Secondly, training labs in holography require complex applying of knowledge on interference, diffraction, coherency and other domains of optics.

Therefore this paper is devoted to holographic training labs. This paper is based on more than 15 years’ experience of carrying out training labs in holography at the university.
2. DESKTOP HOLOGRAPHIC CAMERA

Normally, holograms are recorded using huge installations that should provide protection against vibrations if a cw laser is used as a light source. This is necessary when recording holograms of large scenes or moving objects. At the same time there are many applications where no such cumbersome instrumentation is needed. Among such applications, manufacturing of holographic filters and diffraction gratings can be mentioned. Creation of archives of small objects and production of souvenirs are also examples of such an application of holography. In these cases it is necessary, as a rule, to make small holograms of a stationary object.

We have developed a desktop holographic camera for training labs on holography. But it can be used for above mentioned application as well. This is a compact holographic installation for recording Denisyuk holograms (fig.2). The size of this instrument is 300 by 250 by 500 mm and its weight does not exceed 10 kg. Holoplates ranging in size from 76 by 76 to 127 by 127 mm can be used for holographing. The depth of a scene that can be recorded is about 50 mm. The cw He-Ne laser used in the camera delivers 2 mW power that is quite sufficient for recording holograms of such a size.

The instrument doesn't require additional protection against vibrations even if the exposure time is several minutes. This is achieved by using a vertical frame for assembling a laser (2) and other optical elements of the instrument as well as by a rigid coupling of the object plane and the plane where the photographic material is placed to record the hologram. Mirrors (3) are designed for alignment of the device. Laser beam is expanded by a microlens (4). A microlens can be replaced by a collimator. The holder of a holoplate (5) can be regulated to use holoplates of various sizes - from 76 by 76 to 127 by 127 mm. An object holder can be placed in a desirable position and then fixed by two screws. An object (6) is placed inside the case (1) to protect the object field against the air flows. To record a Denisyuk hologram the pattern (7) of interference between object and reference wave is recorded in thick holographic emulsion (5).

Two light sources from the kit (UMOG, fig.1) can be used in the desktop holographic camera: a laser semiconductor diode (λ=655 nm) and a He-Ne laser (λ=633 nm). Experimentally it is found that the semiconductor laser coherence allows us to record Denisyuk hologram but the quality of reconstructed
holographic image is not high. Therefore we use the He-Ne laser in the majority of our holographic experiments.

![Desktop holographic camera](image)

**Fig. 2.** Desktop holographic camera.

a – picture of camera; b – functional scheme.


### 3. RECORDING OF DENISYUK HOLOGRAMS AND HOLOGRAPHIC INTERFEROGRAMS

In order to simplify the use of the instrument, the holograms are recorded using coaxial optical arrangement (Fig 2b). It is known that a "transparent" photoplate has to be used in such scheme because an object beam is passed through the plate, reflected from an object and returned to the plate. To record the holograms we use silver halide plates such as PFG-03 ("Slavich", Russia). The resolution of these photoplates is up to 5000 mm⁻¹. In addition, their thickness is acceptable for recording Denisyuk holograms. We use developer GP-2 for processing the hologram.

The exposure time in our experiments ranged from 30 seconds to 5 minutes. This fact demonstrates that no additional protection against vibration is needed.

We have been using the desktop holocamera for about 15 years in student labs on holography and optical data processing. Hundreds of holograms have been recorded with the above set-up. Various objects were recorded. It was found that holograms of diffusely reflecting objects allow reconstructing most qualitative holographic images in a white light. It is obvious that because of the simple functioning of the instrument, it is impossible to produce holograms of slightly reflecting objects.
Double-exposed holograms are also recorded in our experiments. This same optical scheme is used. A plane mirror is used as an object (6) (Fig. 2). A small weight is located on the holoplate between two exposures. Therefore two holograms are recorded on the holoplate. One hologram corresponds to the initial stage of the holoplate, another hologram is recorded on the loaded holoplate. Two waves are restored from the hologram so we can observe the interference fringes under reconstruction stage. Various kinds of interference fringes are reconstructed in a white light. Certainly, the shape of the fringes depends on the character of deformation of the holoplate between the exposures. Such an agreement between the appearance of the fringes and the position of the weight is observed in our experiments.

Fig. 3. Examples of holograms and interferograms
A plane mirror could also be used as an object when a reflective holographic filter is recording. In addition to holographing according to Denisyuk scheme the instrument enables the recording of holographic gratings and holograms of some simple objects using Leit and Upatnieks scheme as well. In this case an additional holder should be used. The beam splitting is carried out by the prism. In order to test the device we have recorded a number of holographic gratings, both absorption and surface-relief ones. We used Kodak D-19 for developing the photoplate and Kodak R-10 to make bleached holographic gratings. The spatial frequency of the gratings did not exceed 1000 mm\(^{-1}\) in our experiments. The diffraction efficiency of these gratings and the diffraction efficiency of the gratings recorded by the typical vibration-resistant set-up have the same order of magnitude.

In our training labs students independently carry out the whole holographic procedure. They adjust the scheme, expose and develop holoplate, reconstruct and explore both real and virtual images of object. When students make the double-exposed hologram they should determine the type of deformation of holoplate between exposures and measure its central deflection (sag) using interference pattern in the reconstructed image.

4. DIGITAL HOLOGRAPHY EXPERIMENTS

Digital holography (when the hologram records on CCD and the holographic image reconstruction is done on the computer) provides additional important opportunities of holography. The following advantages can be mentioned for this technique:

- A possibility to create holographic video;
- A possibility to transmit digital holograms by communication lines;
- A possibility to calculate the phase of reconstructed wave.

At present, digital holography is quite a traditional method, therefore we suggest to represent it in student training labs.

Optical scheme for digital hologram recording is presented in fig. 4. In-line holographic scheme is used because of the limited resolution of CCD-camera. For simplicity we use the scheme with direct illumination of object.

Laser beam expanded to necessary diameter illuminates the object scene \((3)\). Laser radiation scattered by objects is the object wave. The other part of radiation passed by the objects is the reference wave. The pattern of interference of these coherent waves is recorded by CCD – camera \((4)\) and stored in the computer \((5)\) memory.

Of course, technical parameters of CCD-camera must provide the correct registration of the interference pattern. For example, in order to register an in-line hologram of a spherical particle with 50 \(\mu\)m size, located on the 500 mm distance, the CCD-camera must meet the following requirements (if the wavelength of laser radiation is 0.63 \(\mu\)m):

- CCD size – larger than 12.6 mm;
- Pixel size – smaller than 6 \(\mu\)m;
- Bit capacity for pixel – not less than 12.

For training purposes we use quite a cheap camera SK-2005 which is easy in operation.

If the CCD-camera allows the correct registering of the interference pattern of the object and reference waves, we can consider a so-called ideal recording of hologram. The recorded hologram is a 2-D discrete array of intensity values. In the case of an ideal hologram recording this same array can be used as complex amplitude \(u(x_1, y_1)\) of restored wave just behind the hologram, on reconstruction stage. Therefore the use of diffraction integral (1) allows us to calculate complex amplitude \(u(x_2, y_2)\) and intensity of restored wave in any plane \((x_2, y_2)\) located on a distance \(z\) behind the hologram.

\[
u(x_2, y_2) = \frac{e^{ikz}}{i\lambda z} \int \int u(x_1, y_1) e^{\frac{ik}{2z}[(x_2-x_1)^2+(y_2-y_1)^2]} \, dx_1 dy_1
\]

Here \(\lambda\) is the wavelength of laser radiation, \(k = 2\pi/\lambda\).
Changing the distance \( z \) of reconstruction in integral (1) with specified interval we can observe reconstructed images in various sections of object volume. To get in-focus image of object we should adjust the distance of reconstruction within corresponding distance interval.

![In-line scheme for digital hologram recording](image1)

**Fig. 4.** In-line scheme for digital hologram recording.
1 – laser; 2 – beam expander; 3 – objects; 4 – CCD - camera; 5 - computer.

![Set-up for digital hologram recording](image2)

**Fig. 5.** Set-up for digital hologram recording

The in-line optical scheme described above (fig. 4) is used for holograms recording in student training labs. We use CW He-Ne laser (\( \lambda=0.63 \, \mu m \)) as a source of coherent light. Holograms are recorded by CCD – camera SK-2005, with 1/3" CCD matrix, pixel size - 9.6 by 7.5 \( \mu m \).

The set-up for training lab on digital hologram recording is shown in fig. 5. An optical bench, holders and optical elements from UMOG base set are used for combining the set-up. Three sewing needles located on different distances from the plane of hologram registration are used as objects of holographing.

In this training lab students adjust the scheme and record digital holograms independently. Then they reconstruct the real images of objects using software which calculates the integral (1). To observe a focused image of each needle they change distance of reconstruction in (1). As a result, several images (frames) corresponding to each distance are obtained. Note that if we put these frames together, the video of the refocusing process will be created. This video corresponds to the refocusing process which is observed, for example, when microscope is adjusted to see a sharp image.

Examples of the images reconstructed from digital hologram of three needles are shown in fig. 6. It is clearly illustrated that the sharp image of each needle is observed on different distances.
Digital hologram recorded on CCD

Distance of reconstruction 170 mm, out-of-focus images of needles are observed

Distance of reconstruction 197 mm, sharp image of right needle is focused

Distance of reconstruction 211 mm, sharp image of middle needle is observed

Distance of reconstruction 225 mm, focused image of left needle is observed

Distance of reconstruction 250 mm, out-of-focus images of needles are observed

Fig. 6. Images reconstructed on various distances.
5. CONCLUSION

This paper outlines several experiments, focusing on recording and reconstruction of Denisyuk hologram as well as digital holograms. The educational kit UMOG \textsuperscript{1,2} is used to prepare these experiments. The methodology of experiments is discussed briefly.

The usefulness of such training labs for the study of optics, photonics, and laser science is confirmed by more than 15 years’ experience of conducting these experiments. The holographic training labs promote better understanding of many optical phenomena, such as coherence, interference, diffraction, etc.

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ABSTRACT

For long time optics’ scientists all around the world realised the importance to the development of optics of providing our school students a good effective education in optics. A large range of quality educational support materials was developed and is readily available. Fortunately this is also true in what concerns materials to be used in hands-on experiments based learning covering virtually all fields of optics and also intended or adapted for use at all school levels. Recent trends in educational policies are given science education an increasing importance within school’ curricula. Further efforts must be developed in order to increase the importance of optics in school syllabus and generalize it throughout all school levels, while guaranteeing a quality effective education. This demands a strong focus on an active investigative hands-on experiments based study of the different subjects of light and optics by the students at the classroom in formal context but also in different informal activities. In this process the role of the teacher is of crucial importance. Quite often, however, teachers are not adequately trained in this type of pedagogic approach and frequently feel the need of further training in these issues but also on the recent advances of optics and photonics. In order to tackle this need a number of different training courses for school teachers, from pre-school to
highschool and vocational training schools, were designed and will be presented and discussed in this communication.

1. Introduction

Science teaching at all school levels should be generalised and rendered more effective in order to guarantee a strong and sustainable improvement of Science and its technological applications while improving and extending scientific literacy in our societies [1]. All over the world this is being, fortunately, accepted by governments and civil society institutions. Europe calls for more Science and Technology graduates trying to achieve the targets set in Lisbon Strategy to make the European Union "the most dynamic and competitive knowledge-based economy in the world capable of sustainable economic growth with more and better jobs and greater social cohesion, and respect for the environment by 2010" [2-5].

These demands add increasing pressure to the school and to school' teachers. Science teachers in particular face higher demands. In these troubled times students, and teachers themselves (all of you in fact…), can hardly foresee a future coherent career, teachers must find ways of attract [6] and engage the students into the learning process. Informal and non-formal activities can have a very positive impact [7,8] but in-classroom activities are fundamental and here a hands-on investigative experiments based active learning is fundamental [9]. Unfortunately frequently our science teacher were trained in an essentially theoretical way and are not used to perform experiments and even less to induce or even allow the students to act hands-on, not being taught to understand the process or trained for it.

Light, Optics and Photonics have a crucial importance in our lives and to the prospects of development of our world with breathtaking developments in many different fields, including fiber optics sensor and communications, image acquisition and processing, lasers, photodynamic therapy, real time holography, optical computing, solar energy conversion and light sources…

On these lines we have developed and are running training courses [10] on hands experiments teaching approaches. The general objectives of these Hands-on Optics, supported by the European Commission (Life Long Learning/ Comenius action) are to provide schoolteachers from basic to secondary and vocational schools strong effective knowledge on the basics of optics, focusing on an intensive training in the execution of hands-on experimental activities on the major optics subjects.
Hands-on/minds-on skills will be developed allowing the teachers to organise experimental activities in their class in a confident and effective way.

2. Methodology

The early as possible in their education the students should introduced to and get acquainted with basic optics concepts as those related to the nature of light, the subjects of general optics, geometrical physical and quantum, but also with advanced subjects of utmost importance and actuality as wave guidance, fibre optics and telecommunications, image digitalization and processing, light production and energy conversion, optical processing and computing, etc.

Not only specific knowledge must be acquired but also and specially the ability of exploring reasoning, acting interactively to be able to find, analyse and solve new interdisciplinary problems, should be explored and enhanced as extensively as possible.

The best way of achieving an effective sound education of the students on these optics issues is by inducing the students to an active committed participation in the teaching/learning process, through investigative practice and experimentation, making use of the new instruments and resources of the Information Society. Although a strong focus should be put into these hands-on approaches the theoretical perspective should not be forgotten and introspective abstract reasoning activities should be allowed, in particular if the characteristics of a student or group of students advise it. Constructivism [11] constructivism [12] and conceptual learning [13] among many other approaches should be explored.

3. The structure of Hands-on Optics training course

Although there will be a theoretical introduction to the theme, the course’s methodology will essentially be based on practical experimental activities hands-on/minds-on, followed by reflection and discussion. There will be a final assessment/evaluation session.

The pedagogic approach we suggest to be used relies on a functional integration of different pedagogical theories and practices namely the constructivism, conceptual learning and pro-active learning by hands on experimentation and research. Responsibility, critical reasoning and observation, method and flexibility, interdisciplinarity, volunteer self-rewarding commitment, joint efforts and teamwork, are the main keywords that should guide all pedagogical activities. Making use of the new instruments and resources of the Information Society.
The week long training course is mostly practical and strong personal interaction among the students (the physics and science teachers) and with the trainers and tutors is expected and will be encouraged (enforced...).

We expect the teachers to act as students also in order for them to better understand the problems difficulties and behaviours of their own students.

Apart from the main curricular optics subjects we introduce lectures and workshop on transversal issues like motivational tools and activities including the resource to non-formal or informal activities. Computer modelling and simulation tools can be very useful in helping complementing or even inducing hands-on experimental works. Often teachers work “alone” and feel that way.

The establishment of cooperation mechanisms among schools and teachers from the same environment but especially when coming from different countries and cultures [14] may be very important for the teachers and individuals but also as educators. This issue will also be explored specially addressing the possibilities in the frames of the European Union foreseeing other opportunities (Erasmus Mundus like for instance).

The preparation for the course is considered important [15,16]. The participants receive in advance two Guides for Hands-on Experimental Activities and the Teacher’s Handbook, which contains a theoretical presentation on General Optics [17,18,19]. One of the guides includes 42 experiments, all to be explored during the course, divided into main topics and graded from elementary to secondary level. The other guide call “Continuous” provides a series of observation based investigative activities covering basic light and optics concepts presented in an essentially non-guided way. The essential idea here is not to “show” or present an experiment but yes to induce the discovery process [17].

The follow-up of the course participants is considered of the highest importance. Enquiries and quizzes will be delivered to the teachers, together with support material to be filled by the teachers themselves and their students for a period no shorter than 3 years, to be returned to the course organiser for analysis and statistical treatment. Further training courses on more advanced topics will be made available in a near future [20]. On the other hand we expect the participants to enrol and be active members of the Hands-on Science Network were they will find a mutually supporting and nourishing ground [20].

In figure 1. we show the schedule of the two Hands-on Optics training course run in 2009 in Spain and Portugal [10].
Syllabus:

1st day
18:00 Registration

2nd day
9:30 Opening and presentation, M. F. Costa
10:00 Optics. Past, present and future B. Dorrio, D. Sporea, M. F. Costa,
11:30 Hands-on science P. Michaelides
14:30 Introduction to optics. The basics I. M. F. Costa, B. Dorrio, P. Michaelides
17:00 Discussion

3rd day
9:30 Constructivism. Theory and practice I S. Gatt
11:30 Constructivism. Theory and practice II S. Gatt
14:30 Introduction to optics. The basics II. M. F. Costa, B. Dorrio, P. Michaelides
18:00 Discussion

4th day
9:30 Introduction to optics. The basics III. M. F. Costa, B. Dorrio, P. Michaelides
14:30 How to organise a hands-on experiments class. The scientific method P. Michaelides
16:30 Safety issues D. Sporea
18:00 Discussion

5th day
Free day. Visits to local schools and interaction with local teachers and students

6th day
9:30 Hands-on activities I. The nature of light. B. Dorrio, C. Lima, M. F. Costa
14:30 Hands-on activities II. Color and vision. N. Tsaglotis, J. Fernandes, M. F. Costa
16:30 Hands-on activities III. Reflection and refraction. J. Fernandes, N. Tsaglotis, M. F. Costa
18:00 Discussion

7th day
9:30 Hands-on activities IV. Ray tracing. M. F. Costa, R. Batista
11:30 Hands-on activities V. Prisms lenses and mirrors. J. Fernandes, C. Lima, M. F. Costa
14:30 Hands-on activities VI. Fiber optics, polarisation, diffraction, holography. M. F. Costa, N. Tsaglotis, C. Lima
18:00 Discussion

8th day
11:00 Computer simulation on Microsoft Excel. V. Fonseca
14:30 Comenius EU School cooperation projects. M. F. Costa, P. Michaelides
16:30 Course’ evaluation and conclusion
19:30 Farewell dinner

9th day
Departure

(Every day: Coffee break - 11:00 and 16:00; Lunch 12:30; 19:30 Dinner)

Trainers: Professor M. F. M. Costa (University of Minho), Professor B. Dorrio (University of Vigo), Professor P. G. Michaelides (University of Crete), Professor S. Gatt (University of Malta), Dr. D. Sporea (NIPNE), Prof. V. Fonseca (University of Minho). Tutors: Dr. N. Tsaglotis, Dr. R. Batista, Dr. C. Lima, Dr. J. Fernandes.
1. Conclusion

The development of optics and photonics requires a large number of well prepared highly motivated scientist and technicians that should be teach and trained as early and as efficiently as possible in a positive rewarding environment. The new stringent requirements of the modern society demand not only the gathering of specific knowledge but also and specially of the competencies the ability of acting interactively to be able to find, analyze and solve new interdisciplinary problems. The best way of achieving an adequate formation of our students on these issues is by inducing the students to an active committed participation in the teaching/learning process, through hands-on investigative practice and experimentation.

Teacher training activities on the hands-on investigative experiments based learning of optics in all school levels and in informal contexts should widely promoted and disseminated.

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Using students’ misconceptions of primary coloured lights to design a hands-on coloured light mixer

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ABSTRACT

A surface mount typed multi-coloured Light-Emitting Diode (LED) is used as a light source for the hands-on coloured light mixer. The LED consists of red, green and blue tiny sources but the mixer is designed to have four switches corresponding to red, green, blue and yellow light. These colours correspond to students’ misconceptions of primary coloured lights; they realize that the primary colours and the rules for lights mixing are the same as those of paints. To generate a yellow light, a microcontroller placed between four input switches and the LED operates both a red and green tiny sources. In addition, the microcontroller is employed to eliminate some combinations of coloured light mixing to simplify the experiment (basic mode) for non advanced students. If the mixer is used with more advanced students, a number of combinations will increase and students need more analytical skills to find out the primary coloured lights (the coloured lights that can not be produced by the mixing of any other coloured lights). Therefore, the mixer is able to use with more advanced and non advanced students depending on the program in the microcontroller and some modifications of the circuit. Furthermore, to introduce students an idea that other hues or shades can be generated by mixing of these three primary coloured lights of different intensities, a tuning circuit is integrated to vary an intensity of the green light source.

Keywords: coloured light mixer, hands-on, primary coloured lights, misconceptions

1. INTRODUCTION

A number of science educators presented that students come to a classroom with their “Prior knowledge”. The knowledge is often opposite to the correct understanding of the nature. Then, it is teachers’ responsibility to help enhance students changing alternative conception to scientific understanding. If the new knowledge fit with students’ prior knowledge, it can be easily assimilated otherwise students need to shape those teacher give to them before they can accommodate. Therefore, an effective active learning teaching module should be designed based on students’ prior knowledge so students can assimilate what the module give to them.

To survey students’ prior knowledge, teachers can simply pose some questions to students or use a conceptual survey at the starting of a class. The examples of very well known conceptual survey are Conceptual Survey on Electricity and Magnetism (CSEM), Determining and Interpreting Resistive Electric Circuits Concepts Test (DIRECT), Force Motion Conceptual Evaluation (FMCE), Geosciences Concept Inventory (GCI) and Heat and Temperature Conceptual Evaluation (HTCE). For more information, students’ alternative conception can be found on the websites.
The alternative conceptions can be used as a guideline to design a learning track, what students need to observe or should be emphasized, to help students change their alternative conception to scientific understanding.

In this research, students’ alternative conception of primary coloured lights, they realize that the primary colours and the rules for lights mixing are the same as those of paints, were used to optimize a number of coloured lights and their mixing for a hands-on coloured light mixer. Furthermore, questions (what students need to Predict, Observe and Discuss) in an activity sheet were designed based on this alternative conception.

The mixing of lights can simply conducted by a light mixer. The mixer used 1) a microcontroller to limit a number of the available combinations of coloured light mixing and 2) a surface mount device (SMD) multi-colour LED (see figure 1) as the light sources. The LED can generate a uniform brightness light without any handwork because there is no epoxy drop lens on the top. Moreover, it consists of three tiny red, green and blue light sources that are very close packed (≈ 1 mm apart) so students perceive a mixing of these beams as a one beam (see figure 2).

The activity was designed based on PODS (Predict, Observe, Discuss and Synthesize) learning cycle. Students were asked to predict a few questions on primary coloured lights and their mixing then they observed some prepared coloured lights mixing. These observations and discussions on the conflicts between students’ prediction and observation with their peer helped them to correct their misconceptions. At the end of activity, a few questions were posed to students to confirm and enhance their scientific understanding.

2. A HANDS-ON COLOURED LIGHT MIXER

There are many research developed the instruments used to demonstrate primary coloured light mixing phenomena. To design a simple hands-on coloured light mixer, a schematic diagram introduced by Planinšič (see figure 3) is used. The circuitry of the mixer is very simple and consists of 1) three LEDs serve as red, green and blue light sources 2) three dimmers used to control the brightness of the three light sources, independently. In addition, three fix resistors (R4, R5 and R6) are used to limit the maximum current passing through a red, green and blue LED, respectively.

An LED is more appropriate to be used as a light source of a hands-on coloured light mixer than a bulb because it can be used with a battery and the price is cheaper than those of bulbs. This means that the LED based light mixer can be produced cheaply as a mass of teaching tools. However, LED still poses a problem. Most students hardly perceive a mixing of red, green and blue lights with the same intensities as
white. The reason behind this problem are human resolving power $^{18}$, a property of LED that is not a point source and can not generate uniform brightness $^{19}$ and is easily disturbed by an ambient light $^{20}$.

![Diagram](image)

**Figure 3:** Schematic diagram of a simple coloured light mixer.

The easiest way to eliminate the problem of an ambient light is using the mixer in a dark room which is not available for most schools.

Gillies and Planinšić also suggested the way to change an LED to be a semi-point source that could generate a uniform brightness light. They used a hacksaw to saw the top part of the LED (function as a drop lens) off then polished the sawed surface with fine water sandpaper. Finally, an abrasive polishing paste was used to make the surface looks clearly transparent.

In addition, the problem of human resolving power can be eliminated by packing the light sources very close together or increasing an observing distance between students and the mixer which is not suitable for a hands-on activity.

Fortunately, modern technology that always makes things easier is a success key of the hands-on coloured light mixer in this research. The surface-mount device LED so-called “SMD multi-coloured LED” is used as the light sources for the mixer. This multi-coloured LED has no lens on the top and consists of very closely packed three internal tiny of red, green, and blue light sources. Therefore, light produced by the LED is uniformly bright lights and viewed as one beam by the human eyes. Furthermore, the beams are bright enough to use in a normal-lit room.

Since the objective of this research is to encourage students to discover the primary colours of light but the simple mixer does not allow students to observe other coloured lights mixing except red, green and blue lights. Therefore, the mixer need to be modified to have more light sources then students can find out the primary colours of light; the coloured lights corresponding to students’ definition of primary colours that they have already learned in the Art subject. This can be done by simply adding the extra light sources to the mixer but we need to face the fact that too much data make more difficult for students to analyze, especially the non advanced students. To optimize the problem, students’ misconception about primary coloured lights can be used as a guide to provide the minimum light sources for the mixer.

As Bill Beaty posed on his website, many students realize that the primary colours and the rules for lights mixing are the same as those of paints, only four “students’ possible primary colours of light (red, green, blue and yellow)” are used as the light sources of the modified mixer. All possible combinations of these four coloured lights of maximum intensities as well as their corresponding results are listed in Table 1. The details
indicate that only combinations 1 to 5 are enough for students to change their understanding about the primary colours of light and learn the conventional secondary colours of light. When students choose combination 1 (mixing red with green) they should realize immediately from observation that yellow is not a primary colour of light. Combinations 2 to 4 give magenta, cyan, and white light sequentially helping students learn the conventional secondary colours of light and the mixing of all primary coloured lights. Combination 5 should also convince students that the rule of coloured-light mixing is not the same as those of paint mixing; if it is, students would perceive the colour of the mixed lights as green. Therefore, the 1st to 5th combinations are provided for non-advanced students and the all combinations requiring more analytical skills to interpret is suitable for instruct more advanced students.

Table 1: All possible combinations of a red, green, blue and yellow lights mixing with the maximum intensities.

<table>
<thead>
<tr>
<th>Combination</th>
<th>Mixing of Coloured lights</th>
<th>Observed results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Red and Green</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Red and Blue</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Blue and Green</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Red, Green, and Blue</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Blue and Yellow</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Red and Yellow</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Green and Yellow</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Red, Green, and Yellow</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Red, Blue, and Yellow</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Green, Blue, and Yellow</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Red, Green, Blue, and Yellow</td>
<td></td>
</tr>
</tbody>
</table>

To limit a number of available combinations of coloured light mixing, a microcontroller (AT89C2051) placed between four input switches and the multi-colour LED is employed to control the three very tiny LEDs, individually. Therefore, the available coloured light mixings are limited by the programme in the microcontroller. A flowchart of the microcontroller programme used in the mixer is presented in Figure 4. Executing the programme which is run as a loop, needs inputs from a combination(s) of the four input switches. If the input matches, the pre-determined combinations coloured light can be observed. If there is no match, no light will be turned on. In addition, pressing the yellow light switch activated the microcontroller to turn both red and green LEDs on simultaneously at maximum intensities to give the yellow light.
As students should be introduced to the idea that other hues or shades could be generated by mixing of these three primary coloured lights of different intensities, only one tuning circuit is added to make a green LED change its intensity by just turning the knob. This feature generates shades of colours; ranging from yellow to orange and pale blue to cyan. The schematic diagram and a complete set of the mixer are illustrated in Figure 5.

Figure 4: Flowchart of the microcontroller programme used in the hands-on coloured light mixer.

Figure 5: Schematic diagram and the third version of mixer.
3. ACTIVITY

The 1 hour activity is designed based on the PODS learning cycle and the aims of the activity are encouraging students to discover, from their definition of primary colours, the primary colours of light and observing the secondary colours also the results from mixing of different intensity of lights.

The PODS learning cycle encourage students to learn from any contradiction between their predictions and observations that could be resolved during the discussion phase. Students then synthesize their newly learned ideas and conclusions into the more general framework of their physics knowledge. However, naïve students should be given some background information in the form of simple introductory activities to increase their confidence to make a prediction rather than just making a random or uninformed guesses. This is because the background information is a backup for students to use logical reasoning to make their predictions.

The activity is started with the classroom discussion to reach an agreement on the definition of primary colours that is “Combination of two primary colours cannot produce a third primary colour when all of them are added together, the white light will be produced”. Students then are asked to predict what the colours are the primary colours of light.

Before students observe some prepared coloured light mixing, they have to predict and write down their predictions in the prediction column of the activity sheet (see Table 2). Students then do the experiment themselves on the five combinations of coloured light mixing with the same intensities as mentioned in the second section. The combinations consist of 1) red mixed with blue 2) red mixed with green 3) green mixed with blue 4) blue mixed with yellow 5) red and green mixed with blue. Moreover, students have to observe the other combination which is red and green light with the intensity of green is less than those of red.

After that students discuss with their peers on these questions 1) why is yellow not a primary colour of light? 2) What are the primary colours of light? In addition, students have to consider the correctness of this sentence “if an object reflects red, green and blue lights with the same intensities to an eye, colour of the object will be perceived as white”.

In the synthesis phase, students have to think about the relation between the primary colours of light and the colour sensitivity of the colour receptors in the human eye and also the colour of the white screen perceived by the red blindness person.

<table>
<thead>
<tr>
<th>Questions</th>
<th>Your group prediction</th>
<th>Observation</th>
</tr>
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<tbody>
<tr>
<td>1. The colour of light produced by the mixing of red light and blue lights, with the maximum intensity is……</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. The colour of light produced by the mixing of red light and green lights, with the maximum intensity is……</td>
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</tr>
<tr>
<td>3. The colour of light produced by the mixing of green light and blue lights, with the maximum intensity is……</td>
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<tr>
<td>4. The colour of light produced by the mixing of blue light and yellow lights, with the maximum intensity is……</td>
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<tr>
<td>5. The colour of light produced by the mixing of red light, green light and blue lights, with the maximum intensity is……</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. The colour of light produced by the mixing of red light and green with the green intensity is less than red intensity is……</td>
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</table>
4. EFFICACY OF THE HANDS-ON COLOURED LIGHT MEXER

To evaluate an efficacy of the teaching module, the module was introduced and conducted by the researcher to four classes of 151, Year-11 female students. Students' response to three questions of primary coloured light and their mixing collected before and two weeks after a class was determined in term of an average normalized gain. This gain is the ratio of the actual average gain to the maximum possible average gain as

$$< g > = \frac{\% < S_f > - \% < S_i >}{100 - \% < S_i >}$$

where $< S_f >$ and $< S_i >$ are the final (post) and initial (pre) class averages.

The questions are 1) what colour(s) are the primary colour(s) of light? 2) Is this sentence correct, “the mixing of blue and yellow light on a white paper can not be perceived as green”? and 3) Can orange light be generated by the mixing of red and green light?

Figure 6 presents students' response to the first question. This reveals that only 30% of students have a correct prior knowledge of the primary colours of light. While the other group of students (30%) believes that the primary colours of light are the same as the primary colours of paints. Some students (11%) have the idea that the primary colours of light should be the same as colours of a rainbow. These results also support the reason behind the development of the mixer that a large number of students are confused the three primary colours of light (red, green, blue) with those of paints (red, yellow, blue).

![Figure 6: Students' responses to the first question.](image)

Furthermore, students' responses to the second and third questions as shown in figure 7 indicate that there is only 15% of students before the instruction know the mixing of blue and yellow light can not generate green light and some students (27%) realize that orange light can be generated by the mixing of red and green light.
After completion of the instruction, the number of students who have a correct understanding of primary coloured lights and their mixing is significantly increased. The average normalized gain corresponding to the 1st – 3rd questions are 0.99, 0.58, and 0.09, respectively.

5. CONCLUSION

The hands-on coloured light mixer developed in this research could eliminate the problems found on the previous research as 1) a requiring of a dimly lit or dark room that was difficult to provide for general schools 2) some modifications of light sources are needed. This could be achieved by employing two modern technologies: a SMD multi-coloured LED set and a microcontroller. The LED has no epoxy drop lens on the top and consists of three tiny red, green and blue light sources that are very closely packed. Therefore, the output beams are uniform brightness and viewed as one beam. In addition, a number of the available combinations of coloured light mixing are limited by the programme in the microcontroller. If the mixer is used with more advanced students, the programme and the circuit need some modifications. Moreover, the mixer was designed to use as a hands-on instrument with an active learning based teaching module to encourage students to investigate the primary colours of light, the coloured lights corresponding with their definition of primary colours, and their mixing. This could help students learn science actively rather than passively.

6. ACKNOWLEDGMENTS

A graduate fellowship from the Institute for Promoting Science and Technology for S.N. is gratefully acknowledged. The authors would like to thank the Faculty of Graduate Studies, Mahidol University for financial support.
Reference:


Introducing Biophotonics to Undergraduates across the disciplines

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ABSTRACT

This paper describes our approach to introducing the basic principles of experimental Biophotonics to undergraduates. We have centred on optical microscopy since this is fundamental to most experimental activity associated with Biophotonics whether as a research, diagnostic or therapeutic tool. The major issues associated with imaging include spatial resolution, image enhancement and image interpretation. We have elected to guide students through the principles underlying these concepts by using three linked experimental investigations. The first deals with Fourier Optics and imaging at the fundamental level including the impact of such factors as numerical aperture, illumination wavelength and spatial filtering. The second is an introduction to optical microscopy including the use of digital image capture and basic image manipulation, whilst the third investigates image enhancement techniques such as the use of fluorescent labels and specifically tailored illumination techniques.

INTRODUCTION

Over the past ten years Biophotonics, the integration of biology with photonics technology and methods, has established a significant place in academic and industrial research, clinical medicine, environmental science and biosensing. Consequently, Biophotonics is now beginning to find a place in both biological sciences courses and those dealing with conventional physical sciences and optics. Our objective in designing these experimental investigations has been to service both communities (through highlighting specific features for each sector) and also to facilitate the essential communication processes between the two complementary but essential scientific disciplines.

Whilst Biophotonics undeniably embraces a very wide range of concepts and experimental techniques we have selected optical microscopy from these as the absolute basic tool which underpins the vast majority of current activity in Biophotonics. There is of course much fundamental science which underpins the use of such microscopic tools including the interaction of light with matter, basic biology, notably at the cell level, and the more specific issues associated with the interaction of light with biological samples. Additionally we must consider the basic physics of light propagation (waves, interference and diffraction), light as a stream of photons and, for some of the more advanced work, the basics of non linear optics which underpins concepts such as fluorescence and Raman spectroscopy. Exploiting all of these tools does however inevitably involve some form or other of imaging and since much of this is associated with cell biology, microscopic imaging is clearly absolutely essential.
In a historical context optical imaging has always been crucial in developing an understanding of the living world. It was with the invention of the optical microscope about 400 years ago that the basic physical structure of life, the cell, was first seen and real biological research started to make rapid progress. Since then there has been a constant desire to image with ever higher resolution into more intact structures, thereby facilitating a true understanding of what is taking place at the sub-cellular level, and in turn how these interactions at the cellular level affect large scale changes within animals. In parallel with the advances in the understanding we have seen significant improvements in the understanding of the imaging process. Contributions from Ernst Abbe in defining the resolution limits and Zernike’s insights into wavefront propagation phenomena have been arguably the most important, though ‘new physics’ is currently beginning to push these concepts yet further.

THE GENERIC PRINCIPLES OF IMAGING SYSTEMS: FOURIER OPTICS

There are three principal aspects to this topic:

- The very basics including magnification resolution and aberrations.
- Image enhancement techniques which can be implemented optically, principally spatial filtering.
- The impact of illumination sources.

Magnification is treated simply as a recapitulation of straightforward imaging optics with in effect a reiteration of the simple thin lens law, enabling students to fall back on work that they would all originally have undertaken in their school career. We are thus building on common and well appreciated ground. At this stage the concepts of principal planes in complex lens structures and similar ideas can be neglected – indeed the conceptual underpinning required for the biological microscope can be reliably obtained through simple thin lens approximation though the lens designer will clearly need to take a different perspective. Figure 1 illustrates the basics of microscope magnification including the simple objective/eye piece basic system and the more common so called “tube lens” approach which includes the prospect for inserting other optical components between the objective lens and the tube lens in order to provide the facility for some types of image enhancement. We include both conventional and infinity corrected microscopy systems to ensure that in practical use students appreciate the difference.

Figure 1: The basic imaging mechanisms in microscopy. Upper – the ‘finite tube” configuration and lower the “infinity corrected” microscope. The latter enables non focussing optical elements to be placed in the infinity space to facilitate image enhancement.
This conceptual underpinning of the straightforward microscope operation however needs further investigation. The essential principles can be gleaned from a thorough assessment of the image performance of a single lens and from this the definition of important image formation parameters. At this stage it should also be noted that the principles involved can be applied to any imaging modality that uses waves from MRI through to ultra-sound. This entails (figure 2) a combination of the concept of image formation involving the collection and reassembly of diffracted light (Fourier Optics) and approaching methods to define the impact of the lens itself on the fidelity of this process.

This in turn involves a simple examination of aberrations and the associated definitions of point spread functions. The objective here is to appreciate the next phase of imaging namely the factors which influence resolution and distortion in the final perceived representation of the original object. Figure 3 presents a simplistic representation of the principal concepts including the effects of numerical aperture and illumination wavelength, the impact of the various lens aberrations and the approach to integrating these tools into an image analysis technique.

**Figure 2**: Elements of the imaging process in a so-called '4f' imaging system. The object diffracts input light, red more than blue and this is collected by the input lens. The diffracted light contains information about the structure of the image. The 'transform plane' focuses each diffracted component and in principle these components, representing specific image components, can be individually manipulated to perform image enhancement.

**Figure 3(a)**: Spatial filtering through the effects of numerical aperture of the imaging lens.

**Figure 3(b)**: Lens aberrations and the impact thereof on a the image of a point object. The sketches are idealised to illustrate the generic features.
Finally we turn to illumination and in particular the basic need for the illumination source and the required final image to be in effect placed an infinite distance apart. Other illumination options also need to be investigated including the implications of coherent illumination (as used to demonstrate spatial filtering effects but rarely useful in actual imaging applications outside confocal microscopy which is a form of spatial filtering). Other possibilities include the effect of changing the spectral distribution of the illumination and the (rarely used in biology though present in some medical imaging), and possibilities for the use for example of side illumination to highlight scattering phenomena. Finally, polarised light could also have a role to play and whilst linearly polarised systems are by far the most common, there are additional possibilities in the use, for example, of circular polarisation in the examination of some types of biological samples.

Spatial filtering is in principle a simple concept (figure 4) in that the use of typically a stop in the filtering plane can highlight specific features in the image plane. Spatial filtering is an extremely versatile tool which can be used to highlight abrupt edges, pick out particular periodicity in an image structure or extract specific complex features through effectively realising a matched filter in the spatial frequency plane. However, it is perhaps worth mentioning that, unlike many digitally implemented techniques, accurate spatial filtering requires the use of single wavelength illumination with the most notable exception of the three principal spatial filtering tools used in biological imaging, known as dark field, phase contrast and confocal microscopy.

The principle underlying the first two of these three image processing tools is to minimise the impact of overall background on low contrast images, in effect taking away the average illumination which often can be much, much larger than the variations which contain the image detail. In the case of the confocal imaging system this background is from light being returned to the detector from outside the focal plane. In all cases the resulting image when viewed directly by eye or when captured electronically invariablv demonstrates significantly higher contrast, and in the end it is contrast that forms the basis, or limit, of any imaging system. Dark field illumination is designed to operate with a more conventional intensity contrast images as for example shown in figure 5.
Phase contrast, however, is designed to highlight images of varying optical thickness but through which the intensity transmitted (or indeed reflected) is essentially unchanged. Here the operation is more subtle and typically includes both a reduction (as opposed to a complete attenuation as in dark field) of the background illumination transmitted through the zero order in the Fourier transfer plane into high attenuation coupled to a carefully designed phase delay. The phase delay has obviously to be matched to a particular illumination wavelength. Consequently phase contrast imaging inherently relies upon relatively narrow band operation for its most successful realisation, but useful white light images can also be produced. However these exhibit 'rainbow' effects which need to be interpreted with care. We have omitted confocal imaging in the present series of experiments. However our overall approach to understanding the basic process involved in imaging should enable more advanced students to relate to both the need for and the principles of confocal systems.

**THE BIOLOGICAL MICROSCOPE**

The aim of this experimental investigation is to introduce familiarity with the basic specific features of biological microscopes and relate these where appropriate to the generic concepts developed earlier. Emphasis is on the core principles but more specific advanced topics, likely to be of importance to the more physically science minded students, are included as optional areas of interest.

By far the vast majority of biological samples are illuminated in transmission where the final image comprises the modulation characteristics on detected intensity (and by implication also colour) of light transmitted through the sample. Consequently illumination system plays a critical part defining the final image quality and thus the first major aspect to be investigated is the Koehler illumination (figure 6) a crucial feature very often overlooked. This includes roles of the various aperture planes in the illumination system and the techniques whereby the illumination source is effectively placed at infinity with respect to the object and therefore the final image. Consequently the student gains an important appreciation of the nomenclature used in practical microscope systems, and the effect of changes in the optical transmission characteristics of each of these planes. Another
essential aspect of this is to recognise the routes through which the light source appears in the Fourier transform plane, linking back with the learning outcomes from the previous module. The consequences of this are to identify approaches through which Fourier transform filters can be realised within the source geometry in addition to directly within the more obvious (figure 2) Fourier planes.

Producing the final image essentially follows the processes outlined previously but thereafter the resulting images are now invariably digitally acquired and stored as digital images. The artefacts of the acquisition and storage process and the interpretation of these artefacts are arguably among the least appreciated microscope phenomena. As an example the implications that images sampled on a regular point by point lattice (i.e. the pixels on a digital camera) can, under unfavourable circumstances, produce significant sampling effects somewhat akin to Moiré fringes. Such effects are considerably more likely when narrow wavelength sources are used.

We also examine the effect of different exposure times on the quality of the recorded image. The benefits of collecting one long exposure compared to averaging several shorter exposures are explored when using a digital camera. This area also explores the use of histograms to ensure that the best configuration for the storage of the data is made. Using this simple software tools ensures that the full dynamic range of the camera is used. We also examine the use of deliberately saturated images to bring out specific features, though the dangers of this are also highlighted. At this stage the student has now learnt how to set up the optical system, what the effect is of incorrect adjustment, and how to capture the best possible image.

However, once acquired, the image must be stored and the normal temptation (and frequently the default option) is to use conventional JPEG compression. However, like all compression systems the JPEG process inevitably removes some data, and hence useful information, from the original image. Whilst for normal visual perception purposes this may be perfectly satisfactory, there are numerous examples in biology where this can throw away critical information. Consequently storing the raw data, whilst memory hungry, is much preferable and the practical investigation of this loss of information is highlighted in the practical work. This area also highlights the difference between pure data and information. In the long term it is information that is required from microscopy and thus “throwing away” information early in the process is “criminal”. Indeed as biological microscopic imaging moves rapidly towards quantified imaging, as opposed to just producing a good image, this loss of information is becoming more crucial and will become increasingly so particularly as temporal information and particle tracking play an increasing role in biological understanding.
The image processing tools now available in standard software packages are immensely powerful and can be highly creative. This creativity is though a hazard since it does give the opportunity to create spurious artefacts and the experimental investigation which we have adopted pursues this through examples. Figure 7 illustrates some of these points. Here we have taken a standard image and passed it through software filters supplied in ImageJ, a freely available and much used Java based package originally developed by the NIH (rsbweb.nih.gov/ij/). The specific filters used are described and it is clear to see what “new structures” can appear by injudicious use of computer manipulation. These are before one even considers the use of Paintshop and the like!

![Figure 7: This is an extreme case to highlight the potential misunderstandings which can arise through injudicious use of image enhancement. The image on the left is germinating pollen grains which are typically 20mm. In diameter (indoor geranium) on the plant stigma running down the style. The right hand enhanced image could be interpreted as showing very significantly enhanced germination activity.](image)

The Open Microscopy Environment (OME) is gaining acceptance in many biology laboratories and addresses the crucial issue of digitally misinterpreting image files. Here using a server environment (which can be downloaded for free) raw image files are stored along with the associated meta-data (e.g. objective lens used, camera settings etc). When academic papers are the submitted the processed image may be submitted to the journal but a link is provided to the raw data enabling either the reviewer, or later the reader, to actually view the real and original image.

ENHANCED MICROSCOPY FOR BIOLOGY

There are three principal features of the basic microscope which are commonly used to enhance its performance. In essence all are attempting to increase the contrast in the image between the features that are desired to be imaged and the unwanted background and noise.

The first involves modifying the illumination system essentially through changing the source itself. Many biological samples have optical properties which depend on polarisation and/or exhibit birefringence. Combining a polarised light source and light image acquisition through a polarisation analyzer can often provide significant image enhancement through relatively simple modifications to the basic structure. However, interpreting the
enhanced image presents significant challenges. Through a series of simple experimental procedures the student is shown how, using some of the basic principles learnt in the earlier modules, the observed images can be interpreted.

Structured light typically in the form of an illuminating grid is a frequently used tool in non-contact profile measurement systems and this can be suitably adopted for microscopic samples. This again links back to the Fourier concepts introduced earlier. As an example if an intensity grid pattern (ideally consisting of a single sine wave) is projected onto the sample a single image can be recorded. If the grid is then moved by a third of the spatial period a second image can be recorded, and similarly for a final phase shift. If these images are just added directly one has a conventional wide field image.

By considering the optical planes at the focus of the objective and at the camera the image is looked at in “Fourier space”. The focal plane is the only one in which the frequency of the illumination (i.e. the grid frequency) is known and thus by selecting out this frequency, the blurred images from the light generated outside the optical plane are removed. The grid, with its known spatial frequency, can be removed from the obtained images by in turn erasing its frequency from the spectrum.

A number of mathematical solutions can be used to select out the grid frequency, but the computation is needed to be as simple as possible. Thus, a sectioned image, not containing the zero order frequency, may be derived by calculating

\[ I_p = \left[ I_1 - I_2 \right]^2 \left[ I_1 - I_3 \right]^2 \left[ I_2 - I_3 \right]^2 \]

The effect of this can be seen in figure 8.

Alongside these technological advances there has been a revolution in the way that much of biology is now undertaken and this was recognised with the award of the 2008 Nobel Prize. Through genetic manipulation techniques it is possible to ensure that specific components of a cell, or organ, produce a fluorescent protein meaning that when the sample is illuminated with the correct wavelength of light only these areas of the cell will fluoresce. Thus it is now possible to examine a specific process within cells with a high degree of selectivity without the addition of extra chemical compounds and this is crucial for the biological interface of Biophotonics (Figure 9).
The basic principles of these markers, using standard samples rather than involving students in sample preparation, also feature in the experimental investigation. The base concepts of fluorescent imaging are introduced such as the correct excitation wavelength selection (LEDs), the operation of dichroic filters and the removal of the illumination wavelength from the final image. However, along with the advantages of fluorescent based imaging methods the complications are also demonstrated including the problem of photo-bleaching and that in punctuated labelled samples, only the labelled features show which can lead to a miss-representation of the sample structure.

The final area explored is that of fluorescent lifetime imaging. This has rapidly established itself as a powerful tool in all areas of biophotonics from clinical tissue diagnosis through to the measurement of protein/protein interactions. We present this important technique through the concept of pulsed illumination and/or variable frequency sinusoidal illumination applied as a stroboscope to slow down cyclical processes. The more normal method is through high speed detectors and complex electronics. However, by using a slow detector (conventional CCD camera) and a pulsed LED of variable frequency, it is possible to determine fluorescent lifetimes, and crucially changes in fluorescent lifetimes. Thus the student also learns to apply simple concepts to highly complex problems.

Finally there is an expanding range of innovative software tools available for manipulating microscopic imaging. Using basic concepts, the principles behind particle tracking are illustrated showing that for regular spherical particles this is a fairly straightforward process but that with objects that change shape as they move a significantly more complex approach is required. The aim here is not to explain or teach complex software routines but to ensure that the student always has a questioning approach to image analysis and quantification. With the rapid growth of quantified imaging this, along with the complications of image compression discussed earlier, is an important point for students in all branches of science using imaging. Methods of Fourier image analysis are also examined, linking what is possible on a computer, with the earliest work undertaken on real optical systems. Again the emphasis is to be aware of the possible complications in the context of the benefits of such complex manipulation.

Figure 9 – examples of images using the ‘green protein’ fluorescent labelling technique

Multi-photon image of networks of interstitial cells of Cajal within guinea-pig colon. Cells were labelled with anti-c-kit and Alexa 488.

Bladder interstitial cell labelled with DAPI (blue) and smooth muscle α-actin antibody.

HEK 293 cells expressing a GFP-tagged potassium channel.
CONCLUSIONS

The series of three experimental investigations serves to underpin the basic understanding of the functions and operation of biological imaging systems in general and microscopes in particular. Microscopy is arguably the most basic enabler for all biophotonic systems and as such will feature strongly in the emerging portfolio of undergraduate and postgraduate courses in the subject. Of course there are other important and versatile tools through which biological imaging can be yet further enhanced. In particular these include spectroscopy and spectroscopic analysis, hyper-spectral imaging and optical techniques for biosensing. We plan to add basic investigations into these subjects within the foreseeable future.

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The green fluorescent protein derived initially derived from jellyfish won the discoverers the 2008 Nobel Prize for chemistry for Osamu Shimomura, Martin Chalfie, and Roger Y. Tsien. Here are many accounts of this, typified by the Nobel Prize website at http://nobelprize.org/nobel_prizes/nobelguide_chemistry.pdf

There are many more detailed introductions to microscopy, for example: Douglas B. Murphy “Fundamentals of Light Microscopy and Electronic Imaging” John Wiley 2001.
Experimental modules covering imaging, diffraction, Fourier optics and polarization based on a liquid-crystal cell SLM

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ABSTRACT

In close collaboration with four German universities, we have developed tutorials for experiments based on a transmissive liquid-crystal spatial light modulator (SLM). The experimental tutorials are grouped in six project modules, which cover a wide range of phenomena and have different levels of difficulty. At a basic level, students can investigate the SLM in its probably most well-known application as an image-generating element in a simple optical projector setup. At more advanced levels, the application as an adaptive optical element can be investigated in three different projects covering wave-optical phenomena. The fields covered include Fourier Optics using the SLM as a dynamic fan-out beam-splitter or kinoform, Computer-Generated Holography and basic Interferometry. For the support of these projects, software was developed which permits the generation of adaptive optical structures by the student with a user-friendly interface, while the underlying algorithms are explained in the theoretical tutorial. The modulation of the light by the twisted-nematic liquid crystal cells of the SLM can be investigated in the two most advanced projects. In the first one, the parameters of the cell and the components of its Jones matrix can be derived from transmission measurements with rotatable polarizers at a number of different wavelengths. This project gives insight to the Jones matrix calculus at the level required for the analysis. In the second one, the complex-valued transmission of the SLM is determined by measuring the diffraction efficiency of dynamically addressed Ronchi gratings.

Keywords: Spatial Light Modulator, Fourier Optics, Diffraction, Polarization

1. INTRODUCTION

Liquid crystal (LC) based micro-displays by now have been used for the manipulation of incident light waves for almost two decades. Initially components taken from commercial projectors were used to explore the suitability of such micro-displays for phase modulation, in order to use them as adaptive optical components like e.g. Fresnel lenses, Diffractive Beam-Splitters or aberration compensators. Since then, new dedicated devices referred to as Spatial Light Modulators (SLMs) have emerged. There are numerous experimental applications for such adaptive optical devices; however it is also evident that SLMs are quite suitable for optics education because especially the fields of Diffractive Optics and Fourier Optics are much more accessible for student laboratories with such flexible dynamic devices, compared to their static counterparts.

Therefore, the development of the ‘OptiXplorer’ education kit based on an ‘LC2002’ SLM started in our company several years ago, in close cooperation with a few German universities. Because an SLM is a flexible device, the laboratory tutorials which were developed in this way have quite different topics in optics, so we decided to group the different experiments into modules. While one group of modules is dedicated to the application side and uses the SLM as an amplitude modulator (i.e. an image source) or as a phase modulator, another group of modules is dedicated to the characterization of the device, which is partly due to the history of SLM development.

Because the main purpose of the LC based micro-displays was to be used as an image source for projection applications, not all parameters that are required for other applications - like phase modulation - were given on the datasheets of the manufacturers. The derivation of those missing parameters from experiments was a relevant topic, and indeed some properties of the liquid crystal cells can be obtained from rather simple
experimental set-ups. Therefore these experiments were developed into independent modules of the ’OptiXplorer’ education kit which provide a more detailed insight on the operational principle and construction of the device, and can be used as an introduction to e.g. to diffraction and polarization. In the following sections, short surveys of the different experimental modules will be given.

2. AMPLITUDE MODULATION AND PROJECTION

This experimental module is at an introductory level of difficulty. A white light source like an LED can be used, and the SLM is sandwiched between polarizers and lenses. The optical paths for imaging and illumination are, of course, different and should be understood by the students. One quantitative goal of this module is to determine the pixel size of the SLM from the amplification of the imaging setup.

The change of contrast of the obtained image can be determined as a function of the orientation direction of the polarizers, and the effect of the SLM on the polarization state of the light can be investigated for monochromatic light sources like red, green and blue LEDs. As can be seen in Figure 2, the orientation of the ellipse is rotated as a function of the addressed grey level.

Figure 1: An example for a projector setup with the optical path for illumination (black) and the optical path for imaging (red)

Figure 2: Rotated polarisation ellipses for different grey levels (GL’s).
3. DETERMINATION OF JONES MATRIX REPRESENTATION AND TN-LC CELL PARAMETERS

In this quite advanced module, the brief investigation of the change of polarization state done in the previous module is followed by a detailed investigation and analysis, which finally permit determination of the twist $\alpha$ of the LC cell and also its wavelength-dependent birefringence $\beta$. The experimental setup is simple, as can be seen in Figure 3.

The Jones matrix of the SLM can be written as a function

$$W^\text{S\text{L\text{M}}\text{-LC}}_{\text{TN}} = e^{-i\beta} A \left( \begin{array}{cc} f - i \cdot g & h - i \cdot j \\ -h - i \cdot j & f + i \cdot g \end{array} \right),$$

of the parameters $f$, $g$, $h$ und $j$, which are related to the physical parameters of the cell by

$$f = \cos \gamma \cdot \cos \alpha + \frac{\alpha}{\gamma} \cdot \sin \gamma \cdot \sin \alpha \cdot,$$

$$h = \cos \gamma \cdot \sin \alpha - \frac{\alpha}{\gamma} \cdot \sin \gamma \cdot \cos \alpha \cdot,$$

$$g = \frac{\beta}{\gamma} \cdot \sin \gamma \cdot \cos(2\psi - \alpha)\cdot,$$

$$j = \frac{\beta}{\gamma} \cdot \sin \gamma \cdot \sin(2\psi - \alpha)\cdot$$

where

$$\gamma = \sqrt{\alpha^2 + \beta^2}.$$
This measurement should preferably be repeated for at least three wavelengths (see Figure 4 for measured curves) in order to determine wavelength-dependent values for the parameters $f$, $g$, $h$ and $j$, and to derive the wavelength-dependent birefringence and the cell twist (which is independent of wavelength) from a numerical fit.

Figure 4: Transmission curves $T(\theta_1) = T(\theta_1, -\theta_1)$ and $T'(\theta_1) = T(\theta_1, +\theta_1)$ for six different wavelengths

In the solution sets obtained for the different wavelengths, which are plotted in Figure 5, only one solution for the twist angle can be found for all six wavelengths: $\alpha = -90^\circ$. The birefringence values are given in Table 1. In summary, this module leads to an unambiguous determination of the physical cell parameters $\alpha$ and $\beta$.

Figure 5: Solution sets obtained using a graphic-numerical analysis in the range (-180°, +180°) for the twist angle $\alpha$ at six different wavelengths with no voltage applied

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<tr>
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<th>$\beta$ [rad]</th>
<th>$\psi$ [deg]</th>
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<tr>
<td>1064</td>
<td>-90.97</td>
<td>1.16</td>
<td>-43.37</td>
</tr>
</tbody>
</table>

Table 1: Solutions of the display parameters obtained from transmission curves with no voltage applied to the LC cell
4. INTERFEROMETRIC MEASUREMENT OF THE PHASE MODULATION

The determination of the Jones matrix parameters can be done also for the case that voltages are applied to the SLM pixels by addressing grey-level images, but the related phase shift cannot be so easily determined from this method. Therefore in this module the phase shift is measured more directly by in interferometric fringe-shift technique. The phase shift $\Delta \Phi$ between two grey levels is given by the shift of the minima $\Delta y$ and the length of the period $g$:

$$\Delta \Phi = \frac{2\pi}{g} \cdot \Delta y$$

$$\Delta y$$

$g$

Figure 6: Shift of the interference minima

In the proposed setup, the fringe pattern produced by the two beams is imaged with moderate magnification to a CCD detector, as shown in Figure 7.

Figure 7: Two-beam interferometer to detect the phase shift

The variable phase modulation between the two beams is introduced by addressing half-screen images (see Figure 8). It is then rather straightforward to determine the relative phase shift from the results, as shown in Figure 9.

Figure 8: Examples for addressed half-screen graylevel images
5. DIFFRACTION AT DYNAMICALLY ADDRESSED RONCHI GRATINGS

In this module a different way to determine the phase shift is explored. By means of diffraction, a simple experimental setup (see Figure 10) is sufficient for this characterization.

For measuring the power transmission, all SLM pixels are addressed uniformly with the same graylevel. From results shown in Figure 11 one can see that the dynamic range of the power transmission is heavily dependent on the orientation of the polarizers.
For the determination of the phase modulation, Ronchi gratings with variable contrast are addressed, with a width of the ridges and grooves of e.g. 10 SLM pixels each. The diffraction efficiency of the 0th order alone is already sufficient for the determination of the phase modulation. For a check of the accuracy, the phase modulation can also be derived from the ±1st orders. As can be seen from Figure 12, both ways of analysis deliver an almost identical result.

Figure 12: Calculated phase shift from transmission measurements in the 0 and ±1st diffraction orders in a ‘phase-mostly’-configuration (θ1 = 59°, θ2 = 110°) with reference grey level ‘black’ at λ=650 nm

6. LINEAR AND X-Y-SEPARABLE BINARY BEAM-SPLITTER GRATINGS

The SLM can be used as an adaptive diffractive beam-splitter element. For an introduction to Fourier Optics and the Fourier series expansion of functions, linear gratings are analysed theoretically and experimentally in this experimental module. As shown in Figure 13, a lens can be used in front of the SLM to observe far-field diffraction at a finite distance.

Figure 13: Fourier lens L1 in front of the light modulator

Even when the SLM is not addressed with a graylevel image, it already works as a diffraction grating due to its pixelized structure. The center-to-center distance in the 2D array of the LC cells can be determined by measurement of the diffraction angles of this 2D grating with a laser of known wavelength. Moreover, a measurement of the powers of these orders is interesting. In Figure 14, the powers measured along the horizontal and vertical directions are shown. The envelope of the diffraction efficiencies permits the estimation of the duty cycles x/g and y/g of the gratings in the two directions, because for a one-dimensional grating with any two transmission values τ1 and τ2 the diffraction efficiency is
\( \eta_l = \frac{\left(\frac{\tau_2 - \tau_1}{\pi^2 \cdot l^2}\right)^2 \sin^2\left(\frac{\pi l}{g} \frac{x_l}{g}\right)}{\pi^2 \cdot l^2}, \)

which means that for \( x_l = g/k \) every diffraction order that satisfies \( l = nk \) disappears. In the experimental results we have minima in about every sixth and every sixth order, respectively, so we have \( x_l/g \approx 1/6 \) and \( y_l/g \approx 1/3 \).

For the measurement of the diffraction orders of actively addressed phase gratings, the diffraction angles will be smaller because of the larger grating period which inevitably is given by a multiple of the pixel pitch. Therefore a setup as shown in Figure 15 is advisable, in which a diverging lens is used to enlarge the observed diffraction angles. For investigation of addressed binary optical elements with a phase shift of \( \pi \), the polarizer and analyzer orientations and the two graylevels used for displaying the images should be chosen carefully from the results obtained in one of the two modules 4 and 5 described earlier.

Binary linear gratings are a particularly suitable subject for the comparison between theory and experiment. The theoretical analysis is relatively easily done by analytic calculation of the Fourier series coefficients. The experiment is also easily doable, because only a small number of spot powers needs to be measured. When carefully set up, the agreement between theory and experiment can be very good (see table 2).
<table>
<thead>
<tr>
<th>Measured value</th>
<th>power [µW]</th>
<th>diffraction efficiency [%]</th>
<th>theor. diffraction efficiency [%]</th>
</tr>
</thead>
<tbody>
<tr>
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<td>199</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>‘Blank Screen’ GL203</td>
<td>204</td>
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<td>n/a</td>
</tr>
<tr>
<td>4/1/4/4/1/4-grating: -3rd order</td>
<td>35.9</td>
<td>17.77</td>
<td>18.01</td>
</tr>
<tr>
<td>4/1/4/4/1/4- grating: -1st order</td>
<td>33.9</td>
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<td>17.27</td>
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<tr>
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<td>0.15</td>
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<td>33.7</td>
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<tr>
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<td>36.0</td>
<td>17.82</td>
<td>18.01</td>
</tr>
</tbody>
</table>

Table 2: Diffraction efficiency for an experimental setup delivering almost ideal binary phase-only modulation with a phase shift of π for the selected polarizer and analyzer directions.

7. COMPUTER GENERATED HOLOGRAMS AND ADAPTIVE LENSES

The optical elements that can be represented by an SLM are not limited to gratings, and in this module more types of optical elements like kinoform holograms, lenses and prisms are investigated. The probably simplest of such elements is a binary Fresnel zone lens (FZL) which is made up from concentric rings. Addressing binary FZLs and determination of their focal length is another way for the students to determine the pixel size of the SLM, because the innermost radius \( r \) of a binary zone lens is given by

\[
    r = \sqrt{n \cdot \lambda \cdot f}
\]

and this radius is of course a multiple of the pixel size. This module is also dedicated to an short introduction into the computation of diffractive elements by numerical methods, and to acquiredment and deepening of the understanding what the diffracted and undiffracted waves are when using an SLM, which in this situation is similar to a conventional hologram or a diffractive optical element (DOE).

![Figure 16: An added lens phase causes a focusing of the diffracted light (red). The undiffracted light is focused behind the screen (black).](image)

The superposition of a spherical phase function representing a lens leads to a spatial shift of the far-field plane along the optical axis. As can be seen in Figure 17, the bright spot representing the undiffracted light wave in the center of the far-field observation plane is defocused in the new far field plane and appears as a background illumination. If in contrast a linear phase representing a prism is superimposed, the center of the diffraction pattern is shifted to the side. With software developed for the education kit, the superposition of these phase functions can be performed instantly, giving the students direct access to vary the settings. Quantitatively, the change of position of the far field diffraction pattern can be measured and related to the parameters of the linear or quadratic phase functions.
8. CONCLUSION AND OUTLOOK

The existing modules already permit a flexible use in optics laboratories of university education, and the feedback we have obtained from the increasing number of users of the ‘OptiXplorer’ education kit is encouraging. We hope to develop the kit further and are interested in suggestions how to improve or extend it.

Of course it is possible to combine experiments from the different modules, for example in order to get a more particular focus on the characterization of the SLM or its application. The characterization of the SLM needs measurements from almost all six modules, including the cell birefringence and director plate orientations obtained from the Jones Matrix parameters analysis, the cell size and geometry from diffraction (with gratings or binary Fresnel Zone lenses) or from imaging in the projector setup, and the voltage-induced phase shift from a measurement with the fringe-shift interferometer or with the Ronchi grating diffraction experiment.

Also, one might also create an experimental module focusing more on the Fourier optical application of the SLM, by taking parts from the two related modules described here and adding more dedicated tasks to it. Further tasks which would fit into such development are the e.g. the set-up of an optical correlator, the investigation of the Talbot effect or a phase-contrast imaging set-up.

ACKNOWLEDGEMENTS

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- PD Dr. Günther Wernicke, Humboldt-Universität zu Berlin
- Dipl.-Phys. Stephanie Quiram (AG Prof. H.J. Eichler), Technische Universität Berlin
- Dipl.-Ing. (FH) Sven Plöger (AG Prof. J. Eichler), Technische Fachhochschule Berlin
Stokes parameters in undergraduate laboratory exercises

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ABSTRACT

Polarization is a concept most students readily understand in terms of the preferential direction of electric field vectors. The visualization of the electric field component of an electromagnetic wave facilitates the understanding of a large body of knowledge concerning propagation and measurement of completely and partially polarized light. Little known to undergraduate students, however, is the Stokes parameters and students typically receive a cursory treatment regarding their usefulness in describing and measuring polarized light in a laboratory or astronomical setting. We present laboratory exercises where students use Stokes parameters when measuring and describing the polarization of electromagnetic radiation and in the statistical analysis of polarized light.

Keyword list: polarized light, Stokes parameters, numerical modeling

1. INTRODUCTION

Most students in science and engineering are introduced to polarization by the preferential alignment of the electric field component of electromagnetic radiation (presumably, after having passed through a polarizer or having been partially polarized upon reflection). In advanced classes further concepts are explored such as birefringence, optical activity, dichroism, and scattering and the mathematical approach to polarization is through the Stokes parameters, the Jones vectors, and Jones and Mueller matrices$^{1,2}$. As thorough as this introduction usually is, students are usually left with few advanced labs where they can explore some of the topics mentioned above. In particular, students may never perform a laboratory exercise where they are required to determine the state of polarization of light in various settings. Likewise, how to correctly handle polarization statistics is requisite knowledge that all students should have an exposure to.
The lab we introduce remedies this situation because it requires students to determine the state of polarization (degree of polarization and position angle) of laser light and how to correctly handle polarization statistics. Additionally, the students gain valuable skill and understanding about optics and optical components (such as the half-wave plate, Wollaston prism, telescope, and CCD cameras) because they are required to set-up and align the experiment themselves.

2. BACKGROUND

The polarization state of radiation is given by the Stokes parameters \( I, Q, U, \) and \( V \) which are defined in terms of the amplitude of electric field components of orthogonal states along two distinct axes perpendicular to the direction of propagation. For example, by choosing the polarization of a simple wave such that \( E_{l0} \) and \( E_{r0} \) are the respective perpendicular and parallel amplitude components in a plane perpendicular to the direction of propagation, the Stokes parameters describing the polarization of this wave are given by

\[
\begin{align*}
I &= E_{l0}^2 + E_{r0}^2 = \sqrt{Q^2 + U^2 + V^2} \\
Q &= E_{l0}^2 - E_{r0}^2 = I \cos 2\beta \cos 2\theta \\
U &= -2E_{l0}E_{r0} \cos(\varepsilon_l - \varepsilon_r) = I \cos 2\beta \sin 2\theta \\
V &= 2E_{l0}E_{r0} \sin(\varepsilon_l - \varepsilon_r) = I \sin 2\beta
\end{align*}
\] (1)

where \( \varepsilon_l \) and \( \varepsilon_r \) are constants, \( \theta \) is the angle the long axis of the polarization ellipse makes with respect to the direction \( l \) and \( \beta \) is the angle whose tangent is the ratio of the two axes of the polarization ellipse.\(^3\) While a more in depth treatment of polarization described above can readily be found in advanced texts\(^4\), it is the properties of the Stokes parameters that we are more interested in, and in particular, the properties of linearly polarized radiation (where \( V = 0 \)).

For plane polarized light, the degree of partial polarization is given by the expression

\[
p = \sqrt{Q^2 + U^2} / I
\]

which can be written in terms of the normalized Stokes parameters \((q = Q / I, \text{ and } u = U / I)\) as

\[
p = \sqrt{q^2 + u^2}.
\] (2)

By decomposing the partially polarized light into two beams that are completely polarized, we can define and \( I_{\text{min}} \) and \( I_{\text{max}} \) that recasts the Stokes parameters as\(^3\)
\[ I = I_{\text{max}} + I_{\text{min}} \]
\[ Q = (I_{\text{max}} - I_{\text{min}}) \cos 2\theta \]
\[ U = (I_{\text{max}} - I_{\text{min}}) \sin 2\theta \]

(3)

from which the polarization position angle can be obtained as

\[ \tan(2\theta) = \frac{Q}{U} = \frac{q}{u}. \]

(4)

It only leaves us now to determine \( I_{\text{min}} \) and \( I_{\text{max}} \) which can be accomplished in a number of ways. One way is to pass partially polarized light through an ideal linear polarizer and measure the transmitted intensity at four angles (0°, 45°, 90°, and 135°). The normalized Stokes parameters would be

\[ q = \frac{Q}{I} = \frac{I(0°) - I(90°)}{I(0°) + I(90°)} \quad u = \frac{U}{I} = \frac{I(45°) - I(135°)}{I(45°) + I(135°)}. \]

In the laboratory exercise we describe below, polarized light is passed through a half-wave plate and then a Wollaston prism which splits the one beam into two distinct, mutually orthogonal polarization states. The total intensity is given by the sum of the intensities of the two beams, which is the \( I \) Stokes parameter, and the difference in intensity is the \( Q \) Stokes parameter. If the fast-axis of the half-wave plate is then rotated by 22.5°, the difference in intensity between the two beams is the \( U \) Stokes parameter. By using a half-wave plate, the Stokes parameters are obtained by a single rotation and measurement of the two intensities at each rotation. Specifically, the Stokes parameters are

\[ q = \frac{Q}{I} = \frac{I_\circ(0°) - I_\circ(0°)}{I_\circ(0°) + I_\circ(0°)} \quad u = \frac{U}{I} = \frac{I_\circ(22.5°) - I_\circ(22.5°)}{I_\circ(22.5°) + I_\circ(22.5°)} \]

(5)

where \( I_\circ \) is the intensity of the ordinary ray and \( I_\circ \) is the intensity of the extraordinary ray measured at the half-wave plate position angles indicated. The half-wave plate can be further rotated in 22.5° increments for subsequent measurements of \( I, Q, \) and \( U \) (only the position angle respect to a fiduciary setting needs to be accounted for).

### 3. EXPERIMENTAL SETUP

The layout of the optical components is shown in Figure 1. The system is a two-beam device in that light from the laser forms two spots on the screen (S) after leaving the Wollaston prism (WP). The laser used is a Pasco diode laser that produces a slightly elliptical shaped beam and the aperture (A) serves to help make the beam...
The neutral density filter (ND) attenuates the light so that variable integration times of the Charge-Coupled Device (CCD) are possible. The polarizer (P1) sets the position angle to be detected. (An additional polarizer can be inserted after this polarizer, P2 in the diagram below, to adjust the intensity as well as observe the Law of Malus). The polarizers are mounted in rotatable stages that can be set to an accuracy of \( \leq 1^\circ \). Since the beam has a fairly large diameter, a telescope composed of two plano-convex lenses (L1) and (L2) are used to reduce the diameter of the beam by a factor of \( \sim 10 \). The analyzer is the half-wave plate (HWP) in a rotatable stage with and the Wollaston prism (WP) has a 20° angle of separation between the two emerging beams. The image of the two spots on the screen (S) is obtained using the CCD camera with lens L3 which is an f/1.8 Nikon camera lens.

![Figure 1. Layout of the optical components.](image)

Figure 2 shows the arrangement of the components on the breadboard for a completed setup and Figure 3 is a close up view of the two spots on the screen with the Wollaston prism and half-wave plate seen on the left. Barely discernable in Figure 3 is the image of the central beam (i.e. the laser beam that has not split into the ordinary and extraordinary rays).

The student starts out by examining Figure 1 and selecting the necessary components needed to perform the exercise. Having learned how to mount components in holders and on the breadboard he precedes to layout the components in the general area where they will be securely mounted. One-by-one he aligns the optical components so that the central beam is in the middle of the camera lens (installing the Wollaston prism and the screen last). The student is asked to build a telescope to reduce the size of the beam by a factor of \( \sim 10 \) and the choice of lenses is left to him. In doing this, the student becomes a contributor in the design process which helps him to take psychological ownership of the project.
Figure 2. Physical arrangement of components.

Figure 3. Image of the two spots on the screen after emerging from the Wollaston prism (left of the screen). The half-wave plate is in a rotatable stage to the left of the Wollaston prism.
Once the layout and alignment is complete and checked by both the student and the instructor, the student is instructed to examine his setup more closely. Using a piece of Polaroid with a marked transmission axis, he examines the beam between the optical elements to ascertain if any polarization is present and what the position angle might be. In the case of the Pasco laser used here, he finds that the beam is polarized to a high degree and easily determines the position angle. He follows the beam with the Polaroid, past the polarizers and telescope, and observes the effect the half-wave plate has as it is rotated. Finally, he sets the fast axis of the half-wave plate vertical and observes the polarization state of the two beams emerging from the Wollaston prism in order to determine their nature. With the Wollaston prism oriented to produce the two spots as shown in Figure 3, the top beam is polarized horizontally with respect to the optical table and the bottom beam is polarized perpendicular to the table.

Since the two beams are the ordinary and extraordinary rays, Figure 4 shows the behavior of the two spots as the half-wave plate is rotated from 0° to 157.5° in increments of 22.5°. The left spot in Figure 4 is the top, horizontally polarized beam shown in Figure 3 while the right spot is the lower, vertically polarized beam. As the half-wave plate is rotated to 180° this corresponds naturally to 0° again and the pattern repeats itself. For purposes of identifying how far the half-wave plate rotates, the measurements obtain until 337.5° at every 22.5° is recorded at the angle it was made.

![Image of two spots on screen](image-url)

**Figure 4.** Image of the two spots on the screen. The left spot is horizontally polarized with respect to the optical table while the right beam is vertically polarized with respect to the table.
In order to measure the intensity of each spot, aperture photometry is performed using the software program Mira Pro by Mirametrics. This involves setting the ON aperture to measure the amount of counts (or ADU – Analog Digital Units) for each of the two spots and subtracting a background (the “OFF”) that has the same area as the ON. The median background is obtained using an annulus surrounding the ON aperture that has an inner radius larger than the ON radius with a typical width on the order of 10 to 20 pixels.

In order to determine an appropriate size of the ON aperture, the student first plots the signal (ON – OFF) in a series of increasing apertures centered on the centroid of one of the spots as a function of aperture radius. Additionally, the signal-to-noise (S/N) ratio is plotted for each of the radii as well. As the size of the aperture increases, the signal will increase as will the S/N ratio. The signal will start to level off as the aperture increases beyond where the signal is indistinguishable from the background noise. This simply reflects the fact that the subtracted background is approximately equal to the signal added by the increased aperture size. However, as the aperture is increased beyond a certain point, the S/N ratio will start to decline as the aperture becomes too large.

![Figure 5. Signal (top) and S/N ratio (bottom) as a function of ON aperture size measured in pixels for a bright spot (left) and dim spot (right).](image-url)
Figure 5 illustrates how the signal-to-noise ratio changes for a bright spot (left graphs) and a dim spot (right graphs). While the signal-to-noise ratio may decrease more rapidly for the dim spot, the actual S/N ratio itself remains quite high. By choosing an aperture radius that is larger than where the S/N ratio peaks, the student is assured of accurately measuring all of the light from both spots using a single size aperture without significant loss of signal.

4. MEASUREMENTS

In order to measure polarization, polarizer P1 is set to a known angle. The neutral density filter should be initially set so that light from the laser does not saturate the CCD. The half-wave plate is rotated by 22.5° increments from the fiduciary setting of 0° with 10 images taken at each angle. Aperture photometry (described above) is performed on each spot in each image in order to determine the intensity of the ordinary $I_o$ and extraordinary $I_e$ ray. From these measurements the normalized Stokes parameters are computed using equations (5). Given the high degree of polarization and large signal-to-noise ratio, it would be acceptable to estimate the degree of polarization and position angle for each pair of measurements and average these values. However, in general, when the degree of polarization is low and/or the signal-to-noise ratio is small, one should not average the individual polarization measurements, rather, the average of the Stokes parameters is acceptable since they are normally distributed. Once the averages of $q$ and $u$ are determined, the degree of polarization and position angle are then computed.

The measurements from one experiment are shown in Table 1. The data show that there is an instrumental polarization of about 1° mostly likely caused by a misalignment of an optical element(s) but is otherwise in agreement with the set polarizer angle. Figure 6 demonstrates the agreement between the measured polarization and set polarizer angle. Students can estimate the error in the position angle using standard techniques in error propagation and their measurements of $u$ and $q$. Since the position angle is given by equation 1.4, calculation of the error in position angle ($\delta \theta$) is

$$\delta \theta = \frac{1}{2} \frac{u \sigma_q - q \sigma_u}{u^2 + q^2}$$

where average values and normal error statistics are used.

The measured degree of polarization was consistently around 99% owing to the polarized output of the laser. Since the degree of polarization is very large in this exercise, no polarization estimator is necessary. However, for the sake of completeness, students calculate an estimation of the polarization as if it were small. When the degree of polarization is small, an estimator is necessary due to the nature of polarization.
statistics\textsuperscript{6,7} and the one used here is the Wardle estimator\textsuperscript{8} given by $\hat{p} = \sqrt{p^2 - \sigma_p^2}$ where $p$ is the measured polarization and $\sigma_p$ the uncertainty in the measured polarization. The uncertainty can be estimated in various ways\textsuperscript{9} however, alignment of the polarizer and wave plate are most likely the largest sources of error. Therefore, a realistic estimate of $\sigma_p$ is given by Serkowski\textsuperscript{3} as $\sigma_p = \rho \cdot \sigma_\phi$ where in this exercise we take $\sigma_\phi$ to be the uncertainty in the alignment of the optics expressed in radians. Since the half-wave plate is rotated by hand and read from a rotation stage, an estimate of $\sigma_\phi$ is on the order of $\sim 1^\circ$ so the estimated uncertainty in polarization $\sigma_p$ is $\sim 0.02$ therefore making $\hat{p} \equiv p$.

<table>
<thead>
<tr>
<th>Angle of P2 (Degrees)</th>
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<th>Uncertainty (Degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>-1.06</td>
<td>0.06</td>
</tr>
<tr>
<td>20°</td>
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<tr>
<td>160°</td>
<td>158.9</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Figure 6. Measurements of the measured polarization position angle as a function of the set polarizer angle.
5. DISCUSSION

This exercise bridges a gap between theory and practice by familiarizing students with Stokes parameters and having them measure polarization using a Stokes parameter technique. The students improve their optics skills by setting up the experiment on an optical bench, calculating distances for the telescope used, and integrating the various components. They acquire knowledge of CCD operation as well as photometry and learn the basics of handling polarization statistics. There is also room for innovation and improvement that students are encouraged to contemplate. For instance, the introduction of a second polarizer in the set up could be used to vary the intensity of the beam and observe the Law of Malus. This is left as an exercise for students to suggest and perform if they wish.

The cost of the experiment can be nominal if various components are readily available in the lab. The CCD and computer software used to acquire and measure the light intensity is a costly part of the experiment and alternative ways of measuring the intensity of the two beams can be explored. The cost of the wave-plate and Wollaston prism can be substantial, but it is assumed that these are found in most optics laboratories.

6. REFERENCES


7. ACKNOWLEDGEMENTS

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Optics in Eastern Connecticut

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ABSTRACT

Through a partnership between EASTCONN, a regional educational service center, and Three Rivers Community College, both located in eastern Connecticut, students from 5th grade through college have been learning about optics and photonics. Using innovative approaches including hands-on workshops on selected topics in light, vision and optics/photonics, field trips to local photonics industries, and authentic learning opportunities at a college campus, students and their teachers are learning about light and optics with age-appropriate activities and are also being introduced to the potential career opportunities.

1. INTRODUCTION

Although many know only of Connecticut’s “gold coast” adjacent to New York City, the two easternmost counties in the state are mostly rural low-income towns with a few small cities scattered here and there. Three of Connecticut’s fifteen “priority” (lowest achieving) school districts are in Windham and New London Counties, and two of these districts have more than 70% of students qualifying for free or reduced price lunch. Median income is well below the state average and fewer residents hold college degrees. However, a thriving network of optics/photonics educators has evolved over the past 14 years despite the relatively low number of photonics employers in the region. The network continues to grow due to the leveraging of several sources of funding and the enthusiasm of the partners involved.

Through its National Science Foundation/Advanced Technology Education (NSF/ATE) grant-funded PHOTON projects, the New England Board of Higher Education (NEBHE) has involved high school and community college faculty in four teacher professional development programs in optics/photonics. Together with EASTCONN, one of Connecticut’s six regional educational service centers, the PHOTON educators have received funding from SPIE, the Optical Society of America (OSA), the NSF/ATE funded Regional Center for Next Generation Manufacturing (RCNGM) and the Interdistrict grant programs funded through the state of Connecticut and facilitated by EASTCONN to bring together students from fifth grade through college in the study of optics and photonics (Figure 1).

![Figure 1. Eastern Connecticut optics education network](image-url)
2. THE PHOTON PROJECTS

Beginning with the first NSF/ATE grant in 1995, NEBHE has involved Connecticut educators in all four of the PHOTON projects which were designed to increase the number of schools and colleges teaching optics/photonics. One of the authors (J.D.) was a participant in the first project, the Fiber Optic Technology Education Project (FOTEP) and with the support and encouragement of the FOTEP principle investigators, developed an associate degree in Laser and Fiber Optic Technology at Three Rivers Community College, located in southeastern CT. This remains the state’s only two-year program in optics/photonics. In 2007, a second photonics-related program was created when a Laser Manufacturing option was added to the Manufacturing Engineering Technology associate degree program after a needs survey of manufacturers in southern New England.

The second PHOTON project expanded the scope of technology covered in professional development workshops to include optics and lasers and it included high school teacher participants from two eastern CT high schools, H.H. Ellis Technical High School and Plainfield High School. PHOTON introduced a “regional alliance” model that encouraged high schools and colleges to work together to improve access and articulation for students. As alliance partners, Three Rivers, Ellis Tech and Plainfield HS began to explore ways they could work together, beginning with informal tours and workshops for high school students held at the college. Teachers from the three institutions were also involved in PHOTON2 and PHOTON PBL (Problem Based Learning) projects with a national scope that strengthened the Connecticut alliance through collaboration with distant partners and industry mentors.

The PHOTON projects produced a number of educational products that have been used in workshops and outreach activities as well as in classroom settings, including a textbook, a laboratory kit with experiment manual and a set of online videos, and instructions for simple optics Explorations also with online video presentation.

3. PROGRAMS FOR ELEMENTARY SCHOOL

3.1 Fifth grade Optics in the Classroom

The collaboration between Three Rivers Community College and EASTCONN began in 2006 when light and vision were added to the Connecticut science curriculum for 5th grade students; these concepts were added to the Connecticut Mastery Test (CMT) in 2008. In order to prepare students for the test, a standards-based workshop was developed to introduce optics concepts to fifth grade students. The workshop, Optics in the Classroom, has been offered each year since 2006, with facilitators from EASTCONN and the Three Rivers Student Chapter of SPIE. The day-long workshops feature three concurrent activities lasting approximately one hour each.

To create lessons that would satisfy the needs of younger students, hands-on activities were adapted from the PHOTON Explorations and the Hands-on-Optics project. The activities selected cover concepts from the Connecticut Core Science Curriculum Framework Content Standards and Expected Performances – Core Science for grades 3-5. Students are expected to not only perform the activities but also to record observations and draw conclusions based on their observations (Figure 2). Activities chosen for Optics in the Classroom have varied somewhat from year to year and have included:

- **Make-and-take Spectroscopes.** Students make spectroscopes from cardboard tubes, diffraction gratings and laser-cut poster board slits. (The slits are cut by students at Three Rivers on an Epilog 45 W laser engraver.) After observing a number of light sources such as incandescent and fluorescent bulbs, LEDs and gas tubes, students take the spectroscopes home to continue their observations. This activity also stresses safe observations by asking students to affix a warning to the tube stating “Do not look at the sun or into a laser!” Some time is spent discussing the dangers of observing bright light sources.

- **Gelatin Optics.** Students use a laser pointer and gelatin slab to study refraction and absorption of light and cut lens shapes to investigate how light behaves at a curved surface. Again, strict laser safety rules are imposed and students who do not follow the rules are told to sit out the activity.
• *The “Magic Box”*. This activity uses four polarizers to create the illusion of a solid wall inside a cardboard box. The activity contrasts “descriptive writing” and “scientific writing” and students are required to write scientifically about what they see.

• *The Mirror Challenge*. Students are introduced to the law of reflection and then must use that knowledge and a protractor to position mirrors in order to hit a target with the beam from a laser pointer. Again, laser safety is stressed.

• *Waves and Sound*. Students make waves with beaded chains and Slinky® toys and measure wavelength and amplitude. The relationship between wavelength and sound is explored.

After each workshop, students have been asked to fill out an evaluation form and discuss their favorite activity. The overall favorite varies from year to year and may be somewhat dependent on the facilitator. For example, in 2009 students particularly liked the Mirror Challenge, led by two enthusiastic young men from the Three Rivers SPIE Student Chapter. In four years of workshops, nearly 500 students from four eastern Connecticut towns have been impacted by the Optics in the Classroom program.

Figure 2. top: Fifth grade students make the cardboard tube spectroscope from the PHOTON Explorations and use it to study the emission spectra of various light sources. Bottom: Protractors are used to line up a “shot” taken with a laser pointer in the Mirror Challenge from Hands-on-Optics.
3.2 Professional development for teachers

Although the workshops for students have been very successful, more students would benefit from our lessons if their teachers were able to conduct them in their own classrooms, reinforcing the concepts and answering individual student questions. To meet the need for teacher professional development in optics, we developed a workshop for teachers in which hands-on activities, scientific inquiry, and scientific literacy are combined to deepen understanding and interest in optics. The yearly workshop has evolved to include some commercially available science materials as well as those developed by PHOTON and Hands-on-Optics. Since 2007, 75 teachers from across Connecticut have participated in the yearly EASTCONN optics workshops.

Even after attending a workshop, some teachers are still reluctant to teach the material because of a lack of background in the subject. To assist these teachers, we provide ongoing technical support and encouragement. Other teachers face the lack of funding to purchase supplies needed for hands-on activities. Through a three-year grant from the OSA Foundation, EASTCONN has purchased a number of Hands-on-Optics kits and made them available to teachers who have been trained in their use.

3.3 Dark Skies at EASTCONN

Dark Skies at EASTCONN is a multifaceted program generously funded by the OSA. The program is part of EASTCONN’s Expanding Horizons, an interdistrict diversity program funded through the state of Connecticut. Expanding Horizons encourages teams of students from diverse backgrounds in grades 5-12 to build positive relationships, critical thinking and problem solving skills while working together in cross-district partnerships on authentic science based projects. High school and college students also participated in Dark Skies on an individual basis through their teachers’ participation in other EASTCONN projects.

In the Dark Skies project, students from 5th grade through college measured the brightness of the nighttime sky using sky quality meters and visual observations of the constellation Orion and then compared the results with national and international student partners. Participating students were from the states of Connecticut, Alaska, Ohio, and New York, as well as New Brunswick, Canada, Wales and Slatina, Romania. Student data is included in our own database for future studies of light pollution and also forwarded to the National Optical Astronomy Observatory (NOAO), Tucson, AZ, and contributed to Globe at Night, an international project to measure the brightness of the night sky.

The initial kickoff meeting in Fall 2008 introduced teachers to the program and featured Bob Crelin, Connecticut author of There Once Was a Sky Full of Stars, a book about light pollution for young children. Each participating teacher received a copy of Crelin’s book purchased with funds from RCNGM. Throughout the fall and early winter, instructional materials were developed to introduce students to the use of the meters and observation and data sheets. Students from a middle school technology class created a set of videos illustrating how to hold and read the meters and record data properly. While the facilitators were busy with developing materials, the fifth grade students wrote pen-pal letters to their distant partners, introducing themselves, their families and schools.

Each of the participating schools received a kit of materials purchased with funds from the OSA Foundation grant (Figure 3). In addition to the Crelin book, each kit contained demonstrations to illustrate the effects of light pollution and how shielding outdoor lighting both improves vision and preserves the night skies. Each class received two sky quality meters so that students could take quantitative as well as qualitative data.

In the first year of the project (2008) the students attended a final workshop where they constructed and used a simple refracting telescope from the Hands-on-Optics kit. Two special guests from NOAO led the activities, assisted by students from Three Rivers and a volunteer amateur astronomer who amazed students with his own “professional model” telescope. For 2009, students attended the telescope workshop before taking data; this workshop was facilitated by students from the Plainfield High School after school Astronomy Club. A second workshop at the end of the project featured a rented indoor planetarium in addition to optics activities.

Another new feature in 2009 was a video conference with Dr. Constance Walker, an astronomer at NOAO, who shared her knowledge with students and teachers from Connecticut, Canada, Ohio and Romania. Participants used Skype, free software for internet telephone, and Bridget desktop-sharing software. This system was also used to enable the students to share and comment on their Dark Skies data.
Future Dark Skies at EASTCONN plans include an ongoing study of the brightness of the nighttime sky with an ever-expanding group of students. In addition, in celebration of the Year of Astronomy, students will be making Galileoscopes in an online class. Dark Skies at EASTCONN is unique because students engage in authentic scientific study while also enhancing their global awareness through an international partnership and study of the nighttime sky. To date, two high schools, two colleges and four elementary schools in the US and their partner schools in have taken part in Dark Skies at EASTCONN.

Figure 3. The Dark Skies activity kit

4. HIGH SCHOOL AND COLLEGE PROGRAMS

4.1 High school courses

Through PHOTON and PHOTON2, both Plainfield High School and Ellis Technical High School received laboratory kits for teaching optics/photonics containing both “science lab” and industry quality materials. Through the College Career Pathway (formerly Tech Prep) each school purchased additional materials to support a complete optics laboratory. Both schools then developed optics/photonics elective courses for their institutions.

At Plainfield High School, the course closely follows Three Rivers’ PHO 101 Introduction to Light and Lasers. The high school course has been approved as either a science or technology elective in the College Career Pathway agreement between the high school and the college. This means that students enrolled in the College Career Pathway program can earn 3 college credits for the optics/photonics course when it is taken as part of their high school program. Students in the College Career Pathway can earn up to 14 college credits in math, English communications, science and a career area while still in high school.

While the students at Plainfield High School all reside in the town of Plainfield, Ellis Tech serves approximately 600 students from seventeen towns in northeast Connecticut. Ellis Tech is a “school of choice,” that is, students are accepted based on standardized test scores and other academic records from middle school. At the end of their freshman year, students choose from among ten specialized areas of study: architectural technologies, automotive collision repair, automotive, carpentry, electronics, electrical, hairdressing and barbering, manufacturing, masonry, and plumbing and heating.

Three Ellis Tech teachers, two from the sciences and one from a technical shop along with a guidance/career counselor participated in the PHOTON and PHOTON2 projects. The full-year Introduction to Optics course was developed by science teacher Donna Goyette with support from the Regional Center for Next Generation Manufacturing. The course is based on the instructional units of the PHOTON and PHOTON2 professional development courses. The technical high school year is divided into eighteen ten-day cycles; one half of the time is spent in academics (mathematics, science, English, humanities and social science, as well as health and physical education) alternating with units in a technical/trade shop. To accommodate this cycle,
Introduction to Optics is structured in nine ten-day units, equivalent to a one-half year course at a comprehensive (non-technical) high school.\textsuperscript{9}

The technical high school optics course is unique in that it uses a hands-on, discovery-based approach integrated with examples from the technology and trade shops at the school. Goyette visited each of the shops to learn where optics was used in each technology. For example, in the automotive shop students learn to troubleshoot automotive optical systems and student hairdressers and barbers see applications of optics in the color pigments of hair dye. Every optics unit is infused with examples from the shops, and learning optics in a science class increases student confidence when they return to the shop environment. Since many technical high school students have difficulty with or are fearful of mathematics, the discovery approach allows them to learn concepts through inquiry-based experimentation and activities. The need for mathematical analysis arises naturally from student observations.

4.2 College Programs

Three Rivers Community College has the only optics/photonics two-year associate degree program in Connecticut, Laser and Fiber Optic Technology (LFOT).\textsuperscript{10} Created in the mid 1990's with assistance from the FOTEP project principle investigators and an industry advisory committee, the program has continuously evolved to keep up with industry needs. Originally focusing mainly on fiber optic communications, LFOT has added courses and course modules in lasers and laser applications as these technologies have become increasingly important in Connecticut. LFOT graduates are employed as technicians in the optics/photonics industry of Connecticut and across the United States.

The LFOT program has also worked with agencies in Connecticut to provide training for both displaced and incumbent workers, including two-day fiber optic workshops, a 15 credit telecommunications certificate offered to workers at a fiber optics company using a combination of online and in-person instruction and non-credit 40 hour laser technology courses taught on site at several laser manufacturing companies. A LFOT certificate has been developed to serve the needs of working technicians whose primary training is in electronics or manufacturing technology. Some of the courses are offered online or and online/in class hybrid versions.

4.3 Laser Camp

For several years, Three Rivers Community College received grant funding from SPIE to offer a summer credit course in optics/photonics to high school students. As college fees increased, fewer students were served and it was no longer practical to offer the course. At the 2006 meeting of the Laser and Fiber Optic Technology Industry Advisory Committee, member Donna Goyette suggested we apply for funding for a “Laser Camp,” a multi-day activity that would introduce students to optics/photonics science, technology and careers. Laser Camp would target high school juniors at Ellis Tech, perhaps encouraging them to sign up for Introduction to Optics in their senior year.

The first Laser Camp was held in 2007 with students from Ellis Tech, New London High School and members of a Scout troop from Plainfield, CT. A few middle school students, friends and relatives of facilitators, also participated. The New London physics teacher had also been a PHOTON project participant and the Plainfield students were in a troop mentored by a Three Rivers SPIE student chapter member. It was decided to hold activities during the school year when students are easily contacted and on Saturdays as a college event to avoid high school travel restrictions and the need for hiring substitute teachers. The 2007 Laser Camp was funded by grants from SPIE and RCNGM and was attended by 30 middle and high school students and six college student mentors. Three teachers/faculty served as facilitators.

Two days of workshops took place in the Three Rivers labs; students created reflection holograms, made pinhole cameras and learned to develop the photos, tried online laser challenges and made laser engraved and cut wooden key tags. Each participant received a tee shirt and took home the items they made as part of the camp. The third day was a trip by motor coach to Boston, MA to visit the Science Museum and the Massachusetts Institute of Technology Museum in Cambridge (Figure 4). Student evaluations of Laser Camp were extremely enthusiastic and it was clear that this activity would need to continue in some form as long as funding could be secured. Three students from Laser Camp 2007 subsequently enrolled in laser-related programs at Three Rivers.
Laser Camp continues to grow; 43 students from four high schools attended in 2008 and 62 students from five high schools in 2009 (Figure 5). Beginning in 2008, collaboration with EASTCONN’s *Expanding Horizons* grant provided funding for the transportation from distant high schools to Three Rivers, a major portion of the budget. Additional funding still comes from grants from SPIE and RCNGM. Because the EASTCONN funding precludes Saturday activities, Laser Camp is now held on three regular school days with two days at Three Rivers and a third day visiting the laser manufacturing and applications facility at Trumpf, Inc. in Farmington, CT. Scheduling three days away from school has proven to be problematic; school vacations, standardized testing, the technical high school academic and shop cycles and the availability of the Three Rivers labs all must be considered. In 2009, one session was repeated on two different days to accommodate the technical and comprehensive high school schedules.

The Laser Camp curriculum has expanded to include EASTCONN facilitated team building activities among students from different high schools and it still includes a number of activities that produce “take-aways” that students can show off when they return to school. In addition to pinhole cameras, holograms and laser engraved key tags, a “polarized light art” activity has been added. Students create colorful “art” by sandwiching laser cut cellophane shapes between squares of polarizing film. Three Rivers pens, Laser Camp tee shirts and logo bags of college and program information are given to each student as well.

When Laser Camp was a small Saturday activity, the facilitators were the three high school and college faculty. College students served as mentors and assistants. The growing size of Laser Camp required additional facilitators, so the Three Rivers SPIE student chapter has taken up the task of leading activities, including providing background information on the science and technology involved. In 2009, ten SPIE members helped out as activity leaders and assistants, serving as role models to the high school students while sharpening their own leadership skills.
5. INTERNATIONAL POSTER CONFERENCE

Light in our Life, an international poster contest for students, was first planned by Romanian participants in PHOTON PBL and the authors during the summer 2008 PHOTON PBL workshop in Boston. A limited contest was piloted in the spring of 2009. Invitations to submit poster art were sent to the Dark Skies at EASTCONN schools and selected schools in Europe. Entries could be in one of three categories: photograph, hand drawn or painted or computer art. Entrants were also required to submit a 100 word statement on how their entry illustrates the theme, Light in our Life.

Two groups of science, technology and art educators screened the entries from each continent before submitting the top few in each category for final judging. Entries were judged on artistic impression, technical merit, originality, and how well the art expresses the theme of the contest. Trophies were presented to winners in two age groups, 10-13 years and 14-18 years, in each of the three art categories. Each winner and honorable mention entry also received a certificate and a copy of their art rendered as a poster. Classroom teachers of winners also received a set of the winning posters. Figure 6 shows the winners in the 14-18 year old photography and the 10-13 year old drawing/painting categories.

The 2009 contest was supported by SPIE, which provided the trophies, and the OSA Foundation grant, which was used to print the posters. The planners hope to expand the contest next year by adding additional schools in more countries.

Figure 6. Two of the winning entries in the Light in our Life poster contest: (top) Age 14-18 Photograph (bottom) Age 10-13 Painting/Drawing
6. CONCLUSION

Through collaboration and pooling of resources, schools and organizations in eastern Connecticut have created a network of educators, students and industry working to promote optics and photonics education and careers. The network continues to grow by leveraging grant funding from a number of sources and including present and former students as mentors and advocates for optics/photonics.

7. REFERENCES

[4] PHOTON project materials, including Laboratory and Exploration videos, are available at www.photonprojects.org
[6] Hands-on-Optics information is found at www.hands-on-optics.org/
[8] Components of the PHOTON Laboratory Kit may be seen at www.photonprojects.org
[10] Program information may be found at www.lasertechonline.org

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FOTEP
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OSA FOUNDATION
The OSA Foundation is a charitable organization dedicated to supporting programs that advance youth science education, provide optics education and resources to underserved populations, provide career and professional development resources and support awards & honors that recognize technical and business excellence
More training modules for an advanced interactive course on optical design

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ABSTRACT
The purpose of this paper is to explain in more detail some of the ideas first presented at earlier Institute of Physics and S.P.I.E. conferences, and to give an update on the work that has been done by the authors and others to develop online tutorial materials, particularly for those who do not intend to specialise in optical design. The latest additions to these courses, involving real lens design and analysis tasks, are now available on the Ancient and Modern Optics web site in unrestricted download format.

KEYWORD LIST
Lens design, optical design, remote learning, on-line course, OSLO-EDU.

1. INTRODUCTION
The question of remote teaching of optics in general and optical design in particular has been of interest to the first author since 2000. At that time he conducted an informal investigation into remote teaching methods in connection with a vacancy for a course manager for the MSc course at an academic institution. This included a brief to bring as much of the material of the course as possible onto the internet to enable at least parts of the course to be undertaken without attendance at the college involved. He was of course aware of the pioneering work of the Open University. What surprised him at the time was how much progress had been made, particularly in countries like Australia and the USA where access to higher education can involve travel over long distances. The internet was relatively young at the time. But some quite sophisticated software packages were already on the market, some of which aimed to integrate the needs of both in-house and remote course participants in academic institutions. Some aspects of remote learning were even compared favourably to conventional methods. For example, the view was expressed that access to a busy teacher was sometimes easier by email than by waiting in the queue outside the teacher's office.

He presented some of the results of this study at Photon02 in an impromptu paper¹ presented at very short notice. This related some of his experience in teaching optical design, not as an academic discipline within a physics department, but as a number of concentrated stand-alone courses, tailored to meet the needs of a specific audience.

2. WHY REMOTE LEARNING?
The second paper² on this subject was presented by the authors in 2005. This proposed, in essence, that optical design should not in future be regarded as a specialised discipline restricted to the small and diminishing number of current full-time professionals with a background in applied physics. It was rather that optical design should be looked on as an additional skill of an engineer who has a full-time occupation in another field such as mechanical design. This skill can be acquired both over the internet and through professional short courses.

If this approach is taken seriously, the candidates for the courses will change. There will be fewer who are students in full-time education, more who are engineers broadening their skills base. Also, because the audience will change, the teaching materials should change (particularly since interactive graphics and Java have now become widespread) and so should the teaching methods.

Optical design is particularly suited to remote teaching methods for the following reasons:

- Many topics can be conveyed better in pictures than in words or formulae.
Interactive computer graphics are already an integral part of today’s optical design software.

Since video is unnecessary, connections to the internet for remote learning do not need to be broadband.

The teaching material is greatly enhanced by the use of colour which can be provided online at no extra cost.

The software necessary for hands-on experience can be downloaded free of charge.

3. WHO NEEDS IT?

There is now so little institutional teaching of optical design that, in most parts of the world, remote learning is in fact the only way in which future demand for optical designers can be met. In many countries, including the UK, demand already exceeds supply. This is evidenced by vacancies advertised month after month on the web. For the same reason, new courses can be developed afresh, outside the constraints of academia, using few, if any, traditional material and methods.

Another point is that optical design has come a long way since the designer could afford to spend months perfecting a design. Results are expected much sooner. Also today’s designer is expected to have proficiency in designing for a much wider range of applications. The specialised optical knowledge needed to design, say, a pair of binoculars, a medical endoscope, a LIDAR objective and a spectrometer, is essentially the same. However the surrounding issues – whether of mechanical engineering, commercial, environmental, or optical manufacture - differ greatly in each case. So the model we are trying to promote is not, for example, an electronics specialist contacting an optical designer for help with a new product. It is rather of, say, an electronic engineer who spends evenings developing optical design skills to enable him to undertake small optical design tasks during the day without outside help. This frees the specialist designer to dedicate more time to specialised optical design tasks.

4. WHAT ARE OTHER PEOPLE DOING?

The temptation with many internet applications is to allow the technology to drive the content rather than the other way round. For teaching of pure optics, there are many websites offering excellent applets in Java which illustrate individual phenomena. Links to some of these can be found on the amoptics.com website under “Links.” Very few, however, teach optical design as such except at the simplest level.

One trend in recent years has been the OpenCourseWare movement, by which universities make large amounts of teaching materials, course notes and video lectures freely available to the worldwide internet community. This reportedly benefits the university by improving the skills of those admitted for full-time study, as well as improving the quality of the teaching material itself. The movement first began at the Massachusetts Institute of Technology in 2003, but has now grown into the OpenCourseWare Consortium (http://www.ocwconsortium.org/) with 200 participating institutions. Currently this has 2386 courses on offer. One good example in the field of optics is the series of 49 video practical demonstrations by Shaoul Ezekiel of MIT. Others are unfortunately marred by the absence of diagrams originally copied from copyright textbooks, which may not be published on the internet.

5. WHAT ARE THE BUILDING BLOCKS?

One of the gratifying aspects of this work is that material which has been originated using familiar Microsoft Office tools can readily be adapted and converted to formats best suited to the internet. The progression from simple textual material to the fully interactive graphical presentation is illustrated by the following examples, all but one of which have now been implemented on the amoptics.com website. The figures give sample images from each.

Text: The glossary of terms used in optical design in English, French, German, Italian and Spanish is now available for free download as a PDF. This uses colour to discriminate between the different languages in a way which would be prohibitively expensive if published on paper. The header for this is illustrated in Figure 1.

Figure 1 Sample of text from the multilingual glossary

OPTICAL DESIGN GLOSSARY
Glossaire d’optique
Glossar des optischen Designs
Glossario di progettazione ottica
Glosario de diseño óptico
**Sequential pictorial:** The basis that Ancient and Modern Optics use to originate their visual aids is Microsoft PowerPoint. The two presentations on "Lens Manufacture" and "Optical Assembly" have been converted for internet display in a format which is easy to access but which discourages downloading. One slide, which illustrates the testing of the first polished side of a lens for form error, is given in Figure 2 as an example.

**Stepped sequential pictorial:** The step-by-step assembly of a diagram, such as would be created by a chalk-and-blackboard teacher, can be simulated in a PowerPoint presentation by rapidly progressing through the slides. An example of this is given in Figure 3 below. This sequence illustrates in simple terms, the transverse ray aberration diagram for a case of primary spherical aberration.

**Interactive sequential pictorial:** Once the presentation is on the internet in HTML, new possibilities open up. For example, one can allow the user to explore the pictorial area with the mouse to locate helpful short notes on a particular feature of the slide. This gives a sense of participation which is missing in a passive presentation. One example of this may be found in the "pop-up" associated with the slide illustrated in Figure 4, which is taken from the multilingual internet presentation Fundamental Optical Design. This password-protected course is offered as a precursor to all optical design training courses offered by the principal author. The diagram is an extension of the slides shown in Figure 3. Note the language and navigation buttons on the bottom toolbar. The presence of a "pop-up" is indicated by a slide number in violet. Another use of a "pop-up" is in the definition of an unfamiliar term.
A similar interactivity is offered in the provision of a “commentary” on the same slide. This is intended as the text of an audio track to be recorded in the future for linking to this slide. The cursor must be placed on the Light Tec logo, as shown in Figure 5, to activate this feature. (Light Tec in France were the sponsors of the courses for which this material was originally developed). The commentary box has some transparency, and it moves with the cursor to enable the user to look at the parts of the diagram which it overlays.

Further interactivity is provided by “movie” presentations in the same course, which play, speeded up, a pre-denominated sequence of slides. For example, one illustrates the non-linear motions of a zoom objective7. The user should view in full-screen mode, and press the cine button in the toolbar along the bottom to start the zoom motion demonstration. The opening slide in this sequence can be seen in Figure 6.

Of course the ability to switch languages has made this popular in European countries. Three examples are shown below in Figure 7. Further language versions are planned in the future.

At present a password is issued for each course. However the site has been implemented in such a way as to allow each participant to have an individual password, if desired. The tutor could then ask for a report of how often each participant had logged onto the website, and for how long. This would be a useful step before implementing the next stage.

Conditional non-sequential presentation: It is not hard to envisage a scheme in which navigation through the presentation is conditional upon responses to multiple choice questions. This would give the fastest learners a quicker route through the course material, and allow for the provision of extra material for slow learners. The bar at the bottom of the slide presentations has been designed with enough flexibility to permit this to be added. Of course, the technology also exists to collect these responses and to report to the tutor. The tutor would then be in a position to give the student timely assistance via email or video link. Implementation of this, however, must wait till another day.

6. CAN REAL DESIGN TASKS BE INCLUDED AS PART OF THE COURSE?

The short answer to this question is an emphatic “yes.” Teaching material written for the express purpose of helping a complete novice to undertake a number of optical design tasks has been written, and it is now available8. Expressed in the clearest possible terms, the participant is shown how to download and install the software (OSLO-EDU ®) and then undertake the aberrational analysis of a spherical concave mirror, and choose the best image plane.
In the second presentation, a plane parallel plate of silica is introduced at the centre of curvature, and slider wheel optimisation (unique to OSLO) is used to determine the best aspheric coefficients to complete the design of an f/1.4 Schmidt camera objective.

The last stage is to design a 10mm f/2.8 40° triplet objective using damped least squares optimisation. This uses OPIC, a routine which defines a merit function as described in the 2005 paper. OPIC is written in the OSLO macro language CCL, and is provided in ASCII format for download and compilation. More advanced students might also like to look for the global optimum of the “Monochromatic Quartet.” Instructions for doing this are given in the 2005 paper.

7. CONCLUSION

Next time you need a telescope designed,
Tailor-made or optics-off-the-shelf,
Don't fumble in the Yellow Pages. Find
A way in which to do the job yourself.
Don't start to try to learn by heart the name
Of every aberration - you will fail.
The principles in each case are the same:
Reduce the spot size, maximise the Strehl.
No earthly pleasure can provide such bliss,
Nor mortal cup of happiness can fill,
Than standing up in triumph, crying this:
"My error function's going down the hill!"
   Be confident, persist, don't flinch the fight.
   With distance learning you shall see the light!

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A conceptual course on LASERs for general education

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ABSTRACT

It is important to improve the technological skills and scientific understanding of students who are not pursuing scientific and technological degrees because they are indirectly asked to support science. To be supportive, they need to be able to evaluate scientific information as portrayed by the media. The difficulty is to find a topic which will stimulate and hold their interest in science. One such topic is LASERs. LASERs hold a fascination for students. LASERs are used in a wide array of technological devices and procedures. To understand LASERs requires an understanding of light and optics; of how light interacts with matter and with the structure of matter. Therefore, a course about LASERs can entice students who typically avoid science classes, and in particular physics classes, into taking a physics class, thereby giving us the opportunity to improve their understanding of science, their critical thinking skills and developing their appreciation of basic physics. Such a course can establish a sense of confidence in these students’ ability to understand.

Keywords: lasers, active learning, interactive engagement, general education, non-technical major students, nature of science

1. GENERAL EDUCATION

In the United States, pre-college science education tends to be weak for students with little interest in science. It is especially weak in physics which is often offered as an elective in a student’s penultimate year. It is not unusual for students to enter university without any physics background at all. Additionally, student experience in science classes all too often stresses memorization and rules rather than understanding, leading to either fear or dislike of science.

U.S. universities require students to complete general education programs in addition to the studies of their major field in an effort to make up for shortcomings in the high school educational experience. As with any program, general education has its own goals and outcomes. Typically, one of the segments of general education is science and it is within this category that physics must compete with other sciences desiring to serve the same group of students. Unfortunately, this is not a level playing field since students have generally taken some biology and chemistry in high school. It is doubly hard because physics has the reputation of being a particularly difficult subject that is mathematics intensive and students have math phobias leading them to avoid physics in favor of other sciences.

One of the courses we developed for attracting the general student population into physics courses is Introduction to LASERs. It is a conceptual course with minimal mathematics but significant emphasis on reasoning and critical thinking. While students will take this course because of interest in the topic, we must endeavor to engage them with science and scientific thinking. This particular task has a number of significant hurdles. First, we must change the way students think about learning. We must convince them that science is not simply about memorizing facts but is an activity; that science is not simply jargon; that science is not dictated by the elite authority known as “the scientist”.

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Rather, we must endeavor to convince them that science is a method of discovery and this approach is applied throughout the entire class. Ultimately, we must teach the students to think critically about physical situations and apply what they know.

Teaching method plays a significant role in this class’ success in achieving its goals. First, to convince the students that science is an activity and to change how they learn we cannot allow the students to be passive. As such, interactive engagement (IE) and Studio teaching methods are used. In brief, IE is a method of teaching in which the students are “minds-on” and “hands-on” with the material. The students do not simply sit and listen to the instructor and later regurgitate the instructors’ words of wisdom back in answer to canned questions. Rather the students wrestle with ideas and discuss topics in groups to develop a consensus that they can articulate during a class discussion. Ultimately, everything in the class is developed through discussion.

Studio methods involve the integration of lecture and laboratory. Laboratory activities are designed to make the students explore and discover rather than blindly follow directions. Both methodologies (IE and Studio) require students to describe what they are doing, not through a formal laboratory report parroted from the laboratory hand-out, but in their own language that their colleagues can understand. It is the use of language that is critical to student learning. Language is developed to describe common reference frames and experiences. The activities in the class, whether paper and pencil or experimental investigations, provide experiences about which the students develop a descriptive language with which to communicate.

The instructor’s role is significantly different in an IE/Studio class from that of a traditional lecture class. The instructor must be affirming and not adversarial, must act as a moderator and facilitator rather than as a source of information. The instructor might give a mini-lecture, but most of the time the students are talking with each other and working with materials. The instructor has the difficult task of creating an environment in which the students feel safe and secure to make mistakes and be free to discover.

2. INTRODUCTION TO LASERS

The Introduction to LASERs course requires activity, discussions and writing. Most students expect classes to be devices of knowledge acquisition and focus on answer making rather than knowledge generation, usage usage and sense making. Having students recognize the difference between these is part of developing the student’s “habit of mind”. Activities are accordingly designed so that students have to think about and observe physical situations. However, for these activities to be successful the instructor must continuously stress that students be thoughtful and provide genuine responses.

The principle goals of the course are to develop an understanding of science and to teach students about basic physics. As such, the course outline is 1) The Nature of Science, 2) The Nature of Light and Models of Light 3) Production of Light and the Interaction of Light with Matter 4) Basic Optics 5) LASERs and 6) LASER applications. In teaching this course for the past 10 years, we have developed a number of activities, both pencil and paper and experimental, to help students gain insight into science, light, optics and laser applications. A few of these activities are described.

3. NATURE OF SCIENCE

It is critical that the students learn about the nature of science (NOS) to help them differentiate between science and pseudo-science, build their critical thinking skills, and have them recognize that science is an activity based upon empirical evidence. Teaching students about the nature of science (NOS) is difficult because to effectively “do” science requires significant background information and understanding. Since students in a classroom are engaged in acquiring that background, it is almost impossible for them to gain insights into scientific thought through traditional laboratory investigations. In most laboratory investigations the students simultaneously explore new concepts and phenomena, use new equipment, and use new analysis techniques in every investigation. The students are overwhelmed by novelty and adopt a strategy of “tell me what I need to know and do,” a strategy with which all too many instructors are willing to facilitate by providing detailed instructions. A “cook-book” like recipe to science reinforces the students’ belief that
science is formulaic rather than discovery, creativity and critical thinking. To overcome these problems we use an activity in which the students can be involved in the process of discovery, of forming and testing hypotheses and creating theories using a knowledge domain with which they are familiar: two player games. This activity is described in a forthcoming article in *The Physics Teacher* and was inspired by a quote from *The Feynman Lectures*:

“We can imagine that this complicated array of moving things which constitutes "the world" is something like a great chess game being played by the gods, and we are observers of the game. We do not know what the rules of the game are; all we are allowed to do is to watch the playing. Of course, if we watch long enough, we may eventually catch on to a few of the rules. The rules of the game are what we mean by fundamental physics... (However) what we can really explain in terms of those rules is very limited, because almost all situations are so enormously complicated that we cannot follow the plays of the game using the rules, much less tell what is going to happen next. We must, therefore, limit ourselves to the more basic question of the rules of the game. If we know the rules, we consider that we "understand" the world.”

In this activity the students are provided with the histories of several games played by two novice, but reasonably intelligent players. The goal for the students is to determine the rules of the game. An individual guess corresponds to a hypothesis which will be supported or refuted by the data. A collection of supported hypotheses form the rules or theory of the game. This activity serves a purpose of having everyone get used to talking with each other and discussing results in the class. It also makes it clear that a scientific theory is supported by the evidence. That changing evidence may change the theory. That one can never be absolutely certain of the end results since additional data may change that. Figure 1 is an example of this activity. It includes board, moves and pieces.

**Move Sequences for Scigame XXVII**

The moves in the games below were made by two novices, but reasonably intelligent, players.

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**Playing Pieces**

Figure 1 – Game history, board and pieces for use in helping students learn some aspects of the nature of science.

The reverse game play occurs after the class has developed definitions for a scientific hypothesis and scientific theory and is used to involve the students in an analogue of scientific process rather than simply discussing it. This activity can be varied in numerous ways. For example, it is possible to provide different
student groups with different sets of game histories (different data), none of which give them the complete game. After some time has elapsed, the groups are allowed to move around and discuss their results which emulate the social nature of constructing scientific knowledge.

The activity is generally put into context through prior discussions about the NOS. These are initiated by asking open ended questions for discussion:

- “What is the purpose of science?”
- “Does science have a basic premise?”
- “Is changeability is a sign of unreliability?”
- “Is science is a social activity”
- “Is science an activity or is it the body of knowledge?”
- “Is there a particular way to do science?”
- “What is the difference between science and engineering?”

The purpose of these questions is to get students to think about their own ideas, talk about them in a small group and write them down (which makes it easier for them to discuss in the class setting). The class discussions are such that the instructor is careful not to say whether an answer is particularly good, but to encourage the students to critique each other’s answers. The instructor tabulates student responses and moderates the discussion by eliciting responses from multiple students.

A second phase of questioning asks students to consider

- Scientific terms such as hypothesis, theory and law, which the students rank in order of “closest to truth” in that order.
- Testability and proof and explanation.
- Comparing observation with explanation.

Finally, in light of the class discussions, the students are asked to determine whether a described activity is scientific or not. For example:

- “Imagine that a child constructs a model solar system using wire and painted Styrofoam balls. Has this child engaged in a scientific activity?”

The scientific structure of discovering reliable knowledge based on empirical evidence is rigorously applied throughout the remainder of the semester.

4. NATURE OF LIGHT AND MODELS OF LIGHT

Nature of light

To introduce “light” the class starts by considering the question “what is light?” Typically this question elicits a number of responses such as:

- “Light is moving energy,”
- “Light is energy,”
- “Light is power,”
- “Light is intense,”
- “Light is made of photons,”
- “Light is a wave”
- “Light is wavelengths”
- “Light moves in waves” or “Light travels in waves,”
- “Light is made of particles moving in waves.”

The purpose of this question is not to get a correct answer; rather it is intended to make the students reflect upon what they think, and for them to hear what others think. Also, the responses, especially the ones related
to energy give the opportunity to explore the complex and abstract concepts of work, energy and power. The core of energy discussions are based on mechanical work, kinetic energy and conservation of energy.

Laser light

While students have seen lasers, most frequently usually small laser pointers, they do not know what precisely makes the laser seem different and they are explicitly queried about the difference between laser light and ordinary light. Typical responses are:

- “Laser light is colored,”
- “it seems to move in a beam,”
- “it is powerful,”
- “bright” or has “concentrated energy,”
- “laser light can travel further than ordinary light”

Students have little understanding of the light spectrum beyond ROYGBIV. Therefore, they have no reference for monochromaticity. Another language problem is intensity (really irradiance). Intensity is used interchangeably to mean brightness of light, vividness of color and light power. The laser beam is believed to be perfectly collimated. Finally, the students have a belief that light has a maximum distance it can travel from a source, that the light’s “energy” is dissipated by traveling through the air since they believe it takes energy for something to move.

The idea of monochromaticity is not addressed until the students have started to work with the wave model of light. However, to address the latter three issues, students work through several hands-on and thought investigations. In each of these activities the students must predict what they believe will happen and then make observations and measurements to test their predictions. Finally, they must explicitly reconcile their results with their observations. Even if their predictions were correct, they must explicitly describe how the measurements support their predictions. These activities are:

A) Measurement of laser beam size with distance from laser.
B) Measurement of relative beam power and size for a lamp with a circular baffle (see Figure 2). This activity confronts the students' ideas about intensity and brightness and the dissipation of energy as light travels. The students measure the cross sectional area of the beam as the light travels farther from the baffle. A detector (photodiode) is placed in the beam at the various locations and measures the relative amount of light hitting the detector. However, since the detector is smaller than the beam of light, the detector readings diminish as it moves farther from the source. Thus, the reading varies as the apparent brightness decreases. The students are queried about why the readings decrease. Even though the students have not used lenses, they use a converging lens to concentrate the light on the detector and to observe the effect of the lens on brightness and readings. Finally, through class discussions the students develop the idea that the light is spread over a greater area, but the overall power is constant and not dissipated.

![Figure 2, lamp with baffle, detector and lens](image)

Scientific models of light: ray model

The ray model is developed through discussions based on the following the questions:

A. What is a ray of light?
B. What information about light can a single ray indicate?
C. What would it indicate if a single ray were to end?
D. Can a single ray be subdivided?
E. What information would a collection of rays provide that a single ray could not?
F. Suppose we wanted to represent two beams of light, but one had twice the power of the other, how could you indicate this on using rays?
G. Is it possible to indicate intensity using rays? If so, how would you do so? If not, why not?

Discussions arising from these questions assist the class in interpreting ray diagrams. It is important for the students to determine what ray diagrams mean for themselves, rather than having them designed by the “authority” figure (the instructor). However, they can be led to having the relative power of a light source determined by the number of rays while the concentration of rays (how close together the rays are) determines the relative intensity. This information is used consistently throughout the semester to interpret how different optical devices function and is related to the other models. In Figure 3, the students must apply their understanding of the ray model to interpreting the ray diagrams.

![Figure 3](image)

**Scientific models of light: wave model**

The wave model of light is developed to provide an explanation of certain observable light behaviors and also to use in understanding the spectrum. We elude student ideas on “what is a wave,” or how do you differentiate a wave from a non-wave. You want to distinguish between what is a wave and what is not a wave. What do you believe are the properties of a wave? Three critical questions:

A. Can a wave transfer energy?
B. Can a wave transfer mass?
C. Can a wave move mass?

Students generally have the idea that the waves are only sinusoidal or that the sinusoid is the path that a wave follows. In a simple demonstration a student is asked to wake a distant sleeping student using an eraser (throwing). Clearly, in this case there is an exchange of energy and also of mass. In a second scenario, the same student is to wake the sleeping student who is advantageously holding one end of a rope. By sending a single pulse down the rope they can “jar” the student awake without transferring mass. By observing the effect of the rope pulse on the “sleeping” student, the class readily agrees that work is done on the student by the wave. The transfer of energy without the transfer of mass provides the basic definition of a wave.
Having this basic definition of a wave the class considers repetitive waves and discusses the issue of wave path, reflecting upon the previous pulse demonstration. A standing wave is NOT used because one cannot see it traveling! The following questions are posed:

A. Imagine that light is a wave, what path does the light follow?
B. Define the following terms: wavelength, frequency, period, amplitude and speed.
C. What would happen to the frequency and wavelength of a wave if you were to double the amplitude of the wave?

In answer to (C), students often respond “That the frequency decreases if you double the wave’s amplitude because for a wave on a string the speed with which the string at one location oscillates up and down is fixed. Therefore, if you increase the amplitude of the wave, it will take longer to complete one cycle, which increases the period and therefore decreases the frequency.” This idea generally gives rise to many heated debates.

To help the students learn about how wavelength and frequency are related, and the effect of amplitude the students “assemble” a simple paper “wave machine” (see Figure 4). The wave machine consists of several different amplitude and wavelength sinusoidal patterns printed on strips of paper (wave-strip). A channel is made by folding a second piece of paper and fastening it with tape. The folded piece has a slot to allow one to see the “wave-strips” through the window. The window allows you to see the wave progressing with the viewer at a single location. By dragging the “wave-strip” more quickly through the envelope, one observes the frequency increasing. To measure wavelength, one has to stop the wave and use a ruler. Changing the amplitude, while keeping wave speed and wavelength constant does not change the frequency or wavelength of the wave. Finally, the students can discover that the wave travels a distance of one wavelength in one period.

Students’ are often confused by our (the instructor’s) 2-D drawing of a wave, thinking that the amplitude of the wave represents the height of the wave (having units of length), and therefore the amplitude represents the spatial extent of the wave. To address this issue students relate the ray model, which describes the spatial qualities of light with the wave model through several activities shown in Figures 5 and 6.
Using the magnifying glass ray diagram of Figure 3B and through experience of lighting paper on fire (or at least making it smoke) using a magnifying glass, the students are led to consider why the lens makes it possible to light a fire from a wave perspective. By the ray diagram the power of the light is not increased, but the intensity has increased. Through this line of questioning, the students make the connection that the amplitude of the wave is related to the intensity of the light. The students are then expected to be able to apply this to various situations as shown in Figure 7.

Spectral power distributions

The spectral power distributions (SPD) is developed to describe light’s power distribution as a function of wavelength, to assist students in understanding monochromaticity, and to introduce the interaction of light with matter. The SPD is generated through student observations of a white light source using a prism. A scenario is presented in which the students imagine a small detector is moved across the spectrum, recording the “quantity of light illuminating the detector. Students consider how the chart would appear if they had only red or blue light. The students explore and refute several hypotheses: 1) the light is “colored” by the prism, and 2) the color we see is a direct property of the light. For 2), the students combine red and green light to produce yellow light and contrast this with the yellow light from the spectrum.

Figure 6 - In this situation, which observer can see the beam of light? How do you know? How would the diagram change if you doubled the amplitude of the beam? Would the increase in amplitude change which observers could see the light?

Figure 7 – Sketch a ray diagram representing as much equivalent information for the wave diagrams in a) and b) as possible. In c), sketch a wave representation of this ray diagram, presenting as much equivalent information as possible.

Figure 8 – Diagram of simple spectrograph for students to produce their own spectral power distribution.
5. INTERACTION OF LIGHT WITH MATTER AND THE PRODUCTION OF LIGHT

The effect of the prism on white light immediately gives rise to the question: “why does the prism make light produce the different colors?” This behavior is explained through the concept of resonance which is explored for a mechanical system.

A. Students observe the effect on a pendulum bob of driving frequency, discovering that the closer one gets to the resonant frequency of the pendulum, the greater the magnitude of the pendulum swings.

B. To model how the resonance frequency would change for different systems, the students imagine that the more tightly bound the electron, the shorter the pendulum string (electron closer to the nucleus in a Bohr model) discovering that the resonance increases as the more tightly bound the electron.

Discussions reveal that prisms are made of a material with resonances in the ultraviolet portion of the spectrum and therefore light with a frequency closer to the ultraviolet portion of the spectrum will have a stronger interaction with the prism material than light of longer wavelengths. Because of this stronger interaction, the shorter wavelength light will travel more slowly, have a greater index of refraction and therefore bend at a greater angle than will longer wavelengths.

Energy level diagrams

The semi-classical resonance model works well for situations describing excitation from the ground state, but not so well to describe multiple transitions. To gain a deeper understanding of the production of light and the interaction of light with matter, we develop the concept of energy level diagrams (ELD’s). However, ELD’s are quite mystifying for students. One significant misconception students hold is that the “electron is excited.” This is because in the Bohr model, when an atom is excited, it is indicated by an electron changing orbital.

ELD’s are expanded to include molecules and condensed matter after the description that atoms cannot all have precisely the same energy levels. Since an atomic gas is characterized by very widely separated atoms that do not interact, these appear as essentially narrow energy levels. However, when there is interaction, such as in a molecule or in a liquid or a solid, the energy levels move around creating a band structure.

Using a paper and pencil activity, the students work with simplified ELD’s. The students are able to construct possible emission and absorption spectra. They are expected to look at the spectra and identify the types of system (atomic, molecular or condensed). Finally, the students look at an atomic source using small spectrosopes and based on relative brightness of transitions, sketch possible energy level diagrams. While these are necessarily inaccurate, they serve the purpose of having the students think, relate and apply what they have learned. Figure 9 is an example activity in which the students must interpret the ELD, and predict a spectrum.

Figure 9 – Energy level diagram used by students to determine which photons interact with which atom and then determining a possible spectrum. The spectrum is determined by starting at the highest energy level shown, and then choosing every possible transition until all routes to the ground level have been determined. Then the number of photons of each energy is plotted.
6. BASIC OPTICS

There are a number of activities that are used to understand basic optics. The first is for the students to discover the difference between point and extended sources through the geometric optics tutorial in McDermot’s Tutorials in Physics. This is particularly important because all image formation is based on extended sources being a collection of point sources.

The laws of reflection and refraction are discovered by visual ray-tracing. Two pins are used to define an incident or exiting ray. Removing the mirror or the refracting object, the rays can be traced so that the way the ray’s path can be observed. Then the formal rules of ray-tracing a point object are discussed. Rather than simply having students repeat the variety of ray-tracing activities that start with an object and end with finding the location, size and orientation of the image, we provide alternative activities, such as that in Figure 10, that require the students to think about the meaning of images and ray-tracing.

Interference and diffraction

To examine interference the students predict what they would expect to see if light were to pass through a double slit, and what they would observe if the separation between the two slits were changed. Based on their observations students realize that the pattern is not simply the shadow of the slits. As part of this activity the students sort a set of wire grids in order of increasing wire separation and explain the ordering.

To explain these observations we use a model of the Michelson interferometer to develop the idea of interference being introduced through path difference. The Michelson interferometer makes the path induced phase shifts more obvious than for the double slit and allows one to ignore the difficulties associated with diffraction.

Figure 8 – On the left is a diagram of a Michelson interferometer. Directions: Assume that we have a wavelength of light that is 2 cm long, that L1=3.5cm, L2=3 cm and that L3 is 4 cm long. A) For the light traveling to Mirror 1 or 2, what is the total path length that the light travels from the beam splitter to the detector and how long is this path in wavelengths? B) Draw lines that are the length of each path for the light to travel from the beam splitter to each mirror. On the right is the expected work showing that light would arrive out of phase at the detector.

Figure 10 – Consider the situation shown below with an unknown type of mirror (plane, concave or convex) hidden by the rectangular box, a small object (the square) and two rays reflected the mirror. A) Determine the location of the image of this object. Explain. B) Determine the type of mirror. Explain your logic. C) Determine the location of the focal point of this mirror and mark it on the diagram. Explain.
The students are expected to "unwrap" each of the paths the wave follows, and determine what the relative phase is for different path lengths. Using the interferometer, students can recognize that the path difference introduces a phase shift between the two beams and then they can apply the principle of superposition. They can figure out what happens as one mirror moves and gain insights into how interferometers work. This lays the groundwork for understanding longitudinal coherence. Later, the students revisit the double and single slit investigations.

7. LASERS

Finally, having explored so many of the intricacies of physics: models of light, spectra, production of light, optics, the students are ready to figure out how a laser functions! To start, the three basic components of a laser (medium, power source, and cavity) are discussed in general. Starting from energy level diagrams, the three photon-matter interactions (stimulated emission and absorption, and spontaneous emission) are discussed. Kinesthetic models using ping pong balls as photons are used to help the students recognize the difference between spontaneous and stimulated processes. Population inversion and lifetimes of various states are explored through a model of water reservoirs with various leak rates and pumps. In Figure 8, an assignment is given that has the students consider what might happen to population inversions if the lower laser level of a medium has a long lifetime. The general models of three and four level laser systems are presented to the students. To make them work with these ideas the students are provided with paper and pencil assignments such as the one shown in Figure 9. They are expected to identify if a system is a 3 or 4 level laser system as in Figure 10.

Figure 9: Consider the two systems A and B. Discuss whether a laser system based on A or B would function as a continuous or a pulsed laser.

Figure 10: Does this system correspond to a three or four level laser system.
8. CONCLUSION

By starting to examine the LASER, one has to teach the students a wide array of physics. The students have to learn about work and energy, light, the spectrum of light, light’s interaction with matter, and the production of light before ever really considering the LASER system itself. Furthermore, the exploration of laser applications uses all of the tools developed earlier in the class such as interferometry and optics. Finally, all of this class is taught, not as a lecture, but rather as a student driven discovery based on the scientific thinking methodology with which the class started.

Even though this is a conceptual class, teaching it has given us insights into how students think about physical problems and these insights are applicable even to advanced physics student. Much of the course material we developed for this class has been modified and adopted in intermediate and advanced classes.

Finally, a text has been written in a refutational style (readers are requested to answer questions like in a discussion format class). This text and activities are available on request by email to the author.

REFERENCES

Web-based photonics simulator for secondary school students

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ABSTRACT
In the “real world”, Photonics is somewhat invisible to those who rely upon it worldwide. We would like students to connect their everyday experiences of communications with the underlying ideas in Photonics. To do this, we have developed the Photonics Simulator to illustrate to high school students how text or information is coded into binary optical signals which are relayed through photonic communications networks from sender to receiver.

Using our simulator, students construct a virtual network, and then test it by sending messages. The messages are coded using ASCII binary code as digital signals in data packets with address headers, which need to be switched, combined, amplified, or delayed to get to their designated address. The students must manage their power budget, correctly target each message address, and avoid collisions of data packets to send their messages uncorrupted and error-free.

We tested an early version of the simulator with five Year 9 and 10 classes. The students provided many constructive comments and their feedback was used to improve the graphical interface of the simulator. We subsequently tested the simulator with 80 Year 9 students in short workshops.

Overall we had a very positive response - it was more fun than a normal class, and interactivity helped students retain information. Students enjoy the visual aspects— they see how messages are delivered, and learn the function of each network component by experiment. Tests of the simulator at the Macquarie Siemens Science Experience were also encouraging, with one student even sneaking back to class to complete his challenges!

INTRODUCTION
The Centre for Ultrahigh-bandwidth Devices for Optical Systems, CUDOS, is an Australian Research Council Centre of Excellence funded for research on Photonics and Optical Communications, with a further aim to do public communications and outreach, targeting school students, their teachers, industry and others. We aim to raise the profile of Photonics amongst school students in particular, so that they may take their place in our highly connected and communications-rich world. We also hope that engaging school students in this manner will influence them to continue their studies of science.

Our experience in doing outreach is that school students and many of their teachers are quite ignorant of the role that photonics plays in the internet and communications generally; for example, they are surprised to learn that their international data and phone calls are transmitted via light pulses through submarine optical fiber cables. This highlights a need for our outreach activities to be educational as well as promotional, that is, aiming to increase understanding of our research, not just awareness that it exists.
We also note a number of challenges concerning resourcing (both presenters’ time and financial support for their activities) and in assessing the efficacy of our communications activities. These challenges can be addressed by developing shareable media online – such as our Photonics Simulator.

The aim of the simulator is to engage students and to educate them, illustrating for them the principles of coding and transmitting information, explaining the function of each individual component within a communications network, and then allowing the students to work through the simulator challenges to create and test their own photonic network on the computer. Each component is introduced in a graded manner with a challenge to explain its properties, which mimic the properties of real components. A subsidiary aim is to demonstrate to students how science and technology contributes to society, encouraging them to study science and technology in high school and beyond, to continue the work of today’s pioneers.

The simulator is based on Flash, which is compatible with both PC and Mac computing platforms. We have included a dictionary of terms to introduce the main components and concepts used in the simulator, and we also included short movies and animations to introduce the game - “Getting started” - and to demonstrate concepts more vividly. We intend that the simulator should become a tool for teachers to use in introducing science students to photonics, and it could also readily be used by the students themselves at home. We also hope that Optics and Photonics researchers around the world could publicize the simulator to their local schools.

In our presentations to school students, we first presented a talk to introduce secondary students to photonic communications systems. We also included other activities such as a worksheet to complete to get the students to work out what each component does before tackling the simulator. In our presentations, we also offered an animation of a photonic chip and a fun freeze-frame movie showing how various photonic components work, and a “real” demonstration of a laser with optical fibre.

In our presentations with the students using the simulator, we deliberately did not direct students as to how to set up their networks as we wanted to give the students an open choice as to how to interact with the simulator. Indeed, we found that most students expected to “hack” rather than be issued with instructions, and many would open the simulator when they were supposed to be busy on another aspect of the presentation. While we have offered the students both the choice of graded challenges or “free play”, we have noted that mostly they prefer to use the graded challenges, as they lack the appropriate background to understand the free play option readily.

**EFFECTIVE SOFTWARE FOR EDUCATION**

The combination of effective teaching and learning is difficult to achieve. Sometimes educational software addresses perceived teaching needs, rather than increasing student engagement, which can make the integration of such software into the classroom problematic. Effective learning by students requires them to actively participate and be engaged in the process, whereas teaching is often focused on conveying ideas. It is also essential that teachers’ needs are considered in order for any software to be adopted by schools. Hence, for educational software to be successfully integrated into the classroom, both the needs of teachers and students must be integrated into the software. Polonoli suggests that there are seven aspects to creating effective educational software, which are:

- appropriate integration of learning and teaching
- contain game-like features
- target to an appropriate grade level
- highly interactive
- friendly interface
- represent the students’ world
- not culture-sensitive.
Of course, educational software must be appropriate for the age, gender and learning style of the students it serves, and not culturally offensive to any group.

Educational software that uses a “game-like” approach has been shown to have a strong cognitive effect on students learning science-based concepts, akin to problem solving in the cognitive processes that are generated \(^3\). According to Randel et al \(^3\) games foster greater interest from students when compared with traditional forms of instruction. When students are engaged, the game makes class time less boring \(^5\) and it is more likely they will remember the concepts taught by the game \(^3\).

On the other hand, other researchers believe that despite games for education being “engaging” for the students, they do not stimulate the constructive reasoning that is required for learning as students are distracted from cognitive reflection on the key concepts. Manske and Conati \(^6\) suggest that little evidence exists to show that games can trigger learning, unless they are supported by other activities. Disconcertingly, Yeo, et al \(^7\) showed that interactive multimedia experiences may not illuminate the key physics concepts for their students, despite interactivity and animated graphics. In their study, “only following researcher intervention, did students develop awareness” of the abstract physics concepts. Hence the level to which the educational software is made “game-like” should be considered carefully, and a total reliance upon the software alone for a student’s education is unwise.

**DEVELOPMENT OF THE SOFTWARE APPLICATION**

This project started as a jointly-supervised Computing and Physics Masters in Information Technology project in which we chose to develop an educational software package to engage and educate students in Photonics. We developed a simulation program that allowed students to build a simple communication network, and to use concepts from optical networking to send messages through the network. We targeted the game at secondary school students (Years 9-11), to match an appropriate level of the school syllabus. We chose Flash as the delivery platform for the simulator because it can be easily hosted online, it is widely available as a free download, and it offers good graphical rendering without too much computational load. In addition to handling the graphics, Flash provides a scripting interface (ActionScript) and is available to a wide range of machine platforms including both PC and Mac. It offers useful features such as silent exception handling, garbage collection and a rich object model. However, as with many such platforms, one of the biggest problems with Flash is performance - it is limited to small applications with relatively few simultaneous graphics and processes.

The photonics simulator may be viewed at the website:

http://web.science.mq.edu.au/groups/cudos/education/Simulator.html

The Photonics Simulator has been developed to balance the needs of students and teachers. The application does not provide students with specific directional information, rather students are provided with open possibilities which may be guided by a teacher, perhaps via worksheets or modeled answers, or alternatively the students may explore different avenues on their own. The Photonics Simulator has three areas: Watch a video; Build a photonic network; and Photonics dictionary. The videos provide an opportunity to present information on photonic chips in general (the ultimate research goal for CUDOS), or more detailed information on Getting Started in the game. Alternatively the teacher may play a video to the class as a whole. This part of the application does not provide much interactivity, but provides content for the students to prepare them for building their own photonic network.

Building a network gives students a chance to actively learn concepts introduced by their teacher, through class discussions, or by watching the movies above. It provides students with fifteen graded
challenges to explain and introduce the individual optical components that the students can use in their networks. The challenges start with a simple requirement to connect the source to the receiver, but Challenge 15 combines four sources, four receivers and eleven possible components in a complex networking task. Given a mixed group of abilities, ages and cultures of the target students, we have chosen to include both a graded defined-challenge approach and a free-play interactive approach. Some students work better in a structured environment, while others strongly prefer to test their own ideas without too many constraints. Thus the graded challenges introduce the students to the individual concepts and components of the simulator step by step, whereas the free-play option offers students various components to combine into their own virtual photonics network, which they can test to see if it sends their message correctly.

The free play option offers an open challenge to transfer a message a student has typed, from any of four transmitters to any of four receivers, without the message being scrambled or attenuated too much. To do this the student must connect the sources (laser transmitters) with the various receivers, using photonics components from their “toolkit” and ensure that their messages are always correctly received. We deliberately do not provide instruction on how they should achieve this, forcing the students to think about what they have learned in the graded challenges or in the class lessons, and to test different approaches to the problem. The aim is to frustrate the student slightly, causing “a mild state of cognitive dissonance that will make the content challenging”.

The open-ended free play section also allows the teacher to set extra tasks or challenges for the students to complete, say to build a network that includes a buffer and a switch. The Photonic network builder also achieves the project aim of introducing the students to the basics of communications networks. A student’s solution to Challenge 10 is shown in Figure 1 to illustrate some of these ideas. When the students send their messages through their photonics network, the messages are converted to binary code and transmitted through the network as light and dark pulses. Bezier curves allow the photons to travel along the waveguides that were drawn by the student. The light pulses appear gradually fainter as they propagate through more components, and through the waveguides, thus requiring the students to implement amplifiers in their system to manage the power budget. There is a photon speed slider that allows the students to slow down the speed of the photons through the network so they can watch individual pulses flowing through the network, and see them translated back into “real” characters at the receiver. They may notice that sometimes their characters are scrambled because the power has dropped below a threshold of about 70% and the ASCII code for that character is changed. Each character is represented by an 8-bit code, with a coloured address header to indicate where that character should be sent. This emphasizes the systems aspects of the network design for the students. It is not enough simply to understand the function of a specific component, but the performance of the network as a whole must be assessed.

Finally, the Photonic dictionary allows students to quickly look up the function of a particular component, or clarify a concept such as coding. The definitions enable the interested student to explore in more depth the concepts and ideas provided by the videos and the Build a photonic network section. This dictionary is also a resource to support students completing worksheets or other activities as required by their teachers.

IS THE SIMULATOR EFFECTIVE?

We performed trials of the Photonics Simulator with 100 Year 9 and 10 students from three schools, to investigate the effectiveness of the Photonics Simulator for educating and engaging the students. Each lesson (50 to 90 minutes) was split into the following components:

- An illustrated talk on photonics including laser and optical fibre demonstration
- A short movie on photonic networks
- Students complete a worksheet using the Photonics dictionary
- Free time to play with Build an optical network
Before each trial, a pre-survey was conducted by the teacher at the beginning of the lesson, and two questions from this survey were repeated in a post-survey in the last five minutes of the same lesson to test the effectiveness of the lesson. These questions were:

- What is photonics?
- What is the function of an optical amplifier in an optical network?

![Figure 1: A snapshot from the Building a photonic network section of the application, showing a student’s solution to Challenge 10, as a message is being transmitted. Each character is represented by an 8-bit ASCII code, with a coloured address header, and the ones and zeroes are shown as the light pulses propagate through the network. The student can assess if the network is satisfactory by whether the message is transmitted correctly to the correct receiver.](image)

The change in responses to these two questions is demonstrated by Figures 2 and 3. There is a significant improvement in the students’ responses to both questions after the lesson and experience of the simulator. Responses have been aggregated by gender in this case (girls first two columns, boys second two columns). Examples of “correct” (blue in the Figures) or “half-right” (violet in the Figures) answers for “what is photonics?” are: “science and application of light as a means of transferring information” and “when you turn information into light signals”. Examples of “correct” and “half-right” responses to “what is the function of an optical amplifier?” are: “produces an exact copy of a signal with increased intensity” or “to boost the transfer of a signal”. In the Figures, pink represents “don’t know” and aqua is “wrong”.

![Figure 1: A snapshot from the Building a photonic network section of the application, showing a student’s solution to Challenge 10, as a message is being transmitted. Each character is represented by an 8-bit ASCII code, with a coloured address header, and the ones and zeroes are shown as the light pulses propagate through the network. The student can assess if the network is satisfactory by whether the message is transmitted correctly to the correct receiver.](image)
As anticipated, when asked if they would enjoy playing scientific computer games in class, almost all students said “yes” (only two boys and two girls said “no”). Rather fewer students would enjoy playing scientific computer games at home: 17 out of 30 girls said “yes”, and 29 out of 68 boys said “yes”. This may be an important consideration for those of us planning to use computer games for individual outreach to students.

Generally students were very positive about their experience of the computer game. 26 out of 30 female students said they enjoyed the game, and 56 out of 68 male students did likewise. Of the females, 28 out of 30 said they learned something, and 51 out of 68 male students said they learned something.

![Pre-survey: students knowledge of photonics](image)

**Figure 2**: Percentages of students answering Questions 1 and 2 in the pre-survey blue – correct, violet – half right, pink – wrong, aqua – don’t know. There were 30 girls and 68 boys surveyed. The questions were: What is photonics? What is the function of an optical amplifier? The overprinted numbers show the actual numbers of responses in each category.

The students were also asked what they liked and didn’t like about the Photonics Simulator. The most-liked aspect of the game was the interactive Build a photonic network section, notably the ability to create their own network, and to send messages through it. The fact that it is image-based appeals to many
students – they can see how messages are delivered, and understand the function of each component in a network by experimenting with it. Dislikes of the game were that it was confusing, needed some more technical or graphical sophistication (e.g. “automate the line drawing” or “use more colour in the dictionary”) or too slow. Overall the response was very positive, indicating that it was more fun than a traditional class, and interactivity helped to improve retention of information. It would be interesting to test if the knowledge was retained over subsequent days or weeks! One student correctly commented “since it’s a game, you’re thinking a lot more, and so grasp the info better”. While some wanted more direction, and wanted to be shown a model answer to start, most students enjoyed the openness and self-direction in the application. Another interesting question is whether the graded challenges or the free-play are more effective for promoting students’ learning.

Teachers commented that “one of the main things the students learned was the application of science to the real world.” “Students enjoyed the interactive nature of the simulation.” “They tend not to read instructions, but just want to get into it.” “This … activity can be used to consolidate knowledge of photonics, or as an introduction to expose students to the necessary components.” “I tried the simulator and was very impressed. There is so much work into this! I find it very interesting. After seeing the tutorial and trying from the first challenges, I find it easy to use. I think it is the kind of tool that should be used in introduction to photonics classes to provide students with a look of what a network looks like.”

Figure 3: Post-survey responses by students: blue is correct, violet is half-right, pink is wrong and aqua is don’t know. The first two columns represent 30 girls, and the second two columns represent 68 boys. The questions were: What is photonics? What is the function of an optical amplifier?
Approximately 80 students in the 2009 Macquarie Siemens Science Experience also enjoyed playing with the Photonics simulator. These students from Year 9 gain exposure to a range of university science activities during a 3-day series of holiday workshops. They are generally well-motivated to do science, but we found that the majority of the students really enjoyed solving the challenges. (One student even snuck back from another group to finish his challenges!) Some of the student comments that we received on this activity were: “computer activities were really great”, “the program was cool”; “challenging, fun”. We did not have the opportunity to assess the students’ learning in this activity.

CONCLUSIONS

The Photonics Simulator was created to engage and educate school students in photonics, with particular focus on incorporating technology into the teaching methodology. We used this application as an aid when teaching the topic, rather than as a stand-alone application. When traditional teaching is combined with additional resources such as a software application, students become actively engaged in the topic through the interactivity of the application, helping to achieve a better understanding of the topic. We are keen to promote the use of the photonics simulator in education and outreach activities, and will continue to trial it in schools. In the future, we would like to make a more overt comparison between electrical and photonic networks, than was possible in this simulator.

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Development of an Intelligent Learning Resource using Computer Simulation about Optical Communications

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ABSTRACT

In recent years there have been some proposals to develop educational tools using multimedia and interactive resources, however, most of them just transpose the traditional materials to the computer screen. The reason for this work is the gap of didactic materials to explore important subjects about photonics and optical communication systems, specially the lack of tools related to Erbium Doped Fiber Amplifier (EDFA) learning. The aim of this research is to provide at the LCMS MOODLE open platform an Intelligent Learning Resource to support EDFA study, providing a set of Learning Objects more suitable for the study of the base concepts needed to optimize the use of the computer simulation tool. The learning resource developed can stimulate the students to understand how amplifiers are designed for a practical application, and the parameters that should be considered in a project. The Artificial Intelligence techniques used for the development of the learning resource consider the learner differences in a way to adapt the system actions according to each student background.

Keywords – Intelligent Tutoring Systems; Learning Objects; Multiagent Systems; Conceptual Maps; Erbium Doped Fiber Amplifiers.

1. INTRODUCTION

The development and availability on Internet of educational tools allow the implementation of interactive and hypermedia projects for education that can provide to students the management of study according to their own learning rhythm. Facing those issues, this research presents the development of an Intelligent Learning Resource for Electric Engineering, Physics, and related fields, in which students can learn about optical communications, in particular Erbium Doped Fiber Amplifier (EDFA). The proposal is to give autonomy to the students, which manage their own study time, and fulfill the basement and prerequisites needed to understand the subject and complete the tasks proposed. Moreover, the learning resource proposes the navigation through a concept map based on a multiagent system architecture, providing an individual treatment according to each student profile.

This paper is organized as follows: at first, the main characteristics of Learning Objects, multimedia and interactive technologies, concept maps and the principles of learning by simulation are briefly presented. Next, the artificial intelligence theory of agent is reviewed followed by the design methodology and the development procedures. Then, the results are discussed and finally the conclusions and further works are exposed.

2. THE REUSABLE LEARNING OBJECTS

The Institute of Electrical and Electronics Engineers (IEEE) Learning Technology Standards Committee (LTSC) define Learning Objects as “…any entity, digital or non-digital, which can be used, re-used or referenced during technology supported learning”[1]. However, the amplitude of this definition requires some delimitation: those elements should be digital entities [2] and that should be characterized by metadata, that describes the learning object content.
For a high availability of learning objects, it is appropriate to provide an infrastructure to keep and maintain them [3]. Usually the learning objects are published in Learning Object Repositories (LOR) or Learning Management and Content Systems (LCMS). The LCMS allows the management of learning objects and provide tools to students’ to plan and run their individual studies, and also exchange information and knowledge with other students and professors, by e-mail, chat, forum in a collaborative environment [4].

Facing the potential, popularization and the growing number systems available, some initiatives have started with the objective of standardization and specification of learning objects, their building and identity. Those specifications are fundamental to enable reusability and interpretability of Learning Objects. Among existing standards, some can be distinguished as Sharable Content Object Reference Model (SCORM) [5]. The following technology resources can be added to the learning object concept in order to optimize the learning process.

3. MULTIMEDIA AND INTERACTIVE RESOURCES

The concept of multimedia in the context of education can be defined by [6] as a presentation material using the verbal form, as a printed or spoken text, and a pictorial form, that is to say, graphics, illustration, dynamic animation or video. The creation of both verbal and pictorial models on the students’ mind helps them to associate new concepts to the ones previously learnt, culminating in the meaningful learning. Moreover, an interactive interface stimulates the students to have an active participation on the learning process. For so, the users are supposed to determinate a sequence of actions: act, comprehend and evaluate the system responses [7].

4. CONCEPTUAL MAPS

The concept maps were developed in the middle of the eighties motivated by the difficulty found by many students to have an effective learning process [8]. The idea is to connect new information to existing knowledge through a graphical representation of a person’s understanding of a specific domain [9].

A concept map consists of a construction of concepts into a coherent hierarchy, linked together, forming propositions. A concept map can show visually the relationship between concepts, helping students to find new meanings [8].

5. COMPUTER SIMULATION TOOLS

The idea of learning by simulation can be considered a modern practical based learning methodology with some benefits that the new software technology can bring when compared to the traditional laboratory experiments, theoretical classes or the traditional teaching methodologies [10]-[11]. Among the advantages of using computer simulation tools in education, the students are given the possibility of changing the parameters of a system then evaluate the results in a real time and interactive way. It permits to create a cause-effect structure of the studied concepts on the students’ mind [10].

Despite the long lasting discussion about using technology in education, it is known that the hopes and expectations of implementing revolutionary instructional materials in schools were unmet [6]. Still according to [6], it can be explained by the technology centered approach taken, that is to say, the students have been forced to adapt themselves to the new methodologies, stimulating negative feeling about the use of cutting edge technology in education.

6. THE AGENT THEORY

In this context the development of the artificial intelligence based systems are important in a way to adapt the system actions to each student needs. The goal of these systems is to adopt the human as model to guide the behavior of the system. In some complex applications, such as in education, the computer needs to act by itself in order to solve a problem and achieve a goal. That is when the multiagent system theory can help in
the insertion of intelligent behavior in the traditional instructional digital tools. Figure 1 shows the relation between an agent and the environment.

![Figure 1: An Agent Environment][1]

According to figure 1, it is possible to see that the environment is responsible for the input, that is to say when the agent percepts the environment state and the output, when the agent performs an action in the environment.

As mentioned before, the concept of agent is related to its interaction with the environment, but there is no universal definition for agents. According to [12]-[13] agents are able to percept the environment (by sensors) and act in this environment in an autonomous way. An agent can be compared to the classical expert systems, however, the main difference between them is the fact that not all the expert systems act directly in the environment [12].

7. DEVELOPMENT OF THE PROJECT

This paper presents the development of a learning resource that can observe the student background profile in order to fulfill the lack of concepts related to the subject chosen using learning objects. The strategy adopted to observe the learner background is based on the communication between the system and the user. In other words, the search for information about each student background is based on a test, but the interaction with the system can also provide new information about each concept studied. The use of the PTDS (Photonic Transmission Design Suite) [14] simulation tool requires a previous understanding of the base principles of EDFA, for so it is important to supply specific learning materials so that the students can get the advantages of having a project based learning using this worldwide popular simulation software. Figure 2 shows the architecture of the learning resource proposed.

![Figure 2: Learning Resource Proposed Architecture][2]
According to the architecture proposed, it is possible to identify three main modules of the system: the multiagent concept map within the connection to the LCMS Content Repository (Learning Objects) and the computer simulation activity.

7.1 Concept Map

The development of a concept map is very flexible, there is not only one way to produce a graphical representation of certain subject in a concept map [9]. The concept map proposed in this paper was produced according to the following steps.

At first, the main concepts related to EDFA were identified to be presented in the map labels. The preference is for using short words in the labels, but sometimes it was needed to use longer expressions in order to have the map correctly labeled. The second step is about the hierarchy of the concepts which were divided into three clusters. The first cluster is related to the factual information, such as the development of EDFA, advantages and limitation of using this technology in telecommunication systems. The second cluster of concepts is about the physics principles that should be known to understand how the EDFA works to amplify an optical signal. Finally, the third cluster is related to project and practical issues involving the EDFA technology. The concepts associated to the third cluster are mainly important to students who will develop new projects or solve problems in applications with optical communication devices. Each concept label in the concept map has an associated learning object, in case the student requires a deep study of any concept presented. The Table 1 shows the classification of the learning objects developed, according to the hierarchy of concepts used to build up the concept map. These concepts should be read from the top to the bottom of the map and it was also used different colors according to each hierarchical level. This strategy was taken to guide the learners during the navigation and to make sure that the proposed hierarchy will be followed properly.

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Associated knowledge</th>
<th>Learning Object Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Factual Concepts</td>
<td>Development of EDFA technology</td>
</tr>
<tr>
<td>1</td>
<td>Factual Concepts</td>
<td>Advantages of using EDFA</td>
</tr>
<tr>
<td>1</td>
<td>Factual Concepts</td>
<td>Limitation of EDFA amplifiers</td>
</tr>
<tr>
<td>2</td>
<td>Physical principles</td>
<td>Base EDFA working process</td>
</tr>
<tr>
<td>2</td>
<td>Physical principles</td>
<td>Stimulated Emission</td>
</tr>
<tr>
<td>2</td>
<td>Physical principles</td>
<td>Spontaneous Emission</td>
</tr>
<tr>
<td>2</td>
<td>Physical principles</td>
<td>Energy Absorption</td>
</tr>
<tr>
<td>2</td>
<td>Physical principles</td>
<td>Properties of the erbium ion</td>
</tr>
<tr>
<td>3</td>
<td>Project based concepts</td>
<td>EDFA base parameters</td>
</tr>
<tr>
<td>3</td>
<td>Project based concepts</td>
<td>Pumping Laser</td>
</tr>
<tr>
<td>3</td>
<td>Project based concepts</td>
<td>Erbium Doped Fiber length</td>
</tr>
<tr>
<td>3</td>
<td>Project based concepts</td>
<td>The erbium ion organization</td>
</tr>
<tr>
<td>3</td>
<td>Project based concepts</td>
<td>The EDFA dynamic behavior</td>
</tr>
<tr>
<td>3</td>
<td>Project based concepts</td>
<td>The amplifier saturation</td>
</tr>
</tbody>
</table>

Table 1 – Hierarchy of the Concepts

The next procedure in the development of the concept map is to connect the labeled concepts. In this project the labels were connected by lines, linking words or short verb expression as well as arrowheads. The importance of connecting labels properly is due to the fact that the linking words are responsible for creating meaning.

The concept map was built up with the IHMC CMap software toolkit [15] which was developed by the Institute for Human and Machine Cognition. Finally, the concept map was uploaded and implemented in the MOODLE learning environment [16].

7.2 Computer Agents

The agent theory culminated in the development of the Multiagent systems, such an important technique used in Distributed Artificial Intelligence (DAI) research area. The multiagent system architecture is composed
of a society of agents working in a collaborative way towards the solution of a problem. For so, a multiagent environment should have a group of autonomous and distributed agents as well as a communication protocol to guarantee the interaction among the system agents and external agents either robots or humans, such as tutors or students [13].

This paper proposes the insertion of a society of agents in the concept map, in order to observe, collect information about the user background profile, and also act in the virtual environment, suggesting the study of the most appropriate learning objects. The use of artificial intelligence techniques within concept maps has been discussed for years due to the free style format that a concept map can take [9]. The insertion of multiagents is a proposal of joining the benefits of a concept map and the needs to adapt the tutoring system to each student profile by the artificial intelligence expertise.

The structure of the system proposed is based on a centralized multiagent architecture, as it is shown in figure 3. For so, one agent was built for each concept labeled in the concept map. It means that each agent is responsible for inferring whether the user shall study the associated learning object or not. That is when the human agent, performed by the student is in charge of coordinating the agent proposals [12].

The agents developed in this project can be classified as purely reactive agents [12]-[13]. The internal structure was composed by a production rule (if [condition], then [action]). It means that the purely reactive agent does not use historical data to take a decision, only considers the current environment state.

<table>
<thead>
<tr>
<th>Related Concept</th>
<th>Activity description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development of EDFA</td>
<td>Put the steps of a process in the correct order</td>
</tr>
<tr>
<td>Advantages of EDFA</td>
<td>Classify sentences either true or false</td>
</tr>
<tr>
<td>Limitation of EDFA</td>
<td>Choose the correct answer to complete properly a timeline of events</td>
</tr>
<tr>
<td>EDFA working process</td>
<td>Organize the information into a hierarchical order</td>
</tr>
<tr>
<td>Stimulated Emission</td>
<td>Select an image for a key reason related to the learning content</td>
</tr>
<tr>
<td>Spontaneous Emission</td>
<td>Choose the most appropriate device to be used in a real world project situation</td>
</tr>
<tr>
<td>Energy Absorption</td>
<td>Summarize the advantages comparing the new technology to the old one</td>
</tr>
<tr>
<td>Properties of erbium</td>
<td>Complete a process diagram properly</td>
</tr>
<tr>
<td>EDFA base parameters</td>
<td>Read a passage and fill in the blanks with the most suitable words</td>
</tr>
<tr>
<td>Pumping Laser</td>
<td>Solve a problem based on the previous knowledge about the concept associated</td>
</tr>
<tr>
<td>Erbium Doped Fiber length</td>
<td>Watch a task (a sequence of images) and determinate if the task was done correctly</td>
</tr>
<tr>
<td>The erbium organization</td>
<td>Pug in pictures into a system and analyze the effects</td>
</tr>
<tr>
<td>The EDFA behavior</td>
<td>Point the mistakes presented in an illustration</td>
</tr>
<tr>
<td>The amplifier saturation</td>
<td>Prepare a training program about a subject by choosing the related concepts</td>
</tr>
</tbody>
</table>

Table 2 – Interaction Conceptual Model
The interaction between the agent and the student is also a way to bring up the motivational and emotional elements related to the communication between a human tutor and a learner [17]-[18]. In this project, it was created an interaction conceptual model based on the activities that the user should do. Table II summarizes the interactions proposed by the agents.

Another important task in the development of the proposed learning resource is the strategy to give feedback to the student after interacting with the agents. The following principles were taken to prepare the feedbacks [19]:

- The students should be given the knowledge of results. That is to say, to inform them if the answer is correct or not immediately after they answer the question;
- The students should be presented the explanation of why the answer is correct or incorrect. This is a way of learning new concepts whether the answer is correct or not;
- The students should be presented a way to learn the related concept if the answer is incorrect. By this time the agent shall act in the virtual learning environment in order to propose the study of the associated learning object.

The agents were developed using the software Adobe Flash [20], which is a popular tool on Internet, frequently used to create animations, 98% of Internet-enabled desktops have Flash Player available [21]. Flash is a tool based on vector graphics, it is recommended for creation of learning objects, because the Action Script language available with Flash version 5, allows better controls and gives support to build sophisticated applications, adding intelligent interactivity, formulas and mathematical calculations and special effects that contribute to keep the students attention. Finally, the agents were added to the concept map.

7.3 Learning Objects

The development of the learning objects can be summarized by basically two principle designs. The first one is related to the multimedia expertise to create audio and animations. The second one is the insertion of interactive resources that requires the definition of an activity model to describe how the communication between the tutoring system and the user will take place.

The animation of each learning object was developed in a way to generate a user friendly interface exploring the use of colors and graphics. However, an optimization criteria was taken in order to avoid cognitive overload that might lead the learners to negative feelings about the instructional digital tool [6].

Still according to [6], the learning process based on multimedia resources can be optimized if the corresponding words and pictures are presented near and simultaneously. It makes the students feel more comfortable because it is possible to hold the presented information in the working memory at the same time. Another important point that was considered in the learning object development process is to eliminate unneeded or irrelevant words, pictures or sounds. The use of unneeded information can divert attention from the important concepts and might lead the learner to organize the information around an inappropriate theme [6]. As the aim of the learning object is to distribute information quickly, straight to the point of interest, the level of interaction was limited to choosing an option or rollovers.

The EDFA learning object was build up on top of Adobe Flash, then the eXe eLearning XHTML [22] editor was used to generate metadata and wrapping up EDFA learning object content developed in Adobe Flash. The objective of the usage of those tools is to aid the development of digital educational resources and its publication on Internet websites without the knowhow about web publishing or programming. Moreover the eXe eLearning tool can easily package the resources according to SCORM 1.2, IMS LD or a simple website. Each SCORM package was loaded as an activity in LCMS MOODLE platform, to be integrated with other educational resources.
7.4 Computer Simulation Activity

Due to the complex physics concepts represented by mathematical models related to the optical communication systems, the use of computer simulation tools is being used in different contexts, such as scientific researches, development of new industrial products or project technical specifications, in order to analyze the behavior of a photonic device. Facing the relevance of using a simulation software tool, the Photonic Transmission Design Suite [16] was developed not only for the optimization and analysis of photonic devices like EDFA, but for the optimization of an optical system with all its elements.

In order to help students before and during the computer simulation activity, it was developed the simulation instruction module as shown in figure 2. It consists of providing instructions of how to use the PTDS software as well as a guideline for the activities related to EDFA proposed by PTDS simulation tool [23].

The initial instructions include information about the development of the PTDS software by VPI [14], followed by the download and installation procedure of the demonstrative version of the PTDS software from the MOODLE platform. The simulation instruction module also provides information of how to navigate on this software, from selecting an activity to changing parameters of a system or exporting results. The simulation instruction module was also developed using Adobe Flash [20] and it was implemented in MOODLE platform [16].

8. RESULTS AND DISCUSSION

The navigation through the learning resource proposed can be divided into two steps. The first part of the study is the use of the concept map and the learning objects, when necessary. The last part is the use of the PTDS simulation tool. The use of the learning resource proposed begins with the initial instructions as shown in figure 4. The initial instruction module presents the aim of the study, the essential prerequisites for the appropriate use of the system and also it provides information of how to exploit the concept map and the learning objects.
Although the initial instruction module makes clear that the use of the concept map should be done according to the hierarchical order, it is important to highlight the strategy of using different colors in the development of the map for each hierarchical group. In figure 5, the graphical knowledge representation of the concepts related to EDFA can be seen.

The agents added to each label in the map can contribute to the flexibility of the learning resource. The main aim of the interaction between the agent and the learner is to collect information about the user background, but the strategy taken also allows the student to have an appropriate feedback of his/her answers as well as to learn complementary information from the correct or incorrect answers. Figure 6 shows the agent related to the properties of the erbium ion. The techniques used for developing the multimedia animations are a way to stimulate the meaningful learning, as shown in figure 7.

In addition to the multimedia resources, the interactivity inserted on the learning objects is also a way to optimize the learning process, leading the students to be active on the process. Figure 7 shows the interaction with an agent.
Finally, for the last part of the navigation through the learning resource, it is expected to have the users with a minimum background about the EDFA base concepts. It does not matter if such knowledge is a result of previous background or the study provided by the learning objects.

The simulation activity is an opportunity to get to an advanced knowledge level about the erbium doped fiber amplifiers and it is also a tool that can be used in real world projects.
Figure 8 shows the interface of the software PTDS which helps students to get used to the optical telecommunication project parameters.

9. CONCLUSIONS AND FURTHER WORKS

The insertion of rational computer agents in the conceptual map permitted not only the adaptation of the system but also the increase of the reusability of the learning resource, which can be used by a wide range of students, either for beginner under graduating students or graduating students.

The navigation through the conceptual map and the learning objects allows the optimization of the computer simulation tool leading the users to fulfill the lack of concepts related to EDFA by accessing the associated learning objects. The use of concept maps as well as the learning objects based on multimedia and interactive technologies are also a strategy towards the achievement of the meaningful learning.

The successful implementation of the learning resource proposed suggests as further works, the development of complementary learning objects, exploiting other topics related to the photonics and optical communication systems, and the evaluation of the learning resource with students in a real world situation.

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Using mobile camera for a better exploitation and understanding of interference and diffraction experiments

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Abstract:
To deduce the wave nature of light, explain its behavior when it interacts with material obstacles (diffraction) or its behavior when light from two coherent sources interfere with each other (interference), we need to explain what are waves and what are their properties (wavelength, frequency, mathematical relationship between wavelength and frequency, superposition principle, …).
Two principal approaches are generally used to introduce waves:
1/ An experimental approach (the example commonly used approach): to observe the water waves pattern obtained when drops of water (with an eye dropper, two eye droppers, or equivalent) fall -at a steady rate- on a calm pool of water surface.
2/ A theoretical approach: Wave coming from one source is represented by a sinusoidal function; Superposition of waves coming from two coherent sources is done by a sum of two sinusoidal functions with constant phase difference.

In Tunisia, different workshops on “wave nature of light based on interference and diffraction” using Active Learning process have been organized for about 150 secondary school teachers in 2009. These workshops are based on UNESCO Active Learning in Optics and Photonics (ALOP) project.
This paper will show how taking water wave’s pattern using some participant’s mobile camera helps to make some misconceptions resolved and includes at the same time other more complex phenomena.

Historical overview of achievements to attribute a wave nature to the light

Historically and until today, light, its origin, its nature, its structure - has been and is still a center of interest for men. Many physicists through many centuries, using optic geometrical model or corpuscular model of light, tried and failed to explain interference and diffraction phenomena which have been explained when considering a wave behavior for light.

- The understanding of light behaviour at, the antiquity, the Egyptians, the Greeks,..., was based on philosophical approach. In the XIth century, Ibn al-Haytham considered as the scientist of the first millennium (R.Power) has studied the various physical phenomena like reflection, refraction, shadows, eclipses, rainbow, and has speculated on the physical nature of light.

-At the beginning of XVIIth century, I. Newton (1616) adopted a corpuscular nature for light, with no success to explain the interference.

Later, 1690, Ch. Huygens adopted the hypothesis that the speed of light is decreasing in dense matter and explained the laws of reflection & refraction based on the wave theory for light.
It was known that light goes in straight lines called rays which do not seem to interact while crossing one another. This was the most powerful argument of Ch. Huygens against the Newton’s corpuscular theory. Because of the “aura” of Newton, the wave nature of light has been put away for almost one century.
At the beginning of the 19th century, wave nature of light is adopted again by Th. Young (1773-1829), F. Arago (1786-1853) and J.A. Fresnel (1788-1827), and the first explanation of light interferences based on that wave nature has been done: compared first to the sound, light waves were supposed propagating with a longitudinal polarization; later transverse polarization has been attributed to light and explanation done for light interference observed in experiments.

Waves phenomena appears in many contexts throughout physics, and the idea of waves has many applications in all branches of physics: sound waves, water waves (long swells coming to the shore or the smaller water waves consisting of surface tension ripples), waves in solid, Earthquake waves, waves of quantum mechanics,…, light waves.

Water waves are usually used in elementary courses - in secondary schools- as an example to introduce the wave model for light through the topic of interference & diffraction.

We used that example for training of trainers in ALOP activity for about 150 teachers of secondary school in Tunisia.

The ALOP approach is a collaborative learning (participants work in groups of 3 or 4) and is based on PADS: Prediction, Activity, Discussion and Synthesis. An ALOP module is such that questions are qualitative, cannot be answered by through memorization and requires qualitative reasoning and verbal explanation.

Participants are asked to sketch the water pattern that they expect to observe if drops of water fall -at a steady rate- into a pool of water. After a common prediction (figure 1) and discussions, participants make observation with a transparent trough filled at about 2-3 cm of water and placed on an overhead projector. One drip drops in the center of the trough at a steady rate with fewer drops per second and more drops per second. The participants sketch the observed pattern, compare it to their prediction, and explain what happens from a point source.

Prediction and observation of this simple experiment lead to very interesting and animated discussions in the class. For some participants, the predictions and observations seemed obvious: propagation of circular waves away from the point source with equal separation (wavelength) decreasing while the rate (frequency) increases. For some others (especially those whose predictions do not agree with the observations) the observation of the phenomena is not clear and they cannot conclude.

We repeat the experience – discussions and confusion increase! Participants are then invited to take pictures with their mobile phone camera at different drop rates : Few drops/sec (figure 2a) and more drops/sec. figure(2b).

![Figure 2a](image1)

![Figure 2b](image2)

![Figure 2c](image3)
Camera is more sensible than the eye: when frequency increases, wavelength $\lambda$ decreases and for high drops rates, waves are not seen by eyes and clearly seen on photos. The photos could be used to deduce the wavelength and the speed of the waves.

For interference: drops fall from two point sources at the same time and with the same rate on the surface of water.

The pattern predicted by most of the participants, continue hyperbolic lines for maxima and minima, is on figure 3. The attributed explanation is based on mathematics: superposition of two sinusoidal vibrations leads to this shape with maximum and minimum related respectively to differences in path length from observation point to the sources 1 and 2, as $d_2-d_1= (n\lambda)$ or $(n+1)/2)$. Even after observations and discussions these participants continue to believe in their predictions. Photos have then been taken by phone camera at different rate of drops and led to the agreement of all the participants on the same result, this one predicted by few people, observed and given on figure 4.

Such photos helped again to note the spatial evolution of waves, to observe superposition of waves from 2 coherent sources, presence of maxima (bright) and minima (dark) (not on continue line). Illustrating double source interference, two moveable waves trains (figure 6) for a variety of path differences has been used and tested by participants. The idea of this analogy comes from R.Baierlein and V.Miglus.

Taking photos using mobile camera helps to make some misconceptions resolved and at the same time leads to other more complex phenomena noted by participants and related to:

a)- water waves: Participants try to make analogy of these ones with waves introduced in mechanic’s courses and obtained with one rap over straight rode. While one rap leads to a propagation of one transversal wave, one drop from one point source leads to a water wave followed by ripples (figure 6), these are still pronounced on patterns with few drops/s (figure 7) and the movement is a mixture of transverse and longitudinal. Participants noted also the presence of some dispersion, different waves have different speeds.

b)- light through water waves leads to light dispersion. This is observed on photos (figure 6,7).

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From university to company – education of optical communications in cooperation with industry at Technical University of Ostrava

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ABSTRACT

Paper deals with cooperation between companies and university, especially with interactions companies and students, companies and pedagogues. At present it is possible to observe insufficient level of practical skills and knowledge among students and their pedagogues, there is no articulation for companies’ demands. We try to solve this situation with the help of pilot compartment. Its main task is to associate university teachers, graduate students and companies’ specialists. Within the scope activities of the compartment is to prepare one or two day’s long special courses. Their mass point is focused to practical training; prepare conditions for trainee-ships dedicated to teachers and students on one side and special courses for technicians, dealers and companies’ management on the other. The main goal of this compartment is an interconnection between university education and requirements out coming from praxis. There are many ways of how to fulfill such cooperation.

Keywords: university education, interconnection between university and companies, practical teaching, laboratory education

1. INTRODUCTION

Department of Telecommunications cooperates with many telecommunication companies for many years. This cooperation is based on applied research or innovation development only. For education purposes it has only a small meaning, main goal is to obtain knowledge about solved problematic and to obtain money for further development of department. For now our department is relatively well equipped with many devices and apparatus, especially in fiber optics and optical communications. Except of fiber optic hardware (laser sources, LED sources, optical powermeters, OTDR-meters, fusion-splices, Raman OTDR-meter, optical tables, benches, etc.) our department is working with SW for designing of optical routes, systems, fibers and devices. We are using Optiwave SW as a multilicence for a group of 10 students.

Teachers in our department prepare many study texts, syllabi and laboratory instruments. But they have a small contact with requirements of praxis. According to our experiences the situation is the same for all universities in Czech Republic. Our department is better equipped with devices in comparison to small and middle companies and may be compared with large telcos. The problem is that educational background is not used for creation of cooperation in education for practice and vice versa. This lack of cooperation has been the main motor for project of new type of cooperation between university department and companies.

2. DESCRIPTION OF PROJECT

As it has been mentioned above nowadays we may observe quite missing system and systematic cooperation with praxis as a basis for education in telecommunications and optical communications. The cooperation is
based on occasional personal bonds between individual teachers and companies. The consequences of such state are limited or zero knowledge of university teachers about requirements of firms. The problem is more serious because of teachers read their lectures according to their best effort. We are trying to change this situation and to achieve two partial goals of the same importance.

a. To increase practical knowledge in optical communications for students and their teachers
b. On the basis of outstanding higher skill level of teachers to reach the state when department will be natural expert authority for optical communications sought out the firms in treatment problems with improving of skills for their staff

Both partial goals may be subdivided into individual goals.

Ad a.
- Creation of study materials for practical teaching both in classical and e-learning form
- To integrate important experts from firms and companies to opposition procedures of these educational materials
- To create natural space for student’s involvement to managed practice in firms and future employers
- To create space for future short-terms stages of teachers in firms and companies

Ad b.
- Creation of specialized study materials for short terms educational activities (one or two days typically) according to firm’s requirements oriented to practical training and evaluate their efficiency in educational process
- Creation of organizing scheme, structure and background for further education of university teachers and researchers

2.1 Content of courses

All courses are prepared on the base of existing lectures. The main ideas of such conception are following:

**Introduction to telecommunications and optical fibers** - Telecommunications, basic ideas, connection point to point, networks, information capacity of optical fibers, transition from analog to digital transmission systems, place and role of the optical communication systems, history and development of the transmission properties and parameters of optical fibers, fiber optical communications systems, basic block diagram of optical transmission, nowaday stage in optical systems, future development trends

**Digest of light and its properties** - Plane electromagnetic wave, refractive index, energy transmission by light wave, linearly polarized light, circular and elliptical polarized light, transmission of light through quarter-wave plate, interference of light, two-beam interference, coherence of light, Gauss beam, Gauss beam diffraction, light as beam of rays, refractive index, reflection and diffraction of light, Brewster angle, total internal reflection, light as a stream of photons, energy levels of electron and transitions among them, absorption and emission of light

**Basics of optical fibers 1** - Light guidance in optical fibers, step index fibers as a basic optical communication structure, total reflection on the core-cladding boundary, refractive index of core and cladding, critical angle on the core-cladding boundary and critical angle of transmission, light launching into optical fiber, acceptance angle, numerical aperture, attenuation on optical fibers, bending losses, microbending losses, light scattering, basic mechanism of absorption, transparent windows for fibers made of SiO2, calculation of total attenuation of optical line, direct method of attenuation measurement

**Basics of optical fibers 2** - Intermodal and chromatic dispersion, description of modes, number of modes, physical meaning of modes, modal dispersion, mechanisms of pulse spreading and its calculations, restriction of the bite rate due to modal dispersion in optical line, first solution to modal dispersion - grade-index fibers, basic ideas of graded-index fibers, reduction of the modal dispersion due to graded-index fibers, second and principal solution of the modal dispersion - singlemode fibers, structure of singlemode fiber, comparison of the modal dispersion in three types of optical fibers

**Basics of optical fibers 3** - Chromatic dispersion, mechanisms of chromatic dispersion creation, calculating pulse spreading caused by chromatic dispersion, definition of bit rate and bandwidth, relationship between bit
rate and bandwidth, electrical and optical bandwidth, total dispersion and bit rate, bit rate calculation, specification of bit rate and bandwidth by optical fibers producers

**Basics of optical fibers 4** - Reading a data sheet of optical fibers, general parameters, optical characteristics, geometrical characteristics of optical fibers, environmental specifications of optical fibers, mechanical specifications, other characteristics

**Advanced description of optical fibers 1** - Maxwell’s equations, interpretation of Maxwell’s equations, wave equations, solving wave equations, plane waves, propagation of the EM waves, wave equations for time-harmonic EM field, distribution of electrical and magnetical part of wave in space, wave propagation in lossy medium, phase and group velocity of waves, group refraction index, EM waves in bounded media, rectangular waveguide, modes in waveguide, cutoff frequency and waveguide wavelengths, advanced description of total internal reflection, effects on boundary of two dielectrics, phase shift in total reflection, evanescent waves, reflectances and transmittances on boundary of two dielectrics, Goos-Haenchen shift

**Advanced description of optical fibers 2** - Cylindrical fibers, modes of cylindrical fibers, LP modes, selecting rules for EM waves in optical fibers, waves and rays of optical fibers, meridional and skew rays, guided, radiation and leaky modes, optical power in fiber, power distribution between core and cladding, number of modes and measurement of attenuation

**Advanced description of optical fibers 3** - Cutoff wavelength and cutoff normalized frequency of optical fiber, cutoff condition and total internal reflection, power confinement and cutoff condition, role of cladding, effective refractive index

**Advanced description of optical fibers 4** - Attenuation in multimode fibers, general approach to attenuation, intrinsic losses, Rayleigh scattering, behavior of SiO2 fibers, choice of operating wavelength, other materials for optical fibers production, fluoride fibers, chalcogen fibers, extrinsic absorption, macrobending loss, microbending loss, influence of mode structure to fiber attenuation, attenuation and attenuation constant, dispersion in multimode fibers, total dispersion and pulse width, electrical and optical bandwidth, mechanism of modal dispersion

**Advanced description of optical fibers 5** - Chromatic dispersion, derivation of the formula for material dispersion, practical calculation of material dispersion according to datasheets, Sellmeier relations, influence of source spectral width, waveguide dispersion, description of bit rate and bandwidth in multimode fibers, choice of operating wavelength according to fiber dispersion, dispersion power penalty

**Basics of singlemode fibers (SM fibers)** - Principle of action, Gaussian beam, influence of core and cladding to mode field diameter (MFD), cutoff wavelength of SM fiber, attenuation in SM fibers, macrobending loss, microbending loss, absorption of light and light scattering of SM fibers, dispersion and bandwidth, chromatic dispersion, material dispersion, waveguide dispersion, conventional fibers, shifted fibers, dispersion flattened fibers, polarization mode dispersion (PMD), bandwidth and bit rate of SM fibers, reading of datasheets, general characteristics, transmission parameters, MFD and cutoff wavelength, geometric characteristics, mechanical properties of SM fibers

**Advanced description of SM fibers 1** - Mode field, Gaussian model and real mode field distribution, cutoff wavelength and V-number, effective cutoff wavelength, detailed description of SM fiber attenuation, bending losses for step-index SM fiber, more sophisticated refractive index profiles of SM fibers, coping with dispersion in SM fibers, dispersion solution for WDM fibers

**Advanced description of SM fibers 2** - Compensation of chromatic dispersion with compensating fibers (DCF), designing of DCF systems, dispersion compensating gratings (DCG), fiber Bragg gratings (FBG), production of FGB fibers, polarization mode dispersion (PMD), PMD characteristics of SM fiber, polarization-maintaining fibers, PMD compensation, nonlinear effects in SM fibers, nonlinear refractive effects, self phase modulation (SPM), solitons in optical fiber, cross-phase modulation (XPM), four-wave mixing (FWM) in SM fiber, stimulated scattering effects, trends in fiber design

**Fabrication of optical fibers and cables 1** - Requirements on technologies, preparation of molten glasses, fusible technologies, fiber drawing, drawing of long fibers - double-crucible method, deposition technologies, OVPO, VAD, MCVD, PCVD technologies, optical fibers coatings, primary and secondary tight coating, optical cables for telecommunications and data transmission, basic structure of optical cable

**Fabrication of optical fibers and cables 2** - Mechanical parameters of optical cables, protection and humidity resistivity, gels in optical cables, protection of optical cables to biological influences, materials for cable coatings, PVC, polyurethane (PUR), HDPE, nylon, teflon, LSZH materials, examples of optical cable datasheets
Installation methods and procedures with optical cables, Installation methods, installation in climbing-irons, cable laying into protective pipes, protection to lightning, self-supporting cables, cables for chemical industry, cables for higher temperature, blowing technologies, new cable laying technologies of optical cables, structure of telecommunication optical lines, structured cabling systems, optical switchgears, design of optical lines, attenuation budget, total dispersion budget

**Optical fiber cable connectorization 1** - Mounting splices, fixed splices, intrinsic and extrinsic losses in splices, reflection loss, insertion loss, optomechanical splices, fused splices, fusion splicers of optical fibers, fusion splice protection, optical connectors, basic structure of optical connectors, insertion loss of optical connector, return loss

**Optical fiber cable connectorization 2** - Distribution curve of insertion loss, repeatability of connection, mounting density of optical connectors and their compatibility with optical cables and appliances, types and materials for optical ferrules, types of optical connectors-SMA, FC, ST, SC, FDDI, ESCON, E2000, new types of optical connectors-MTRJ, MTP, MU, MINIMAC, the latest trends in connections with optical connectors

**Tests and measurements of optical fibers and cables - 1** Kinds of measurements, measurement at SM and MM optical cables, attenuation measurement, conditions for correct attenuation measurement, cut off method, direct method of attenuation measurement, OTDR-metr, basic parts of OTDR-metr, dead zones

**Tests and measurements of optical fibers and cables - 2** Curve routing of backscattering, cable factor, shape of faults on the backscattering curve, chromatic dispersion, methods for chromatic dispersion measurement, differential phase shift, time delay of pulses, BERT, measurement of insertion loss of connectors and other passive elements in optical lines, return loss measurement

**Basics of sources for optical communications** - lasers Basic properties of lasers, spontaneous and stimulated radiation, population inversion, positive feedback, material loss, laser activity and conversion laser characteristics, characteristics and laser light properties, diode lasers, basic structures of laser diodes, DH, BH, stripe lasers, QW lasers, VCSEL, optical resonators, restriction of the bandwidth, DFB and DBR lasers, laser diodes with and without active cooler, datasheets parameters of laser diodes

**Basics of sources for optical communications** - LEDs Advantages and disadvantages of LEDs to laser diodes, creation of photons in semiconductors, light radiation from pn junction, basic description and LED characteristics, homostructure LEDs, heterostructure LEDs, surface radiating LEDs(SLED), edge radiating LEDs(ELED), light coupling into optical fiber, technology improving coupling of optical fiber to LEDs, datasheets parameters of LEDs, modulating bandwidth

**Sources for optical communications-advanced description 1** - Intrinsic semiconductors: Fermi energy levels and number of charge carriers, charge carriers density, effective mass of electrons and holes, doped semiconductors, materials for optical communications, PN junction unbiased, density of electrons and holes, biased PN junction, direct and indirect transitions, conservation of energy and momentum law, E-k diagram, Einstein’s rate relations, two-levels systems, equilibrium radiation from two-levels system, relationship between spontaneous and stimulated radiation, emission and absorption of radiation, absorption coefficient and linear coefficient of material amplification

**Sources for optical communications-advanced description 2** - Conditions for light amplification, population inversion-description, population inversion and methods of its realisation, three levels and four levels systems, optical feedback, phenomena in optical resonator, threshold condition for laser amplification, losses in optical resonator, total amplification and population inversion, amplification coefficient for small signals

**Sources for optical communications-advanced description 3** - Efficiency of laser diodes-internal, external, differential, power, laser resonator efficiency, threshold amplification and line width, radiating and nonradiating recombinations and their influence to laser diodes efficiency, conditions for high laser efficiency, heterostructures and their function, efficiency in terms of an E-k diagram, characteristics of laser diodes, threshold current and operating current of laser diode, spectral properties of LDs, radiation patterns of LD, longitudinal and transverse modes of laser radiation, LD modulation

**Sources for optical communications-advanced description - 4** Theoretical limit of laser modulation rate, analog and digital modulation of LDs, rate equations of LD, relaxation oscillation of LD, Transfer function of LD, intensity modulation of LD, chirp, noise of LD, RIN and its description, transmitter modules, function block diagram, driving circuits of LD transmitters, link codes for data transmission, circuit solution of optical transmitters with LEDs and LDs
Sources for optical communications - advanced description: Modulation circuits, controlling and monitoring circuits, coupling light from LED transmitter, coupling light from laser transmitter, back reflection protection of LD, integral characteristic of optical transmitter-eye diagram, faults of optical transmitters and their consequences in eye-diagram, internal and external modulators, Mach-Zehnder modulator, electro absorption modulator

Basics of detectors and receivers for optical communications: Basic requirements on optical detectors, basic principles and fotodetector structures, photodiode with PN junction, photovoltaic and photoconductive modes of operation, responsivity of photodiode, responsivity versus wavelength, short and long cutoff wavelength of photodiode, sensitivity of photodiode, photodiode bandwidth, equivalent circuit of a PN photodiode, bandwidth and photodiode digest, PIN photodiode, avalanche photodiode APD), MSM detectors

Detectors and receivers for optical communications - advanced description 1: SNR a error rate of receiver, photodiode noise sources, shot noise, thermal noise, dark current, noise 1/f, noise equivalent circuit, total noise figure, normalized noise value, SNR for PIN photodiode, SNR for APD, dependence of SNR on APD amplification, noise equivalent power (NEP), bit error rate (BER), BER and decision threshold, error function (erf), complementary error function (erfc)

Detectors and receivers for optical communications - advanced description 2: BER description - Q parameter, relationship between BER and SNR, BER versus Q parameter, minimum optical power - photodiode sensitivity, minimum number of photons per bit, quantum limit

Receiver units for optical communications: Functional block diagram of optical receiver, input receiver unit, equivalent circuits of an optical front end, quantizer, clock recovery, decision circuit design, datasheets and parameters of optical receivers

Components of fiber optic networks 1: Point to point links, fiber optical networks, TDM and WDM, add/drop problems, repeaters and amplifiers in optical networks and signal amplifiers, passive and active elements of fiber optical networks, transceivers for fiber optic networks, transmitter requirements in WDM networks, tunable lasers, receivers for optical networks, receiver requirements in WDM networks, amplifiers in optical networks, functional types of optical amplifiers, semiconductor optical amplifiers(SOA), SOA advantages and disadvantages

Components of fiber optic networks 2: Fabry-Perot amplifier(FPA), travelling-wave amplifier(TWA), Gain of FPA, gain of TWA, gain saturation, FPA bandwidth, TWA bandwidth, crosstalk, polarization dependent gain, noise in optical amplifiers, amplified spontaneous emission ASE, datasheets and parameters of optical amplifiers

Components of fiber optic networks 3: Erbium doped fiber amplifiers (EDFA), principle of operation, energy band structure, amplifier pumping, C-band and L-band, gain and noise in EDFAs, EDFA components, splicing of erbium-doped fibers, ways to reduce splicing loss, pump laser diodes, datasheets and parameters of EDFAs, other types of optical networks amplifiers

Passive components of fiber optic networks 1: Fused biconical tapers and couplers, port configurations of couplers, characteristics of a WDM coupler, datasheets parameters of couplers, basics of WDM coupler theory, coupling length, phase mismatch, WDM multiplexers and demultiplexers, broadband narrowband WDM MUX/DEMUX


Fiber optic networks: Telephone networks, data networks, access networks, transport networks, multiplexing hierarchy in telecommunication networks, metropolitan networks, synchronous and asynchronous network, modulation and optical network multiplex, cable TV networks, place of optical networks in OSI model, coherent communication systems

Fiberless optical networks: Atmosphere as a transmission media, phenomena limiting range and bit rate, directional and diffused networks, sources and detectors for fiberless networks, principles of design for fiberless networks
3. WHY COOPERATION BETWEEN DEPARTMENT AND COMPANIES

As it has been mentioned above, nowadays is no managed connection between department and companies in educational process. Study materials are not consulted or disputed by firms even if these materials will be used for laboratory education or other practical training. The consequence is that the disaffection of university education from firm’s requirements is increasing. That manifests both by students and their teachers.

Firms and companies (as consumers of products of university educational systems) instead of appealing to suitable university departments solve better their questions and problems of staff further education by their selves. Authors of this paper have been opponents of many educational technical projects for companies and met with such effect dominantly. In any project figured university as a educational institution in spite of it acts about technical education.

This state may be improved by managed process only. This process provides educational materials according to requirements of practice. It is necessary to work with three task groups – the first one is created by students, the second one by their teachers and the third one by technicians.

Students
They will be integrated within direct educational process. The main idea is to increase the laboratory and experimental part of their study including project teaching, managed stages, bachelor and diploma work are coming out from needs of firms and companies. Students’ motivation is the same as motivation to study university; authors of this paper have experiences that the student motivation is higher if study is more practically oriented.

Teachers
At present many teachers have never been outside university and knew no needs of firms and companies and ways of thinking of technicians outside universities. Any forced compulsion of teachers to absolve stages in firms and companies have no meaning if it not created natural place for meeting of both sides. As the starting point it is necessary to put the new prepared study materials for rout of technicians not of other teachers. It is impossible to continue with state when study materials especially practical teaching are disputed by other teachers. Further it is necessary for teachers to be students for several days. The goal is creation the short time activities for technicians at higher educational level. Motivation for teachers is a real obtaining of contacts, knowledge and skills about ways of thinking.

Technicians
Their main motivation is possibility to influence the study process as their future employers, possibility to create system for further education of their own staff and possibility to create real setting for creation of expert teams. Part of this group will be addressed with offer to participate in educational activities for the first groups, the rest will be participated as a regular students in short term courses.

4. CONCLUSION

This project is a pilot project at the Technical University of Ostrava. If the project is successful it will be spread to other departments. For Department of telecommunications in case of success it will be created new source of real cooperation with firms and companies. The starting point will be improvement in educational process; other points are creation expert teams and solving difficult science and technical tasks.
Precision engineering for optical applications: Knowledge Transfer into UK industry

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ABSTRACT
A means of facilitating the transfer of precision engineering knowledge and skills from academic institutions and their research partners into UK optics and optical engineering companies is described. The process involves the creation of an Integrated Knowledge Centre (IKC), a partnership led by Cranfield University with the support of the University of Cambridge, University College London, and the OpTIC technium. This paper describes the development of the three main vehicles for knowledge transfer. These are a Masters level postgraduate degree course (the Cranfield University led MSc in “Ultra Precision Technologies”), a portfolio of industrial short courses which are designed to address key skills shortages in the fields of precision engineering for optical applications, and an e-learning package in precision engineering. The main issues encountered during the development of the knowledge transfer teaching and learning packages are discussed, and the outcomes from the first year of knowledge transfer activities are described. In overall summary, the results demonstrate how the Integrated Knowledge Centre in Ultra Precision and Structured Surfaces’ approach to knowledge transfer has been effective in addressing the engineering skills gap in precision optics based industries.

Keywords
Knowledge Transfer, Precision Engineering, Ultra Precision Optics, Postgraduate Masters degree.

1. INTRODUCTION
A number of UK manufacturing sectors require staff with postgraduate level skills in ultra precision technologies and applications. These sectors include, optics and optoelectronics, space, energy generation (including nuclear fusion and solar), and display technology. The common thread running through all of these products and applications is the need for skilled mechanical engineers with an additional specialization in the field of ultra precision. Within the UK, the large optics and optical components sectors are of strategic importance. As a result, a shortage of engineers with the skills to precisely machine materials for optics and optically-based products needs to be addressed as a matter of some urgency.

2. UK INDUSTRIAL CONTEXT
The UK ultra precision optics industries are thriving, despite challenging economic environments and the increasingly competitive globalisation of its markets. However the demand for the specialist mechanical engineering skills needed to realise the opportunities presented by the expansion of the technologically advanced customers within the new economies has not been matched by the supply.

The need for greater integration between UK Higher Education and the manufacturing sector has been well documented. From the industrialist’s standpoint there are a bewildering number of undergraduate and postgraduate courses that feed into the labour market. Similarly there are a large number of Higher Education establishments that provide training, often with very different learning objectives for their students. Without any guidance it is often difficult for a manufacturing organization to recruit effectively in this environment. The recruitment operation is seen as a one-way process with little or no opportunity for the specialized needs of the manufacturer to be catered for. The student, employer, and the academic institution are essentially remote and isolated from each other. In such circumstances the successful recruitment of employable and technically capable staff becomes largely a matter of chance.
This is particularly true for the recruitment of ultra precision engineers into the precision optics sector of UK business. Here a prospective employer must decide whether to recruit a seasoned professional, or a new/recent graduate. The individual will probably possess a first or second degree from one of 117 academic institutions of Higher Education within the UK, in a subject including mechanical engineering, physics, material science, electronic engineering, general engineering, and chemistry. It is against this backdrop that the Integrated Knowledge Centre (IKC) in Ultra Precision Structured Surfaces (UPS²) and the Cranfield University led Knowledge Transfer activities were conceived, as discussed in the next section.

3. THE INTEGRATED KNOWLEDGE CENTRE (IKC) IN PRECISION ENGINEERING

Partnerships between academic institutions and manufacturing industry have been developed in a number of fields, including mechanical engineering². In the current context of UK ultra precision engineering for optical applications this link is provided by a unique partnership between UK academia and industry, the UPS² Integrated Knowledge Centre (IKC), located at the Technium OpTIC within the North Wales optics and optoelectronics business cluster. (see Figure 1).

The Ultra Precision and Structured Surfaces Integrated Knowledge Centre (UPS²) is the cornerstone of an EPSRC funded approach to support UK industry through a range of industry-facing technology transfer initiatives. Its success is to be identified as a self-funding UK Centre of Excellence housed at the Technium OpTIC. It is working towards world class research facilities with a vibrant research and IP portfolio, supporting participating companies. Although it is the knowledge transfer activities that are of most interest in the context of this paper, there is an opportunity for optical engineering and photonics partners to link through facilities, equipment, plus research and development.

4. SYSTEMIC LINKAGE BETWEEN INDUSTRY AND ACADEMIA

The MSc in “Ultra Precision Technologies” is the flagship of the IKC knowledge transfer programme, and reflects the strength of the link between academia and the needs of precision engineering businesses. This link is illustrated schematically³ in Figure 2. In the model the students are regarded as inputs to a teaching and learning system, with corresponding outputs. However there is a need for stronger links between students, academia and industry throughout the whole sequence of processes that make up the system. This has been addressed by the addition of an intermediate shell of sub-systems which are described in Figure 2 in systems terms as the “Course-level interface” and “Company, Student, and HE establishment engagement” sub-systems; and define the role of a dedicated HE academic or professional. It is through this structure that the
precision engineering and optical application industries are able to play a proactive part in all of the key activities from student recruitment to course design.

The roles played by the industrial partners and the proactive links between the University and its engineering sponsors are described in the context of the Cranfield University led MSc in “Ultra Precision Technologies” in the following section.

5. TEACHING AND LEARNING – MSc IN ULTRA PRECISION TECHNOLOGIES

The concept of the course, and its role in attempting to address a UK skill shortage for precision engineers, is a direct response to the needs of the UK “large optics” industrialists – expressed through the appropriate research councils. Simply, there is an urgent need for skilled and employable precision and ultra-precision engineers who can employ those skills effectively in an optics and photonics industrial environment. In order to meet these criteria a one-year full-time Masters degree course was constructed. The Masters (M-level) structure has the benefit of joining three components of study within a proven overall framework. These are a block of taught courses or modules, a group project, and an individual project which is written up as a thesis.

5.1 Taught elements

The taught modules are listed in Table 1. The topics reflect the engineering skills required to be learned, the applications to be addressed, and the business skills that will aid new products and wealth generation. The “Precision Engineering” module contains the core of the precision engineering principles and techniques for optical applications – such as grinding, polishing, and plasma technology for advanced 3D form, figuring and roughness adjustment. The “Metrology and Optical Test” module explains how the drive for ultra-precision drives the push for ultra-precise measurement. Since the required accuracies are fractions of a wavelength, optical techniques predominate. In line with the prerequisite for excellence in both teaching and learning the course includes an in-depth series of lectures in Interferometry from Professor Jim Wyant of the University of Arizona. Module 3, entitled “Managing Innovation and New Product Development”, is unique in its brief to develop the student’s managerial skills. This is in response to an industrial need for engineering students who have a good appreciation of entrepreneurship and the creation of new products within a manufacturing environment. In a wider industrial context it also prepares the student for the role of a new business creator.
<table>
<thead>
<tr>
<th>Subject</th>
<th>Co-ordinators</th>
<th>External Partners</th>
<th>Location / date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precision Engineering</td>
<td>Cranfield, Precision Engineering Centre</td>
<td>University of Huddersfield, MIT, Euspen</td>
<td>Cranfield, Oct.</td>
</tr>
<tr>
<td>Metrology and Optical Testing</td>
<td>Cranfield, Precision Engineering Centre and OpTIC</td>
<td>University of Huddersfield, University of Arizona, ETH Zurich, Philips Applied Technologies</td>
<td>OpTIC, Oct</td>
</tr>
<tr>
<td>Managing Innovation and New Product Development</td>
<td>Cranfield, School of Management</td>
<td>Institute for Manufacturing, Cambridge</td>
<td>Cranfield, Nov</td>
</tr>
<tr>
<td>Computer-aided engineering for ultra precision</td>
<td>Cranfield, Precision Engineering Centre</td>
<td>Cimatron, ForeGone Solutions</td>
<td>Cranfield, Dec</td>
</tr>
<tr>
<td>Optical Design and Fabrication</td>
<td>UCL, Optical Sciences Laboratory</td>
<td>University College London, Zeeko</td>
<td>OpTIC, Jan</td>
</tr>
<tr>
<td>Surface Engineering and Coatings</td>
<td>Cranfield, Surface Engineering Centre</td>
<td>PJ Coatings</td>
<td>Cranfield, Feb</td>
</tr>
<tr>
<td>Modern Optical Technologies</td>
<td>Cranfield, Precision Engineering Centre and OpTIC</td>
<td>University College London, UK ATC, Imagine Optic, Bookham Technology Centre for Modern Optics</td>
<td>OpTIC, Mar</td>
</tr>
<tr>
<td>Laser Micromachining and Surface Structuring</td>
<td>Cambridge, Centre for Industrial Photonics, IfM</td>
<td>Oxford Lasers, Laser Micromachining Ltd (LML), TW Ltd, Optek Systems</td>
<td>Cambridge, Apr</td>
</tr>
</tbody>
</table>

Table 1. MSc in Ultra Precision Technologies – taught modules showing industrial partners

Following a course on CADCAM for product design the Taught Element syllabus returns to its optics heartland for the “Optical Design and Fabrication” module, located at the OpTIC technium in North Wales, but taught out of the Optical Design department of University College London. The aim is to provide students with an overview of modern technologies for designing and optimising optical systems, and fabricating precision lenses and mirrors. In line with the rest of the course, practical issues are emphasised, alongside the interactions between the design and fabrication stages of a project. Details include the teaching of ray-tracing and numerical optimisation as design and tolerancing tools for optical systems, and the importance of some theoretical insight to ensure sensible solutions.

The module entitled “Surface Engineering and Coatings” is a good illustration of the marriage between ultra precision engineering and optical engineering which underpins the course as a whole. In addition to providing an understanding of the role that surfaces play in materials behaviour, the module increases focus to concentrate on the optical applications of coating systems. An understanding of the suitable analytical techniques used to evaluate and characterise surfaces and thin samples is also gained. The penultimate module is concerned with the applications of ultra precision technologies to optical and photonic applications. In “Modern Optical Technologies” the student is introduced to market sectors that include optical telecommunications, astronomy, sensors and displays, lasers in nuclear fusion, MOEMS, and holography. Finally, the course relocates to the University of Cambridge for the “Laser Micromachining and Surface Structuring” course from the Centre for Industrial Photonics within the IfM (Institute for Manufacturing). The unique partnership of academic departments that sit at the core of the IKC is apparent from the locations given in Table 1. The MSc is a Cranfield University degree, but the world class expertise of the IKC partners is well represented in the curriculum.
The taught modules vary in style from traditional lectures for subject based learning (see Figure 3a), to practical sessions with a more problem based learning style. The latter can be found throughout sections of the “Managing innovation and new product development” module (see Figure 3b), whilst experiential learning predominates in the “Computer-aided engineering” module. The different teaching styles are designed to address the need for different learning styles, in an attempt to reduce gender bias and increase appeal to mid-career change applicants. As discussed by Rae, entrepreneurial learning can aid the mid-career change applicant by facilitating a successful transition from a role that utilises existing skills and expertise to a new role in a field that utilises newly learned skills and expertise. In making the transition to a career in precision optics or photonics, an experienced candidate may not have the same recollection of basic science and engineering knowledge as a new graduate. This can also be addressed during the Introductory week, and in tutorials held throughout the academic year.

5.2 The Group Project

The Group Project provides another dimension to the student learning experience, and an opportunity to align with other qualities required by industry of newly recruited precision engineers. As mentioned earlier, the optics and photonics high technology industries require staff with a high emotional maturity, motivation, and team working skills – in addition to technical knowledge. These are all tested in the Group project phase of the Masters degree. The students, typically in groups of between four and ten in size, undertake a precision engineering project with a study time of 400 notional learning hours. Although the technical output is crucial, and can be sponsored by an industrial partner, the learning from the activity should include a better understanding and experience of working in a project team. The example shown in Figure 4 demonstrates the challenging nature of a typical project. The 2009 Group Project involved the machining of an image slicer similar to that delivered by Cranfield University to NASA, a component within the MIRI (Mid-InfaRed Instrument) of the James Webb space telescope – scheduled for launch in 2013.
5.3 The Individual Project

The final component of the Masters degree consists of the individual project and its associated thesis. This is intended to be a thorough examination of the student’s learning, accounting for 40% of the overall course mark. It is a feature of the course that great effort is taken to place students in an industrial environment for the duration of their individual projects. From the company perspective the benefits are clear – access to a newly trained precision engineer on a project of interest to the company. For the student too there are considerable benefits, to the extent that the company placement scheme has become an important marketing aid for student recruitment. The student not only gains valuable work experience, but also has the opportunity to practice new skills and enhance their employability. Matching of the individual student to a participating company is a three-way process, once again demonstrating the close relationship between the company, the University, and the student – as drawn schematically in Figure 2. During the early stages of each academic year a “Selection Event” is held at the OpTIC technium, to match students to Companies for the activities of the Individual project (see Figure 5). To date, the event has been enthusiastically attended by both students and companies.

During the day, which includes tours and presentations, students are interviewed by the industrialists in order to assess their suitability for project work. Great care is taken to align the wishes of Companies to the expectations of students. In the event that there are more students than participating companies at the Selection event the remaining students are allocated projects within Cranfield University, University College London, or the University of Cambridge.

We should not underestimate the challenge for a new engineer entering the world of industrial manufacturing. Hurdles exist to complicate the transition from Higher Education into the workplace, which has been discussed by many authors. By undertaking a Masters level project in a company, the student practices their newly acquired technical skills (building on the learning from the taught modules) – but also have to adapt to working within teams and groups which stretch their interpersonal skills and motivations. The Individual project in-company placement programme provides a “safe” and controlled environment within which the student can experiment in order to optimize their effectiveness in a precision engineering role. However the expectations of the course team are more ambitious than this, and the student is challenged to exhibit originality in their research and excellence in their project management and presentation style. This is clearly in evidence from the fact that three students emerged from the first year of the course to progress directly into PhD research projects within the Cranfield University Precision Engineering Centre.
5.4 Student recruitment

As reported previously\(^3\) we have used a number of approaches to locate, select, and recruit suitable students onto the MSc in “Ultra Precision Technologies”. This includes the use of recruitment consultants and specialist web-based engineering databases. However, there is a common thread that links all of our successful recruitment to date, namely the importance of addressing the individual aspirations of applicants. Precision optics and photonics has roles for new graduates and mid-career engineers and scientists\(^11\). The machining and structuring of surfaces for optical applications can attract a range of academic disciplines. We are also keen to attract students from home and overseas, and to avoid the traditional engineering gender bias\(^12,13\). These requirements, and the exclusive nature of the course, lead us to treat students as individual clients – an approach that can be continued throughout the period of study owing to Cranfield University’s pre-eminent position in terms of staff to student ratio (In the current [2009] Times Higher World University Rankings Cranfield University’s achievements included being ranked first in the UK for staff to student ratio, and sixth place in the World).

6. CPD COURSES AND E-LEARNING PACKAGES

Each module of the MSc forms a 5-day short course as a stand-alone teaching and learning experience. These mainly attract delegates from the UK and EU plus occasional delegates from further afield. These Continuing Professional Development (CPD) courses provide a means for industrially-based scientists and engineers to update their skills or add to their existing skills. The CPD courses are targeted at different market sectors, with the courses on Modern Optical Technologies, Optical Design and Fabrication, and Laser Micromachining and Surface Structuring being those aimed especially at engineers in the optics and photonics industries and laboratories. As a further aid to knowledge transfer, subsets of some 5-day courses are marketed as 1, 2, or 3 day CPD offerings. Examples of these are the courses in “Ultra Precision Optical Applications” and “Optical Testing”. At the more bespoke level, UPS\(^2\) will design and deliver courses to the optical and photonics industries that are within its portfolio of teaching capabilities.

Aimed primarily at the international market, but also appreciated by UK and EU delegates unable to spare the time to attend the CPD short courses, UPS\(^2\) is creating distance learning packages that distill the essence of each 5-day CPD short course. The first of these to be released, entitled “Precision Engineering”, is a genuine teaching and learning on-line package. In addition to accessing audio recorded lectures and MS Powerpoint slides the delegate is guided through marked assignments, with on-line tutor help available. Screenshots from the first on-line course to be released is shown in Figure 6.

![Figure 6 – Actual screenshots from the “Precision Engineering” e-learning package](image-url)
7. MEASURES OF SUCCESS

The three main measures of success are a blend of academic and industrial. Firstly, as a provider of precision engineering skills to UK industry it follows that the destination of the students at the end of their postgraduate studies is of major interest. Linked to this measure is the output of the company placement scheme, particularly the research carried out by the student and written up in the individual project thesis. All such projects are aimed at understanding, investigating, or solving real engineering problems in an industrial context. Therefore the feedback from participating companies will also be an important yardstick for gauging the success of the venture.

The second measure of success relates to the provision of support to UK and EU manufacturing by the leverage of facilities, equipment, and skills of UPS2. This requires a conveyor belt of talent to enter the academic departments of the IKC partner Higher Education institutions, including a desire to study at PhD level. Students emerging with the MSc in Ultra Precision Technologies are in position to fulfill this need. The success of the development and sale of CPD short courses for industrial delegates is also a key success metric. The e-learning and distance learning outputs have a dual role. Apart from generating additional revenue they also provide an advertising platform for the IKC activities and are a means of promoting the UPS2 brand.

The third important metric is financial, and reflects the desire that the IKC attains sustainability within the period of Research Council funding. The Masters course resides within a portfolio of knowledge transfer activities, including short courses for industry and the development of novel learning methods such as e-learning and distance learning. The special nature of the Masters course does bring additional costs, and these must be covered by outreach events, courses, and teaching packages of the type described above. These items comprise a blended learning approach to knowledge transfer, promoted through both the academic institutions and the UPS2 brand.

8. CURRENT STATUS

In order to retain competitive advantage, the UK manufacturing engineering industry requires a regular supply of technically excellent and organizationally aware graduates. In the specialist field of precision engineering for optical and photonics applications, where the UK has world class capability, this need is being addressed by a Masters level course in Ultra Precision Technologies with accompanying CPD courses. The portfolio of teaching activities and events has mainly grown out of the needs of the optics industry, and this paper has attempted to show how the industrial links have helped to sculpt a structure for knowledge transfer that incorporates a system to deliver highly skilled postgraduates directly to the workplace.

The MSc in “Ultra Precision Technologies” is in Year 2 of an initial 4-year primary phase. To date 16 “Home” students plus 2 “EU” students plus 4 “Overseas” students, as defined by the UK Higher Education regulations, have entered study. Despite the small sample size the achievement of 73% “Home” students is extremely encouraging, since the percentage of “Home” students on postgraduate courses (excepting PhD and the Postgraduate Certificate of Education) at all UK HE institutions is 34%. Equally promising is the statistic that 23% of the total intake are female, which compares favourably with the 8.5% women who study mechanical engineering at UK Higher Education level. This statistic includes both undergraduate and postgraduate students, but excludes PhD and Postgraduate Certificate of Education students.

The reasons for selecting the course, as given by the students shortly after their first meeting with the participating companies, give an insight into the importance that the industrial partners played in attracting applicants. For the students, company involvement scored highly, in the guise of enhanced employability plus company placements for projects and financial support. It is also encouraging to note that the students have realized that the course is intended to attract people with a range of first degree backgrounds, and that there is scope not only for employment but also higher level research on completion of the Masters degree. Other factors scoring highly demonstrate effective communication during the recruitment process. This reflects well
on the central Marketing activity within the University, and is also a feature of the intermediate shell process of Figure 2.

Other comments made by the students at the end of the questionnaire mention the ambition to find a more fulfilling role in mechanical engineering or optical applications, or the more general ambition to make a career change. It is also interesting to note the qualifications of applicants, at the time of application. By emphasizing the practical nature of the learning experience, and the opportunity for enhanced employability, students with previous Masters degrees and PhDs have applied. As further evidence for the credibility of the course as a retraining medium the applicants also possessed a first degree in a range of subjects. These included the expected subjects of mechanical engineering and physics, but also students with qualifications in electronics, chemistry, medical devices, materials science, and nuclear engineering.

The companies that have participated in the first two years of the course cover a range of applications, again demonstrating the extensive demand for ultra precision engineers. The companies include Airbus, Gooch & Housego, PJ Coatings, OpTIC Technium, Qioptiq, PV Crystalox Solar, Perkin Elmer, Microsharp, and Surrey Satellite. Most of these had previous involvement with UPS² and some were sited near to UPS² headquarters at the OpTIC Technium amongst the North Wales opto-electronics business cluster. For this reason it was decided to locate four students in North Wales, to better serve the industrial clients in that region.

Looking forward to the third cohort and beyond, the challenge is to repeat the successes of the first two years as well as expanding the numbers of both students and companies. The IKC is also keen to globalize its operations, including its knowledge transfer activities. The MSc in Ultra Precision Technologies has already attracted interest from Italy and India. The participating companies are expected to grow in number over time, further strengthening the links to the IKC, and taking opportunities to increase the effectiveness of the course to industry. In the future, we can expect the gap between supply and demand for these strategically vital skills to be narrowed.

9. ACKNOWLEDGEMENTS

The authors wish to acknowledge the help of their academic colleagues in the development of this work. In particular we would like to recognize the part played in course planning, design and structure by Professor John Corbett and Professor David Allen. Special thanks are also due to the MSc Course Module coordinators and to Cranfield University School of Applied Sciences Marketing team. The industrial contacts are too numerous to list in person, but deserve great credit for their foresight, imagination, and commitment to the programme.

10. REFERENCES


• Nick Tyson – Head of Faculty - Engineering & Built Environment

• Vicky Barwis – Marketing and External Funding Manager

• Faris Maghuk - Technician
Overview of the Session

- Introduction to the project (VB)
- Overview of Engineering at Deeside College & Modern Apprenticeship delivery options. (NT)
- Course Content Technician programme (FM)
- Any Questions
Technicians in Opto-Electronics Project [TOP]

• Funded By the Welsh Assembly Government and run by the photonics academy 2006-2009

Main Aims:

• Development of a Technicians Course
• Marketing to young people
• Leadership and Management Sessions
Technicians in Opto-Electronics Project [TOP] Cont.

Targets:

- Develop and pilot training with at least 10 learners.
- Implement a Marketing Plan.
- Raise awareness of the sector with young people to increase new entrants into the sector.
- Engage Employers in Development.
- Provide information on leadership and management
Engineering & Manufacturing Technologies @ Deeside College

- Management Team: - HoF; 5 x PAMS; Work-based Supervisor.

- Staff: 26 lecturing staff; 22 Technical Training Officers; 4 Instructor Demonstrator, 5 Assessors; 4 Admin.

- Programme Areas: - Aerospace; Mech/Elect; Fab & weld; Motor Vehicle.

- A team of dedicated Staff employed to support Photonics and Optoelectronics training
Deeside College – Photonics lab
Apprenticeship Frameworks:

- **Foundation Modern Apprenticeship**
  - Knowledge Based Element. Technical Certificate @ L2
  - Competence Based Element. NVQ @ L2
  - Key Skills @ L1 & Employer Responsibilities

- **Modern Apprenticeship**
  - Knowledge Based Element. Technical Certificate @ L3
  - Competence Based Element. NVQ @ L3
  - Key Skills @ L2 & Employer Responsibilities
Example 1: Photonics Modern Apprenticeship

Yr 1  September 2009
Apprentice attends Deeside College on a Full Time Basis to complete an NVQ L2 and a Technical Certificate L3

Yr 2  September 2010
Apprentice based in Company ‘A’ and commences NVQ L3. Apprentice attends college on a day release basis to complete Technical Certificate L3

Yr 3  September 2011
Option: Depending on company requirements. Apprentice can continue @ college to complete HNC/Foundation Degree

Yr 4  September 2012
Completion of NVQ L3 and Modern Apprenticeship. (1 additional year to complete HNC/Fd – June 2013.)
Apprenticeships:

“Industry owned and led, SEMTA aims to increase the impact of skilled people throughout the science, engineering and manufacturing technologies sectors”.
Example 2: SEMTA Sponsored Pilot Scheme Shared Modern Apprenticeship (Follow same training pathway as example 3)

Primary Company

1) Responsible for main training of apprentice.

Skills Transfer

Apprentice

Secondary Company

1) Fill in the gaps in the appropriate apprentice training
Learners on a National Award programme complete a unit in the Principles of Photonics at the Optics Technium at St. Asaph. Photonics is the science of generating, controlling and detecting photons. It is closely related to the optics industry and controlling the particle properties of light. Learners work with a world-leading organisation in this advanced technology. They attend lectures and complete practical activities in photonics to a very high standard. This unit of study is the first of its type in the UK. (*Estyn, Her Majesty’s Inspectorate for Education and Training in Wales  October 2008 Deeside College*)
TOP’s Project to date – what have we achieved?

- Extended existing provision by Deeside
- Content of delivery driven by local need
- New ‘Photonics Engineering’ pathway through existing framework
- New/existing level 3 NVQs in photonics
- Technical Certificate (BTEC) for underpinning knowledge including units of Photonics.
TOP’s Framework

- Support in delivery given by Ray Davies - Optic
- TOPS will develop much needed workplace skills
- Assessments via *practicals* and assignments
Recap:

- Technician Training available now
- Allow companies to up skill and grow
- Fills a much needed training gap
- Employers to take up the offer!
- 7 Apprentices and 50 FT students to date.
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Creating and Using Industry-Based Problem-Based Learning Challenges in Photonics: Lessons Learned

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ABSTRACT

Problem-based learning (PBL) is an educational approach whereby students learn course content by actively and collaboratively solving real-world problems presented in a context similar to that in which the learning is to be applied. Project PHOTON PBL, in collaboration with photonics industry and research university partners, created eight interdisciplinary multi-media Challenges to be used in high school and community college math, science and technology courses. Each Challenge was recorded on location and features the scientists, engineers and technicians who originally solved the problem engaged in authentic problem solving. In this paper we describe the evolution of the development of the Challenges and we provide instructions on creating a Challenge and using it in the classroom to enhance student learning.

1. INTRODUCTION

Since 1995, the New England Board of Higher Education (Boston, MA) has been developing curriculum and materials and offering professional development to high school teachers and college faculty in optics/photonics with support from the Advanced Technological Education program of the National Science Foundation (NSF/ATE). Projects FOTEP (Fiber Optic Technology Education Project), PHOTON and PHOTON2 resulted in the creation of a textbook, laboratory kit, an experiment manual, online instructional videos and a hands-on web-based teacher professional development course, Introduction to Photonics. As the first three PHOTON projects progressed, the PHOTON team realized that developing exemplary materials was not sufficient; it is equally important to address the teaching and learning process if the materials are to be used successfully in the classroom.

As part of an engineering or science team, technicians must apply their knowledge of optics, electronics and related technologies to solve “real-world” problems. Yet there is very little about typical lecture-based instruction followed by back of the chapter problems and stand alone laboratories that prepares students for the ill-structured open-ended problems they will face on the job. The fourth PHOTON project, PHOTON PBL, was designed to meet the need for instructional materials that have been shown to address the way students learn best while at the same time requiring that they engage in the critical thinking and problem-solving skills they will need to be successful lifelong learners. To accomplish this task, eight multimedia problem-based learning challenges were created, based on actual problems solved by industry and research universities. At weeklong summer workshops in 2007 and 2008, 48 high school and college educators were introduced to the PBL method of instruction and the PHOTON PBL Challenges. During the following academic year, teachers field-tested the Challenges in their own classrooms. Evaluation surveys of students and teachers were used to refine the Challenges and develop new resources for problem solving and assessment.
2. WHAT IS PROBLEM-BASED LEARNING?

PBL was developed in the 1970s for use in medical education, and it teaches students content and enhances critical thinking through the collaborative solving of authentic real-world problems. Unlike project-based learning that requires students complete a project after they have mastered the material, in problem-based learning students master the material in the process of solving a problem. Students are active participants in their own learning, placed in a situation where problem parameters are not well defined and more than one outcome is possible.

PBL usually involves four steps: problem analysis, self-directed learning, brainstorming discussions and solution testing (see Figure 1). In the first step, students are presented with a problem and asked to identify what is known and unknown and if any constraints apply. After working together to analyze the problem and its requirements, students then create their own plan for acquiring the knowledge necessary to solve the problem. The instructor acts as a facilitator as students seek out their own resources. Once the self-directed learning phase is complete, the group reconvenes to brainstorm possible solutions and then to evaluate the chosen solution. If the solution does not in fact address all the parameters of the original problem, the cycle is repeated. When an acceptable solution is found, it is presented for peer review and comment.

![Figure 1. The PBL problem solving cycle](image-url)

Research has shown that compared to lecture-based instruction, PBL improves student understanding and retention of ideas, critical thinking, communication and problem-solving skills. In addition, they are better able to adapt learning to new situations, an essential skill for working technicians and life-long learning.\(^1,2\)

3. THE PHOTON PBL CHALLENGES

3.1 Creating the challenges

The first step in developing real-world optics/photonics challenges was to enlist the aid of industry and research university collaborators who had potential problems that would make engaging PBL Challenges. Appropriate problems are open-ended with several possible solutions, stimulate the interest of students, are interdisciplinary in nature, and address several optics/photonics topics normally covered in a first semester course at the community college level. The problem has to have been solved by the organization so that students can compare and contrast their solutions to the organization’s solution. Such comparison often leads students to the realization that the most technically advanced solution is not necessarily the best solution if it is cost prohibitive or exceeds time constraints. Contacts from the PHOTON projects’ advisory committees, OSA, SPIE, and companies that served as faculty internship hosts for previous PHOTON projects were all contacted for possible problems suitable for adaptation as PBL Challenges.

Four companies, three research universities and one trade organization provided material for the PHOTON PBL Challenges. An effort was made to include Challenges covering diverse applications from medicine to material processing to energy efficiency while at the same time including as many optics topics as possible. Table 1 lists the eight PHOTON PBL Challenges along with a brief description of each.
<table>
<thead>
<tr>
<th>Challenge Title</th>
<th>Partner Organization</th>
<th>What the challenge is about</th>
<th>Photonics Principles</th>
</tr>
</thead>
</table>
| Blinded by the Light         | In collaboration with the International Laser Display Association (Orlando, FL)      | Can an airplane pilot be permanently injured by a green laser pointer? What laser hazards does the pilot face? | • Laser safety  
• Irradiance  
• Divergence  
• MPE  
• Glare, flashblindness |
| Hiking 911                   | Penn State University Electro-Optics Center (Freeport, PA)                           | Two boys are lost in deep woods in rough terrain. Penn State Electro Optics Center (EOC) needs to recommend the best technology to locate them. | • Electromagnetic spectrum  
• Thermal imaging  
• Pixel size  
• Resolution |
| Stripping with Light, Fantastic! | PhotoMachining (Pelham, NH)                                                         | PhotoMachining needs to develop a process for stripping the coating from 50 micron wire for a medical device. | • CO₂ and excimer laser characteristics  
• Laser power measurement  
• Optical system design  
• Laser material processing |
| DNA Microarray Fabrication   | Boston University Photonics Research Center (Boston, MA)                             | Boston University graduate students need to determine the best starting exposure time for a DNA microarray fabricator. | • Radiometry  
• Absorption spectra  
• Optical power budget  
• Optical system design  
• Micromirror arrays |
| High Power Laser Burn-In Test | IPG Photonics (Oxford, MA)                                                            | IPG Photonics needs a way to run 100-hour unattended burn-in tests on a 2-kw laser.          | • Fiber lasers  
• Laser power and wavelength measurement  
• Laser safety  
• Laser beam collimation |
| Shining Light on Infant Jaundice | Photodigm, Southern Methodist University Drexel University, Onsite Neonatal Partners and (Richardson, TX, Dallas, TX, and Philadelphia, PA) | Can technology provide a safe and effective portable home treatment for newborn jaundice? | • LED spectral output  
• Irradiance  
• Scattering  
• Absorption spectra |
| Watt's My light?             | California State Polytechnic University at Pomona (Pomona, CA)                        | The package says a 26 watt fluorescent has the same light output as a 100 watt incandescent. Can Cal Poly Pomona students verify this? | • Radiometry and photometry  
• Spectral output of light sources  
• Optical power measurement  
• Integrating spheres |
| Of Mice and Penn             | University of Pennsylvania McKay Orthopaedic Research Laboratory (Philadelphia, PA)   | Can optics provide a non-contact non-destructive measure of the cross sectional area of mouse tendons for medical research? | • Geometric optics  
• Reflection  
• Laser micrometers  
• CCD cameras |

Table 1. The PHOTON PBL Challenges

After a problem had been agreed upon, the PHOTON PBL team visited the company or university for a one- or two-day production meeting. At the initial meeting, the PBL team provided an overview of problem-based learning and the goals of the PHOTON PBL project. A tour of the facility followed, recorded on video to provide students with a look at the environment where the problem was solved. In a few cases, the video that resulted was of high enough quality to be edited and included as a tutorial in the completed Challenge. To produce the actual Challenge video, engineers, scientists and technicians at the partner organization were asked to reenact the original introduction of the problem, being careful to include specific details and any constraints necessary to guide students’ problem solving efforts. For example, for the PhotoMachining Challenge, Stripping with Light, Fantastic!, a PBL team member posed as a customer who needs fine copper...
wire stripped and cut to length for an implantable medical device. The type of wire and coating and finished dimensions are specified, but the problem parameters are otherwise undefined.

Following the problem statement, the partner technical team was asked to recreate the brainstorming session where they discussed possible solutions. To add a bit of realism, the technical staff was asked to bring a change of clothing to give the impression that the problem and brainstorming were taking place on separate days. The brainstorming discussion provides several hints that might guide a student toward a solution, but the exact details of the solution are not revealed. In the PhotoMachining discussion, for example, two engineers talk about using either an excimer or CO\textsubscript{2} TEA laser and that in the past they used some sort of mask for a similar job. They discuss the need for a beam delivery system (but give no details) and that they will need a method to advance the wire, cut it, and check the quality of the final product. In addition to guiding students toward the solution, the brainstorming discussion emphasizes the teamwork skills necessary to be successful in industry. The videos clearly show the technical staff referring to their laboratory notebooks, reinforcing the importance of record keeping and communication skills.

Finally, the PBL team recorded the organization’s solution to the problem so that students would be able to compare and contrast their own solutions. Each company visit resulted in several hours of video and a few hundred still photos. Originally, the intent was to create short video segments by editing the original video, but inadequate lighting and the hum of machinery in most industrial settings made that impractical. Instead, the video was edited and transcribed and a script was developed using the actual words of the participants wherever possible. Videos were created from the still photographs with a voice-over-still-photo technique. Voice actors – PBL team members, their family, students and friends – provided the audio. Using video effects such as pan-and-scan (the “Ken Burns effect” available in Apple’s iMovie HD) and interspersing actual video footage effectively created the “feel” of the location where the problem was solved.

The partner organizations also helped to locate additional video, print and web resources for students to use in the solution of the problem, including documents describing the organization solution, relevant data and web links. The draft Challenges were reviewed for technical accuracy by representatives of the organization before being field-tested by PHOTON PBL teacher/faculty participants.

3.2 Components of a Challenge

Originally, the PBL team planned to create a PowerPoint template that could be easily adapted to new Challenges. However, as the project progressed it was evident that only a web-based format would allow the password protection necessary to allow teachers to control the flow of information. In the final implementation, each PHOTON PBL Challenge consists of five main sections with embedded video (Figure 2). Challenge presentation is preceded by an overview slide that provides a brief description of the problem and a list of photonics concepts addressed. The five main sections are:

1. **Introduction** - An overview of the particular photonics topic to be explored
2. **Company/University Overview** - An introduction to the organization that solved the problem to set the context of the problem
3. **Problem Statement** - A re-enactment of an authentic real-world photonics problem as originally presented to the organization’s technical team
4. **Problem Discussion** - A re-enactment of the brainstorming session engaged in by the partner organization’s technical team
5. **Problem Solution** - A detailed description of the organization’s solution to the problem

The **Problem Discussion** and **Problem Solution** sections are password protected; teachers are provided with the passwords. This feature gives students the opportunity to brainstorm and test their own solutions while providing a safety net in the event that they become stuck and need further direction. Each of the five main sections contains additional information and resources (video scripts, websites, spec sheets, and so on) designed to guide the student through the problem-solving process. The **Problem Solution** section resources include summaries of the organization’s solution with details such as drawings, calculations and comments from the organization technical team.
3.4 Resources for Problem Solving

Most high school and community college students do not have a great deal of experience solving open-ended problems and expect to simply sit in class writing down the information delivered by their instructor, returning it in much the same form at a later time on a test or quiz. PHOTON PBL participating instructors, including the authors, report that students’ first reaction to the PBL Challenges is often confusion and dismay – a blank stare and “Now what do we do? We don’t know anything yet!” To ease students’ entry into problem-based learning, the PHOTON PBL challenges include a unique resource, the Problem Solvers Toolbox, to guide students’ creative thinking and provide a framework for solving open ended problems.

The Problem Solvers Toolbox (see Figure 3) is reached by clicking on a Toolbox icon on both the Problem Statement and Problem Discussion sections. It is designed to help students develop a systematic approach to problem solving. The four-stage recursive process includes:
**Problem Analysis** – Identifying what is known, what needs to be learned, and any problem constraints

**Self-Directed Learning** – Setting specific learning goals, identifying necessary resources, and developing a timeline for achieving those goals

**Brainstorming** – Productively engaging in collaborative learning to identify the best course of action for solving the task at hand

**Solution Testing** – Developing a plan to validate the solution based on specific performance criteria

Figure 3. (left) The Toolbox help icon. (right) Problem Solving Toolbox with icons representing Problem Analysis, Self Directed Learning, Brainstorming Discussion and Solution Testing

Clicking on each of the cycle’s icons reveals a “whiteboard” graphic designed to emulate an actual classroom whiteboard (Figure 4). The whiteboards help students systematically capture their thoughts, ideas, and learning strategies during each stage of the problem solving process. Students may cycle through the whiteboards several times for a given problem, revising their problem solution each time until they converge on an optimal solution. For instructional purposes, the whiteboards can be projected onto an actual classroom whiteboard using an LCD projector.

Figure 4. The PHOTON PBL white boards for (top row) Problem Analysis, Self-Directed Learning, (bottom row) Brainstorming, Testing Solutions.
4. IMPLEMENTATION

4.1 The Three-Level Model

One issue with pure problem-based learning is that its implementation can be very stressful both for students who are used to passively listening to lectures and for teachers who are perhaps reluctant to give up "control" of the learning environment. To ease the transition from traditional instruction to PBL, the PHOTON PBL team developed a three level approach, allowing teachers to reveal only as much information as needed depending on the technical requirements of the problem and problem solving ability of the students. Figure 5 illustrates the PHOTON PBL three-level model, ranging from structured (instructor-led) to guided (instructor-guided) to open-ended (instructor as consultant).

![PHOTON PBL three-tiered approach to problem-based learning](image)

Given the variations in course schedules at different institutions, the PHOTON PBL Challenges are designed to be implemented in one or more 3-hour time blocks per week to conform to the traditional 3-hour weekly lab sessions common in most college technology curricula. This allows the Challenges to be incorporated into most curricula as a supplementary laboratory activity. The following example illustrates how the challenges might be implemented at each of the three levels (structured, guided, and open-ended) in a college setting.

**Structured Challenge (Instructor Led)**
*Estimated Time for Completion: One 3-hour class + 1-hour follow-up*
Used for students with no PBL experience and/or limited technical background. This approach is essentially an interactive multimedia case study. A structured challenge can be introduced in one 3-hour lab period with follow up review during the next class.

**Guided Challenge (Instructor Guided)**
*Estimated Time for Completion: Two 3-hour classes + 1-hour follow-up*
Once introduced to the PBL process using the structured approach, students can progress to the guided approach. The guided approach is similar to the structured approach, but student groups work with limited instructor supervision and are provided more time to develop a more complete solution. The instructor acts as a facilitator to ensure that students stay on track, but refrains from providing solutions or answers to specific questions. This strategy is intended to further develop students' problem solving and critical thinking ability by providing a greater level of autonomy, but at the same time providing a safety net so that learning occurs without risk of failure. Once students have
presented their solutions to their peers for review, the Problem Solution video is shown, allowing students to compare their solution to the organization’s solution.

Open-Ended Challenge (Instructor as Consultant)

Estimated Time for Completion: Three 3-hour classes + 1 hour follow-up

In the open-ended approach, students are presented with the most realistic representation of the problem, as it would be encountered in the real world. In the open-ended approach, students are provided only with information from the Introduction, Company/University Overview, and Problem Statement, and are tasked with researching and developing their own solutions without the benefit of viewing the Problem Discussion. The instructor acts as a consultant, providing hints or clues on request, but for a price (e.g., points deducted from a mock budget). Only after student solutions have been presented in a mock design review are the Problem Discussion and Problem Solution revealed. Student solutions are then compared and contrasted with the industry/university solutions in a group discussion and recommendations for improvements are explored.

By allowing students to gradually progress through the PBL Challenges along a developmental continuum, we believe students will be more likely to develop the knowledge, skills, and confidence to take responsibility for their own learning.

4.2 Teacher resources

To assist teachers in making the transition to problem-based learning, each PHOTON PBL challenge includes a Teacher Resources section accessed through password protected link on the Challenge Overview screen. Teacher resources include:

- Technical background – scientific and technical information related to the challenge
- Assessment strategies – assessing student performance on the Challenges
- Implementation stories – how other teachers used this Challenge
- Standards alignment – how the Challenge addresses content in the national academic standards

Since many of the participating teachers and faculty in the PHOTON PBL project do not have optics/photonics backgrounds and/or experience, the technical background document provides basic information on the science and technology involved in the problem. In some cases email correspondence with the technical team at an organization is included, providing additional detail on the organization’s thought process and final solution. Each technical information document includes a warning that this information is not to be shared with students who are in the process of solving a Challenge, although it may be used in discussions after student solutions have been presented.

Teachers who field-tested the Challenges in their own classrooms submitted feedback to the PHOTON PBL team through emailed reports or on a dedicated discussion board in an online Blackboard® course site. This information was used to modify the Challenges and it is also summarized in Challenge-specific implementation stories, allowing teachers to learn through the experience of their peers. For example, some high school teachers expressed a need to modify the Challenge delivery to accommodate the diverse student population in their classes and offered alternate tools for evaluating student performance.

Although each state in the U.S. has its own educational standards, a set of national standards exists in key content areas. Since teachers need to be able to show their school administrators how instructional materials will assist students in meeting the standards, the teacher resources for each Challenge include a standards alignment link. The standards alignment document details how the Challenge addresses the National Science Education Standards (science as inquiry and science content), and the National Standards for Technological Literacy and Mathematics.

A concern of many teachers implementing PBL in their classrooms is “how do I assign a grade?” Unlike traditional tests that have right and wrong answers, problem-based learning is about more than just “getting
an answer.” The PHOTON PBL assessment tools are adapted from research-based strategies for assessing student performance in problem-based learning that include content knowledge, conceptual knowledge, and transfer of knowledge and skills to new situations (problem-solving strategies). Content knowledge is assessed through traditional means: end of chapter problems, tests and quizzes. The Teacher Resource section of each challenge includes a question bank that can be used for this purpose. Conceptual knowledge may be assessed through creation of a concept map, that is, a graphical tool used to organize knowledge and show relationships between concepts (Figure 6). Concepts may be provided by the instructor, chosen by the students based on their own learning and problem solution or some combination of the two. A sample concept map and a scoring rubric are included in the Teacher Resources for each Challenge. Finally, problem-solving ability may be assessed through a report on the process used to solve the Challenge, as detailed in the students’ completed whiteboards. A final technical report form summarizing the whiteboard information and a scoring rubric are included in the Teacher Resources.

![Sample concept map from the Stripping with Light, Fantastic! PHOTON PBL Challenge](image)

Figure 6. Sample concept map from the Stripping with Light, Fantastic! PHOTON PBL Challenge

In addition to the resources found within each challenge, a complete guide for using the Challenges was developed to accommodate the needs of educators who were not part of the original project as well as to provide a refresher for participating teachers. The pdf document, PBL Challenge Implementation Guide, is an introduction to the PBL method and a complete step-by-step guide to using the PHOTON PBL challenges, including information on the placement and identification of icons and links within the Challenges, suggested timing for problem delivery, and instructions on assessment. The flow diagram in Figure 7 is included in the guide to illustrate the implementation process and the three-level structure of the challenges.

4.3 Using the PHOTON PBL Challenges in the classroom

To date, 19 science, technology and mathematics teachers from 11 high schools and 8 two and four year colleges in the U.S. and Romania reported that they field-tested seven of the eight PHOTON PBL Challenges.
(The final challenge will be released for testing in late spring 2009.) The teachers and their students provided feedback to the PHOTON PBL team through survey forms at the completion of each field-tested Challenge. The participant reports will be used to both refine the Challenges and conduct research on the efficacy of the method. Results of a pilot study designed to examine the efficacy of assessment strategies are reported elsewhere.  

![Figure 7: PHOTON PBL Challenge Implementation Flow Diagram](image)

Teachers who used the Challenges generally report that students were engaged and motivated by the Challenges. High school teachers were more likely to report problems with student motivation than college teachers; this was not unexpected since high school classrooms typically include a wider variety of skills, abilities and interests. Students reported that they felt they learned more by solving a problem than by reading about it or listening to a lecture. Comments from students included: “It was good that you could think outside the box for a solution, without having to have only one way to solve it.” and “Enjoyed collaborating with teammates, which made it feel like you were working with fellow coworkers on a real problem.” Some students also commented that the PHOTON PBL problems were more realistic than the back-of-the-chapter problems they were usually assigned. These students expressed a desire to continue solving PBL challenges rather than return to taking notes on instructor lectures.

Teachers also report that students who become adept at the problem solving method introduced in the Challenges continue to use it in other courses and situations and in some cases introduce other students to
the PBL white boards. Students gain confidence in their own critical thinking ability and are more likely to try to figure out a problem than to immediately ask for instructor assistance.

5. Conclusion

The Photon PBL project, a three-year National Science Foundation Advanced Technological Education (NSF/ATE) project developed a series of multimedia problem-based learning Challenges in optics and photonics and trained science, technology and mathematics educators from across the US and abroad in their use. The classroom presentation of the Challenges may be tailored to the technical knowledge and problem solving ability of students. Resources to assist students in problem solving and to guide teachers in implementation are included in the web-based Challenge platform. Field-testing high school teachers and college faculty report student improvement in student problem solving ability and critical thinking skills with the instructional method.

5. References

[4] www.laserist.com, the International Laser Display Association

6. Acknowledgements

FOTEP

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PHOTON

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PHOTON2

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PHOTON PBL

Funded in-part by the Advanced Technological Education program of the National Science Foundation (ATE #ATE 0603143) Principal Investigator, Fenna Hanes (Project Manager), New England Board of Higher Education; Co-Principal Investigators Judith Donnelly, Three Rivers Community College; Nicholas Massa Springfield Technical Community College; Richard Audet, Roger Williams University. Website: http://www.photonprojects.org.
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ABSTRACT
Polarimetric techniques are widespread employed in many research fields as optics, medicine or biology. In this sense, the use of polarimeters has significantly increased, being a tool with huge perspectives of future. As a consequence, the spreading of the basic knowledge of this topic becomes interesting for many professionals and a master studies is an excellent environment to this aim.

We are participating in a mandatory laboratory subject (Laboratory of Optics, LO) of a Master degree in Photonics with an experiment on polarization. In particular, the main structure of the experiment has been built around of a polarimeter set-up. Basically, we use a He-Ne laser beam, a polarization state generator and a polarization state detector. The experimental measurements are acquired by means of a photometer connected to a computer and processed by an own developed software. It allows us to obtain a complete description of any polarizing element tested. In combination with the laboratory work, it is provided a mathematical description of the polarization theory, the Stokes-Mueller formalism, which gives us the base required for a fully understand of the experiment.

Throughout this work, we explain the polarimeter experiment structure and the achievements reached by students. We want to emphasize that a different degree of expertise and knowledge in function of the specific background of every student is provided. However, a minimum knowledge level is reached for all students, including among others, the improvement in the scientific, communicative or interdisciplinary competences.

Key words: Laboratory of Optics, polarimetry, polarimeter, Stokes, Mueller, synchronous detection.

1. INTRODUCTION
The knowledge of the state of polarization of light beams and of the polarimetric properties of polarizing samples is necessary in a large number of applications as in medical physics\textsuperscript{1,2}, in astronomy\textsuperscript{3} or in polarizing samples characterization\textsuperscript{4,5}, among others. In order to obtain this type of information, the use of polarimeters is required in these applications. Polarimeters are optical instruments capable to characterize the state of polarization of a light beam just by means of radiometric measurements. The radiometric data are obtained by projecting the analyzed light beam upon different configurations of a polarization state detector (different polarization analyzers). On the other hand, by properly combining a polarization state generator with a polarization state detector, all the polarizing properties of polarizing samples can also be determined.

By taking into account the polarimetric data provided by polarimeters or its set-up design, they can be subdivided in different subtypes\textsuperscript{6}. For instance, we can divide them as complete or incomplete (complete if fully determine light beams or polarizing samples, being incomplete otherwise), as light-measuring and sample-measuring polarimeters (light beam or polarizing sample characterization) or as a function of its data acquisition methodology.

In order to spread the basic knowledge related to polarimetry\textsuperscript{7}, the Image Processing Laboratory (IPL) of the Optics Group of the University Autonomus of Barcelona (UAB) is participating in a mandatory laboratory subject (Laboratory of Optics, LO) of a Master degree in Photonics with an experiment on polarization. In particular, the main structure of the experiment has been built around of a complete polarimeter set-up.
Basically, it uses a He-Ne laser beam in which a polarization state generator (polarizer and quarter-waveplate) and a polarization state detector (quarter-waveplate and analyzer) are inserted. The experimental data are acquired by means of a photometer connected to a computer and processed by an own developed LabVIEW software, leading to a complete description of any polarizing element tested.

The educational structure of the Laboratory of Optics subject is divided in three different units. In this sense, in the first unit the basis of the Mueller-Stokes (M-S) formalism is provided. The M-S formalism is a useful mathematical tool that allows the description of the state of polarization of light beams and of the interaction of light beams with polarizing samples. Note that this first unit is essential for the fully understanding of the experiment. Next, in the second section, the experimental calibration of the optical elements of the set-up is conducted. This is a first step for the assimilation of the theoretical concepts revised in the previous unit because the calibration protocol is based on the M-S formalism. Moreover, the calibration procedure taught in this unit is useful not only for the specific set-up used for the complete polarimeter implementation but also, in a more general way, for the optimization of optical systems based on polarizing elements. Finally, in the third unit of the LO, the polarimeter is used to characterize some samples. First, by using the detector system the students detect different types of polarized light. Then, by means of the fully operation of the polarimeter, the Mueller matrices of diverse polarizing samples are obtained: polarizer, waveplate, Faraday rotator, among others. Note that this unit is a key issue in the experiment, allowing for instance, the experimental manipulation of the set-up, the complementation of the theory with different experimental examples, and the polarimetric analysis of the obtained results. In addition to the experiment on polarimetry conducted by students, they have to deliver a mandatory report and to perform an oral presentation. These two works are very important for the experiment complete understanding. In this sense, the students achieve a further internalization of the experiment conducted, observe the benefits of the team work and improve their communicative skills.

The outline of this paper is as follows. In section 2, the Mueller-Stokes formalism basis explained to students is provided. In section 3, the calibration protocol followed by the students for the calibration of the optical elements of the set-up used is detailed. Next, in section 4 we show the characterization process used for the obtaining of the Stokes vectors of light beams and the Mueller matrices of polarizing samples. Finally, in section 5 a summary of the experiment and achievements reached by students is provided.

2. MUELLER-STOKES FORMALISM: MUELLER MATRICES OF THE MAIN OPTICAL ELEMENTS

There exist different mathematical formalisms, as the Berreman or the Jones formalisms, which allow the correctly describing of the state of polarization (SoP) of light beams and the interaction of light beams with polarizing elements. However, in the cases where it is important to take into account unpolarized light contributions or depolarizing effects, the so-called Mueller-Stokes (M-S) formalism is very suitable and thus, it is used in a large number of applications. In the M-S formalism, the state of polarization of light beams is described by means of four real parameters that can be obtained readily by radiometric measurements and they are usually presented as a column vector (the Stokes vector). On the other hand, the description of polarizing samples is given by Mueller matrices, 4x4 matrices of real elements which keep useful polarimetric information. In addition, the Mueller matrices relate the incident and exiting (reflected, transmitted or scattered) states of polarization S of a light beam as follows:

\[ S_{\text{exiting}} = M \cdot S_{\text{incident}} \]  

where M is the Mueller matrix of a polarizing sample.

In the first unit of the experiment and with the aim of provide the students of the Master degree of Photonics with this useful and potent tool, the physical interpretation and the manipulation of the M-S formalism is taught. We want to emphasize that the degree of detail given to students strongly depends of the specific polarimetric background of every student. In this sense, for students without previous knowledge in this issue,
an initiation to the M-S terminology and basic manipulation is provided. On the other hand, more specialized
students are trained on more difficult problems related to polarimetry and we give them a further insight on
this topic.

A basic knowledge that students have to learn when conducting this experiment is the awareness of the
Mueller matrices of the main polarizing optical elements, as polarizers or waveplates. This is an important
issue because the internalization of this information is the basis required for the achievement of more complex
polarimetric problems. An example of different Mueller matrices representing typical optical elements is given
in Table 1. Note that the Eq. (6) is very important when working with the M-S formalism because it leads to
the obtaining of the Mueller matrix of any polarizing element rotated an angle $\theta$.

$$M_{LP}(\theta) = \begin{bmatrix} 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

(2)

$$M_{WP}(\phi, 0^\circ) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \cos \phi & \sin \phi \\ 0 & 0 & -\sin \phi & \cos \phi \end{bmatrix}$$

(3)

$$M_{k}(\theta) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos 2\theta & \sin 2\theta & 0 \\ 0 & -\sin 2\theta & \cos 2\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(4)

$$M_{LP}(\theta) = \frac{1}{2} \begin{bmatrix} \cos 2\theta & \sin 2\theta & 0 \\ \sin 2\theta & \cos 2\theta & \sin 2\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(5)

$$M(\theta) = M_{k}(-\theta)M_{k}(\theta)$$

(6)

$$M_{WP}(\phi, \theta) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos^2 2\theta + \cos \phi \sin^2 2\theta & (1-\cos \phi)\sin 2\theta \cos 2\theta & -\sin \phi \sin 2\theta \\ 0 & (1-\cos \phi)\sin 2\theta \cos 2\theta & \sin^2 2\theta + \cos \phi \cos^2 2\theta & \sin \phi \cos 2\theta \\ 0 & \sin \phi \sin 2\theta & -\sin \phi \cos 2\theta & \cos \phi \end{bmatrix}$$

(7)

Table 1. Mueller matrix of the main polarizing elements.

3. SET-UP CALIBRATION

Once some fundamental theory related to polarimetry has been provided to the students, we begin with the
second and third units of the experiment, where by means of an experimental set-up the students reinforce
and consolidate the theoretical content. In this section, we detail the unit 2, where the students perform the
calibration of the experimental set-up. The main structure of the experiment has been built around of a
polarimeter set-up and its corresponding design is plotted in Fig. 1. It contains a He-Ne laser beam, a
polarization state generator (polarizer LP$_1$ and waveplate WP$_1$) and a polarization state detector (waveplate
WP$_2$ and analyzer LP$_2$). The sample to be analyzed is placed between both. The waveplates can rotate 360
degrees and they are electronically controlled from a personal computer. The intensity measurements are
acquired by means of a photometer connected to a Digital-to-Analog Converter (DAC) that sends the digital
signals to a computer. Then, the set-up is controlled and the data is processed by an own developed
LabVIEW software that the student may change.
The specific function of the different elements used in the set-up sketched in Fig. 1 is explained to the students. Then, we lead them into a set-up calibration protocol based on the synchronous detection. We think that this knowledge is very useful because it is necessary not only to decrease the associated measurements errors when using the polarimeter but also to optimize the performance of any optical system involving polarizing elements.

3.1. Determination of the rotation angle between two polarizers

The first step for the characterization of the elements of our setup is the determination of the polarizer’s orientation. Polarizers are mounted in manually rotary stages, graduated every two degrees, but the transmission axis may not coincide exactly with the zero of the rule. Then it is necessary to determine the position of the transmission axis. The first polarizer transmission axis is taken as our x axis, and all the elements are aligned with it. Then, after the first polarizer the Stokes vector is given by

\[
\begin{bmatrix}
S_0 \\
S_1 \\
S_2 \\
S_3
\end{bmatrix}
= \begin{bmatrix}
1 \\
1 \\
0 \\
0
\end{bmatrix}
\]

Let us assume that the transmission axis of the second polarizer is at an unknown angle \( \theta_0 \) with respect to the zero of its rotary stage. Then when the rule of the rotary stage marks \( \theta \), in fact the transmission axis is at \( \theta + \theta_0 \). Therefore, the Stokes vector after the second polarizer is

\[
\begin{bmatrix}
S'_0 \\
S'_1 \\
S'_2 \\
S'_3
\end{bmatrix}
= \frac{1}{2} \begin{bmatrix}
1 & \cos(2(\theta + \theta_0)) & \sin(2(\theta + \theta_0)) & 0 \\
\cos(2(\theta + \theta_0)) & \cos^2(2(\theta + \theta_0)) & \sin(2(\theta + \theta_0)) \cos(2(\theta + \theta_0)) & 0 \\
\sin(2(\theta + \theta_0)) & \sin(2(\theta + \theta_0)) \cos(2(\theta + \theta_0)) & \sin^2(2(\theta + \theta_0)) & 0 \\
0 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
1 \\
1 \\
0 \\
0
\end{bmatrix}
\]

And the intensity is given by \( S'_0 \)

\[
I(\theta) = \frac{1}{2} \left( 1 + \cos(2(\theta + \theta_0)) \right) = \frac{1}{2} \left( 1 + \cos(2\theta_0 \cos(2\theta) - \sin(2\theta_0 \sin(2\theta)) \right)
\]
Note that the intensity is a periodic function of the rotation angle \( \theta \). The coefficients of the cosines and sinus terms can be determined by Fourier analysis. This is the basis of the synchronous detection. In fact, this method appears in many experimental data analysis like in phase shifting interferometers. Then, \( N \) intensity measures are taken at \( N \) equally spaced angles \( \theta_r = \frac{2\pi (r-1)}{N} \); \( r = 1, \ldots, N-1 \). By multiplying the measured intensities by \( \sin(2\theta_r) \) and adding the results one obtain

\[
2 \sum_{r=1}^{N} I(\theta_r) \sin 2\theta_r = t \sum_{r=1}^{N} \sin 2\theta_r + t \cos 2\theta_0 \sum_{r=1}^{N} \cos 2\theta_r \sin 2\theta_r - t \sin 2\theta_0 \sum_{r=1}^{N} \sin 2\theta_r \sin 2\theta_r = -t \sin 2\theta_0 \frac{N}{2}
\]

In this last equality we have taken into account the orthogonal properties of the sinus and cosines (See Appendix). By multiplying the measured intensities by \( \cos(2\theta_r) \), adding the results and again by taking into account the orthogonal properties of the sinusoidal functions we have:

\[
2 \sum_{r=1}^{N} I(\theta_r) \cos 2\theta_r = t \sum_{r=1}^{N} \cos 2\theta_r + t \cos 2\theta_0 \sum_{r=1}^{N} \cos 2\theta_r \cos 2\theta_r - t \sin 2\theta_0 \sum_{r=1}^{N} \sin 2\theta_r \cos 2\theta_r = t \cos 2\theta_0 \frac{N}{2}
\]

Finally, the offset angle \( \theta_0 \) can be obtained as

\[
\theta_0 = \frac{1}{2} \arctg \left( \frac{\sum_{r=1}^{N} I(\theta_r) \sin 2\theta_r}{\sum_{r=1}^{N} I(\theta_r) \cos 2\theta_r} \right)
\]

Once this offset angle \( \theta_0 \) is measured, we can correct it when positioning the second polarizer. Figure 2(a) shows the plot of the measured intensity as a function of \( \theta \). As the transmission axis was rotated an angle \( \theta_0 = 27.775^\circ \) the sinusoidal function is shifted. Figure 2(b) shows the same plot once the offset has been corrected when positioning the second polarizer.

![Figure 2](image2.png)

Figure 2. (a) Graph of the measured intensity \( I(\theta) \) from which the offset angle \( \theta_0 \) is determined. (b) The same graph once the offset has been corrected.

### 3.2. Determination of the rotation and the phase-shift of a linear retarder placed between two polarizers

Once we know the transmission axes of the polarizers, it is necessary to determine the fast axis of the retarder of retardance \( \phi \). This axis can be rotated an offset angle \( \theta_1 \), with respect to its rule. Let the two transmission axis of the polarizers be parallel, and the retarder rotated an angle \( \theta \), that in fact will be \( \theta + \theta_1 \). The Stokes vector after the system is given by:
\[
\begin{pmatrix}
S_0' \\
S_1' \\
S_2' \\
S_3'
\end{pmatrix} = t M_{LP} M_{WP}(\theta, \theta + \theta_t)
\]

Where the \(M_{LP}\) and \(M_{WP}\) matrices are given by Eq. (2) and Eq. (7) respectively. Then, the measured intensity is given by

\[
I(\varphi, \theta) = \frac{1}{4} \left( 1 + (\cos 4\theta_1 \cos 4\theta_1 - \sin 4\theta_1 \sin 4\theta_1) (1 - \cos \varphi) \right)
\]

(15)

Again this intensity is a periodic function of the rotation angle \(\theta\). Then performing a Fourier analysis the offset angle can be determined. This intensity is measured for \(N\) equally spaced angles \(\theta_r = \frac{2\pi(r-1)}{N} ; r = 1, \ldots, N-1\).

By multiplying the measured intensities by \(\sin(4\theta_r)\) or \(\cos(4\theta_r)\) and adding the result one obtains

\[
4 \sum_{r=1}^{N} I(\varphi, \theta_r) \sin(4\theta_r) = \cdots = t(1 - \cos \varphi) \sin 4\theta_1 \frac{N}{2}
\]

(16)

\[
4 \sum_{r=1}^{N} I(\varphi, \theta_r) \cos(4\theta_r) = \cdots = t(1 - \cos \varphi) \cos 4\theta_1 \frac{N}{2}
\]

(17)

Then, the offset angle \(\theta_1\) can be obtained as

\[
\theta_1 = \frac{1}{4} \arctan \left( \frac{- \sum_{r=1}^{N} I(\varphi, \theta_r) \sin(4\theta_r)}{\sum_{r=1}^{N} I(\varphi, \theta_r) \cos(4\theta_r)} \right)
\]

(18)

Once this angle is know we can also obtain the phase shift of the retarder. By adding the intensities one obtain

\[
4 \sum_{r=1}^{N} I(\varphi, \theta_r) = N t
\]

(19)

\[
\frac{4 \sum_{r=1}^{N} I(\varphi, \theta_r) \cos(4\theta_r)}{4 \sum_{r=1}^{N} I(\varphi, \theta_r)} = \frac{t(1 - \cos \varphi) \cos 4\theta_1 \frac{N}{2}}{tN} = \frac{1}{2} \cos 4\theta_1 (1 - \cos \varphi)
\]

(20)

then
As an example of the calibration results, Figure 3 shows the plot of the measured intensity as a function of the waveplate rotation angle θ, from which the waveplate offset angle θ₁ is obtained. The sinusoidal function is consequence of the projection of the state of polarization exiting from the polarizer+waveplate system upon the fixed analyzer. The maximums correspond to the positions where the neutral lines of the waveplate are parallel to the polarizer transmission axis (it happens four times in a whole turn). On the other hand, the non null minimums correspond to the projection of circular polarized light. Then, from the shift of the first maximum from the x=0 position we obtain the θ₁ angle and Eq. (21) gives us the phase-shift φ value. The values corresponding to the sinusoidal function given in Fig. 3 are θ₁ = 29.546 and φ = 90 degrees.

![Figure 3](image)

Figure 3. Graph of the measured intensity \( l(\theta) \) from which the offset angle \( \theta_1 \) and phase shift \( \phi \) are determined

### 4. STATE OF POLARIZATION AND POLARIZING SAMPLES CHARACTERIZATION

In this section we detail the third unit of the experiment. Here, the students learn and practice the methodology which leads them to the obtaining of the SoP of light beams and of the Mueller matrix \( M \) of polarizing elements. The physical interpretation of the results obtained is a key issue in the polarimetry training of the master students.

#### 4.1. Rotating linear retarder Stokes polarimeter

Once the polarizers and the retarders are characterized we can build a Stokes polarimeter. The system is composed by a motorized rotating retarder (WP₂), a fixed polarizer at 0° (LP₂), and a photodetector (see Fig. 1). Let \( S \) be the Stokes vector to be measured. The stokes vector \( S' \) after the retarder is

\[
S' = M_{WP} (\phi, \theta) S = M_R (\theta) M_{WP} (\phi, \theta) M_R (\theta) S = S_0 \begin{bmatrix} S_1 & S_2 & S_3 \end{bmatrix} \begin{bmatrix} \cos^2 \theta + \cos \phi \sin^2 \theta & \sin^2 \theta & 0 \\ (1 - \cos \phi) \cos 2 \theta & \sin 2 \theta & S_1 \sin \phi \sin 2 \theta \\ (1 - \cos \phi) \sin 2 \theta \cos 2 \theta & \sin 2 \theta & S_1 \cos \phi \sin 2 \theta \end{bmatrix} \begin{bmatrix} S_0 \\ S_1 \\ S_2 \end{bmatrix}
\]

And then the intensity after the polarizer is given by

\[
\cos \phi = 1 - \frac{2 \sum_{i=1}^{N} l(\phi, \theta) \cos(40_i)}{\cos 40_1 \sum_{i=1}^{N} l(\phi, \theta)} \tag{21}
\]
In the particular case of a $\lambda/4$ retarder ($\phi=\pi/2$) the above expression is

\[
I(\pi/2, \theta) = \frac{1}{2} \left[ S_0 + \frac{S_1}{2} (1 + \cos \theta) + \frac{S_1}{2} (1 - \cos \theta) \cos 4\theta + \frac{S_2}{2} (1 - \cos \theta) \sin 4\theta - S_3 \sin \theta \sin 2\theta \right]
\]  

(24)

The measured intensities are periodical functions of the angle $\theta$, and contain several sinusoidal functions whose coefficients depend on the Stokes parameters. A Fourier analysis permits us to obtain these coefficients. To this end $N$ measures at equally spaced angles of the WP $\theta_r = \frac{2\pi (r - 1)}{N}$; $r = 1, \ldots, N-1$ are taken and multiplied by the corresponding value of the sinusoidal. Then the following expressions are obtained:

\[
\begin{align*}
2 \sum_{r=1}^{N} I(\phi, \theta_r) \cos 4\theta_r &= \sum_{r=1}^{N} \left( S_0 + \frac{S_1}{2} (1 + \cos \phi) \right) = N \left( S_0 + \frac{S_1}{2} (1 + \cos \phi) \right) \\
2 \sum_{r=1}^{N} I(\phi, \theta_r) \sin 2\theta_r &= -\frac{N}{2} S_3 \sin \phi \\
2 \sum_{r=1}^{N} I(\phi, \theta_r) \cos 4\theta_r &= \frac{N}{4} S_3 (1 - \cos \phi) \\
2 \sum_{r=1}^{N} I(\phi, \theta_r) \sin 2\theta_r &= \frac{N}{4} S_3 (1 - \cos \phi)
\end{align*}
\]  

(25)

And then the Stokes vector can be obtained as

\[
\begin{pmatrix}
S_0 \\
S_1 \\
S_2 \\
S_3
\end{pmatrix} = \frac{1}{N} \begin{pmatrix}
2 \sum_{r=1}^{N} I(\phi, \theta_r) - 4 \frac{1 + \cos \phi}{1 - \cos \phi} \sum_{r=1}^{N} I(\phi, \theta_r) \cos 4\theta_r \\
8 \left(1 - \cos \phi\right) \sum_{r=1}^{N} I(\phi, \theta_r) \cos 4\theta_r \\
8 \left(1 - \cos \phi\right) \sum_{r=1}^{N} I(\phi, \theta_r) \sin 4\theta_r \\
4 \sin \phi \sum_{r=1}^{N} I(\phi, \theta_r) \sin 2\theta_r
\end{pmatrix}
\]  

(26)

In the laboratory, the students measure different SoPs: linear states of polarization with different orientation, right-handed and left-handed circular polarization and diverse elliptical states of polarization. These SoPs are generated by themselves by properly setting configurations of external quarter-waveplates and polarimeters. Then, they interpret the experimental Stokes parameters obtained by using the polarization state detector (Fig. 1) and Eq. (26). Some polarimetric concepts, as unpolarized light, azimuth angle ($\alpha$) or ellipticity angle ($\epsilon$) are revised by taking advantage of the obtained results. As an example, Table 2 shows some students measurements corresponding to the detection of linear polarized light at $0^\circ$ of the laboratory vertical, right-handed circular polarized light and a specific elliptical polarized light. The ellipses of polarization of the SoPs shown in Table 2 are plotted in Fig. 4. In the Fig. 4(c), the azimuth and ellipticity angles are also represented.
<table>
<thead>
<tr>
<th>Linear polarization (0°)</th>
<th>Right-handed polarization</th>
<th>Elliptical polarization</th>
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<td>1</td>
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<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
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<td>0.578</td>
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<td>-8.628·10⁻³</td>
<td>-0.521</td>
</tr>
<tr>
<td>2.443·10⁻³</td>
<td>0.998</td>
<td>-0.628</td>
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<tr>
<td>Experimental</td>
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</tr>
<tr>
<td>measurement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Table 2. Some Stokes parameters obtained by master students.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Figure 4. Ellipse of polarization of the SoP shown in Table 1.](image)

4.2. Rotating linear retarders Mueller polarimeter

The Mueller polarimeter contains a Polarization State Generator (PSG) composed by a linear polarizer LP₁ at 0° and a rotating linear retarder WP₁ with phase shift ϕ₁ and a Polarization State Detector (PSD) like the described in the previous section. When the linear retarder of the PSG is at a rotation θᵣ, the generated SoP is given by

\[
\text{Si}' = \begin{pmatrix}
    \frac{1}{2}(1 + \cos \phi_1) + \frac{1}{2}(1 - \cos \phi_1)\cos 4\theta'
    \\
    \frac{1}{2}(1 - \cos \phi_1)\sin 4\theta'
    \\
    \sin \phi_1 \sin 2\theta'
\end{pmatrix}
\]

This input SoP passes through the polarizing device M that we want to characterize and the output SoP is given by

\[
\text{So}' = \begin{pmatrix}
m_{00} & m_{01} & m_{02} & m_{03} \\
m_{10} & m_{11} & m_{12} & m_{13} \\
m_{20} & m_{21} & m_{22} & m_{23} \\
m_{30} & m_{31} & m_{32} & m_{33}
\end{pmatrix} \text{Si}'
\]

The k component of this output SoP is given by
strips of adhesive tape is like performing a characterization without any polarizing sample. In other words, the characterization of two identical crossed polarizing elements with the aim of understanding the physical meaning of the Mueller coefficients. The experimental obtaining of the Mueller matrices of the elements tested are accomplished by the properly combination of the polarization state generator and the polarization state detector plotted in Fig. 1 and by following Eq. (31). In particular, among others, they obtain the Mueller matrix of a retarder of a given orientation and retardance. However, when using two crossed strips the phase added by one strip to one component of the electric field is subtracted by the other strip, leading to the identity matrix. It can be observed by normalizing the matrix shown in Table 3(b) by the \( m_{00} \) Mueller matrix coefficient (the irradiance exiting from the polarizing sample). In other words, the characterization of two identical crossed strips of adhesive tape is like performing a characterization without any polarizing sample.

\[
\begin{equation}
\begin{aligned}
S'_{0} &= m_{k}\phi + m_{k,2} \frac{1}{2}(l + \cos\phi)^{2}(1 - \cos\phi') \cos 4\phi' + m_{k,3} \frac{1}{2}(l - \cos\phi') \sin 4\phi' + m_{k,4} \sin\phi' \sin 20' \\
\end{aligned}
\end{equation}
\]

This output SoP can be measured by the PSD. Then, if \( N \) equally spaced rotations are used in the PSG, the coefficients of the matrix can be calculated as:

\[
\begin{equation}
\begin{aligned}
\sum_{r=1}^{N} S'_{r} \cos 4\theta' &= \frac{N}{4} (l - \cos\phi') m_{k,1} \\
\sum_{r=1}^{N} S'_{r} \sin 4\theta' &= \frac{N}{4} (l - \cos\phi') m_{k,2} \\
\sum_{r=1}^{N} S'_{r} \sin 2\theta' &= \frac{N}{2} \sin\phi' m_{k,3} \\
\sum_{r=1}^{N} S'_{r} \cos 4\theta' &= N m_{k,0} + \frac{N}{2} (l + \cos\phi') m_{k,1} = N m_{k,0} + \frac{N}{2} (l + \cos\phi') \sum_{r=1}^{N} S'_{r} \cos 4\theta'
\end{aligned}
\end{equation}
\]

Then the Mueller matrix of the device is

\[
M = \frac{1}{N} \left( \begin{array}{cccc}
\sum_{r=1}^{N} S'_{0} - 2 \frac{1 + \cos\phi'}{1 - \cos\phi'} \sum_{r=1}^{N} S'_{0} \cos 4\theta' & \frac{4}{1 - \cos\phi'} \sum_{r=1}^{N} S'_{1} \cos 4\theta' & \frac{4}{1 - \cos\phi'} \sum_{r=1}^{N} S'_{1} \sin 4\theta' & \frac{2}{\sin\phi'} \sum_{r=1}^{N} S'_{1} \sin 2\theta' \\
\sum_{r=1}^{N} S'_{0} - 2 \frac{1 + \cos\phi'}{1 - \cos\phi'} \sum_{r=1}^{N} S'_{2} \cos 4\theta' & \frac{4}{1 - \cos\phi'} \sum_{r=1}^{N} S'_{2} \cos 4\theta' & \frac{4}{1 - \cos\phi'} \sum_{r=1}^{N} S'_{2} \sin 4\theta' & \frac{2}{\sin\phi'} \sum_{r=1}^{N} S'_{2} \sin 2\theta' \\
\sum_{r=1}^{N} S'_{0} - 2 \frac{1 + \cos\phi'}{1 - \cos\phi'} \sum_{r=1}^{N} S'_{3} \cos 4\theta' & \frac{4}{1 - \cos\phi'} \sum_{r=1}^{N} S'_{3} \cos 4\theta' & \frac{4}{1 - \cos\phi'} \sum_{r=1}^{N} S'_{3} \sin 4\theta' & \frac{2}{\sin\phi'} \sum_{r=1}^{N} S'_{3} \sin 2\theta'
\end{array} \right)
\]

In this case, master students measure different polarizing elements with the aim of understanding the physical meaning of the Mueller coefficients. The experimental obtaining of the Mueller matrices of the elements tested are accomplished by the properly combination of the polarization state generator and the polarization state detector plotted in Fig. 1 and by following Eq. (31). In particular, among others, they obtain the Mueller matrix of polarizers with different orientation, of linear retarders of different retardance, of adhesive tapes with different thickness and of a Faraday rotator. They also have the chance of characterize the Mueller matrix of any polarizing element that they bring to the laboratory. Some polarimetric concepts as diattenuation, retardance, polarization or depolarization are revised by taking advantage of the obtained results. As an example, Table 3 shows the obtained Mueller matrix for an adhesive tape strip of a given thickness (Table 3(a)) and for two crossed strips of adhesive tapes of the same thickness (Table 3(b)). Note that in both cases the diattenuation vector (the three last coefficients of the first row) and the polarizance vector (the three last coefficients of the first column) are almost null, and as a consequence we are obtaining the Mueller matrix of a retarder of a given orientation and retardance. However, when using two crossed strips the phase added by one strip to one component of the electric field is subtracted by the other strip, leading to the identity matrix. It can be observed by normalizing the matrix shown in Table 3(b) by the \( m_{00} \) Mueller matrix coefficient (the irradiance exiting from the polarizing sample). In other words, the characterization of two identical crossed strips of adhesive tape is like performing a characterization without any polarizing sample.
6. SUMMARY

Polarimetric techniques are a very useful tool in many research fields as optics, medicine or biology. A polarimeter is the basic scientific instrument used to make polarimetric measurements, leading to the characterization of the state of polarization of light beams or to the obtaining of some polarization information of polarizing samples. Therefore, the spreading of the basic knowledge of this topic becomes interesting for many professionals and a master studies is an excellent environment to this aim.

By participating in a mandatory laboratory subject (Laboratory of Optics, LO) of a Master degree in Photonics we are conducting an experiment on polarization. The main structure of the experiment has been built around of a polarimeter set-up that allows us the obtaining of the complete description of any polarizing element tested. The polarimetric experiment is subdivided in three different units which lead to specific educational trainings. In this paper, a detailed explanation of the experiment is provided.

Basically, the first unit gives students the fundamental background required for the understanding of the experiment, being in particular the basis of the Mueller-Stokes formalism. The second unit allows us to lead them into a set-up calibration performance based on the synchronous detection and the M-S formalism. This knowledge is a first step into the M-S application and provides students with a calibration procedure able to optimize the performance of any optical system involving polarizing elements. Finally, in the third unit the students use the polarimeter to detect different states of polarization and to characterize diverse polarizing elements. By taking advantage of this third unit of the experiment, concepts as unpolarized light, ellipticity, azimuth angle, despolarization, retardance or diattenuation are revised. The third unit is an essential part of the experiment, leading students to important issues as the manipulation of the set-up, to the theory reinforce by using different practical examples, and to the polarimetric analysis of the obtained results. Additionally, the students have to deliver a mandatory report and to perform an oral presentation. This fact adds complementary information to the scientific training of the students. In this sense, the developing of the reports help students to achieve a further internalization of the experiment done, show them the benefits of the team work and help them to improve their communicative skills.

Finally, we want to emphasize that the mandatory laboratory subject is structured with the aim of provide students with a minimum knowledge level. However, as a function of the specific background of every student in polarimetry, they are trained with a different degree of complexity. For instance, advanced students are taught with a higher degree in depth when performing the polarimetric data analysis, they are able to work with the LabVIEW software font code, to perform simulations in MATLAB or C++ of the estimated error associated to the measurements, among others.

\[
\begin{array}{cccc}
0.253 & 1.01 \times 10^{-2} & -2.50 \times 10^{-2} & 2.90 \times 10^{-2} \\
5.77 \times 10^{-3} & 0.231 & 0.147 & -5.57 \times 10^{-2} \\
-3.75 \times 10^{-2} & 0.133 & -0.120 & 0.206 \\
-4.70 \times 10^{-2} & 8.70 \times 10^{-2} & -0.205 & -0.146 \\
\end{array}
\]

\[
\begin{array}{cccc}
0.255 & -0.016 & 0.040 & 0.003 \\
-0.021 & 0.271 & 0.027 & 0.005 \\
0.052 & -0.025 & 0.273 & 0.010 \\
0.002 & -0.010 & -0.005 & 0.239 \\
\end{array}
\]

Table 3. Mueller matrices of an adhesive tape: (a) one strip; (b) two strips crossed.
APPENDIX

The equally spaced sampled sinusoidal functions fulfill the following properties:

\[
\frac{2}{N} \sum_{i=1}^{N} \sin \frac{2\pi ri}{N} \sin \frac{2\pi rj}{N} = \frac{2}{N} \sum_{i=1}^{N} \cos \frac{2\pi ri}{N} \cos \frac{2\pi rj}{N} = \delta_{ij}
\]  

(32)

\[
\frac{2}{N} \sum_{i=1}^{N} \sin \frac{2\pi ri}{N} \cos \frac{2\pi rj}{N} = 0
\]

(33)

\[
\sum_{i=1}^{N} \sin \frac{2\pi ri}{N} = \sum_{i=1}^{N} \cos \frac{2\pi ri}{N} = 0
\]

(34)

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An international Interdisciplinary Graduate School in Laser and Material science

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Introduction

The main objective is to establish the first transatlantic Graduate School, proposing a truly international education, training and research platform in the field of Photonics and Material sciences. The wide scope of Photonics encompasses many application fields that will be mostly covered by various curricula involving Laser Optics and Material Sciences and Interactions. This cooperation will build a very efficient scientific international community able to address the 21 century challenges in Photonics and applications. Indeed, the highest level of education, namely Master and PhD , will address the so called “Skill shortage” that impact on our economy. The truly interdisciplinary theme of this graduate school is also a guarantee for the insertion of the graduate into the workforce.

The cluster culture existing in the consortium (Cluster ‘Route des Lasers ‘in Bordeaux, “Florida Photonic Cluster” in Orlando and “Material Science Cluster” in Clemson) will provide the necessary guidance in the market area. The workforce and international collaborations between research and Industry that will be built during this program will revive, if necessary, the economic growth of our regions through efficient research programs and technology transfer.

The success of this GRADUATE program will be assessed by the number of MS and PhD theses, eventually under cotutelle agreement, and dedicated MASTER classes are organized to fulfil this standard. The main goal of our project is then to facilitate the access of students to PhD while maintaining the excellence in curricula. This project strongly relies on the TRANSATLANTIC MASTER MILMI (Master In Laser Material Interactions) which has been settled between the partner Universities in September 2008 under the European ATLANTIS funding (2008-2012).

Research based learning system

A strong tutoring from the very beginning of the program will help the students to define an optimized path throughout the partner’s institutions. The partners jointly intend to foster a work force at the highest level based on research and education. Moreover, a global culture where European and US approaches in structure and management will build a very efficient population of scientist and engineers in this high technology field

The many research teams in each institution have the required international reputation in these fields to guarantee the high level of teaching and training the students deserve. Training will be ensured by two years long laboratory internship leading to defend the “Master thesis”. Then, if the research project of the student fits into the development of the themes implanted in the consortium, a PhD contract will be signed with a strong emphasis on the cotutelle framework where all the partners benefits from the activities.

Strong industrials links through the cluster’s structures will also enable close collaborations within the triangle Industry/education/applied research as a keyword for innovation. This whole organization is clearly devoted
to an efficient insertion of our PhD into the High Tec workforce.

**History of the partnership**

Long time research history among all the partners of this consortium has focused on furthering the fundamental scientific understanding which links material science and laser material processing. These have been successful not only on the research side but also on the education side as we all early understood that we need good students able to work in very competitive area with strong employment opportunities at the highest level. All the partners associated in this proposal where the most active, since 1998, in the International REU program, funded by the National Science Foundation and national European institution for a more modest part. This program, intended to attract talented students to research activities in science, allows for long internship- in the US (UCF and later Clemson Univ.) for French (Bordeaux 1 University) and German (FSU-Jena) candidates and in the corresponding European institution for the US Undergraduate students. For the past 9 years, the educational action was focused mainly on the undergraduate level and has fostered collaboration between Chemistry Materials, Engineering and Physics departments nation-wide, both in France, Germany and in the US. This program has permitted the hiring of outstanding candidates based on their academic background, provided them a prior research experience and foreign language competency. As an outcome, we have been able at UB1, FSU, UCF and Clemson to channel appropriate candidates for graduate studies and our own PhD programs.

In order to establish a global, truly international, education and training platform in the field of Laser materials and interactions, we found easier to first address the PhD degree issue and have first proposed - and obtained in 2005- a bilateral agreement for a joint doctoral supervision between UCF and UB1- a so called ‘cotutelle agreement’ (see annex 1). This agreement is, for the first time, a generic framework in which students can evolve in an international culture. This unique agreement is already under evaluation between Clemson University and UB1 and its form can be easily adapted to other bilateral situations. Already 7 candidates (US and French) have entered this program and we now need to build a complete, vertically-integrated education and training effort, blending and sequentially building on educational research experiences, benefiting participants at all levels. Obviously, the master level will be very strategic in this approach as it will attract good candidates from all over the two nations.

In 2005 the two project leaders (UB1 and UCF) address this graduate level to find ways to bridge our two systems, not only vertically inside each country, but also transversely to allow the complete mobility of students. The timing was apparently quite appropriate as France recently adapted its academic program to be quite similar to the US on introducing the LMD framework. But, if each institution has a well defined set of requirements for Masters Degrees, each of which leads on naturally to their respective PhD programs, the requirements in France and respectively UCF and UC are quite different. We proposed to the FACE council a project to find common ground that will result in the development of a universal set of requirements which can allow MS students to seamlessly move between the French and US systems. Since UCF and UB1 have already established a cotutelle ‘joint’ agreement for PhD the establishment of common Master of Science requirements will create a truly compatible transatlantic system. Progress will be made to achieve the same agreement for individuals studying at UF and UB1 as well. This project was funded in 2005 and some keys items have been obtained that we wish to extend to the community through this proposal.

In 2008 the two project leaders (UB1 and UCF) enlarge the frame of this original proposal to bring a true European approach, in association with the prestigious of CLEMSON (SC-USA) that bring the complement in the Material science in the US and Friedrich Schiller University in Jena –Germany as a world expert in Laser technology. They introduce the concept of International Master degree and all partners commit themselves to this double degree program that was successfully presented to The EU-US -ATLANTIS program (accepted in September 2008). The EU-US ATLANTIS program of cooperation in higher Education and Training, with the funding of the EC for Europeans and the FIPSE for US students support the so called MILMI (International Master degree in Laser, Material Science and Interaction. The first mobility students (12 students total –3 from Jena, 3 from Bordeaux, 4 from UCF and 2 from CLEMSON) will experiment this project in September 2009 by studying one year in a transatlantic University. This approach of building a strong EU/US association in Higher education and research will fulfill the discussion and wishes explained during the ATLANTA workshop in November 2008 (Internationalization of Research and Graduate Studies and its Implications in the Transatlantic context).
On the research side, the recent development of the partnership evolves through new structured international programs. Beginning of 2008 for example, a GIS program “LASINOF” involving all research groups in Bordeaux working in the domain of Laser-Matter interactions (2008-2013) has been funded that includes strong international mobility. We are also planning to extend to at least 8 more Master student mobility grants each year until 2012 through other funding. At least 4 mobility grants for PhD students each year are also necessary to ensure our co-tutelle programs. We globally (US and French) expect to exchange 14 Master students, 4 PhD students, 10 staff each year until the next three years. The French ministry of higher education already supply this program with 3 PhD supports/year for the next 4 years.

To complete the visibility of such a vertically integrated program, we found that the missing label will be a ‘Graduate school’ that will foster and blend education with high technology in a very attractive technology, all along a structured research experience. This label of an International Graduate School will bring to the market new students with all the technical skills in the very exciting key theme of PHOTONICS and Material Science.

The International Master structure

The course consists of study-tracks jointly designed by the partner universities.

Core education in fundamentals of Physics, Optics, Laser and Material science by lectures, laboratory work and research projects, together with transferable skills (such as Social and language courses) is provided at all sites.

New trends in the second year are more specific to locations as described in the preceding table. Most of these options will be taken during the second year, along with a long internship preferably in the home institution.

A 'business' training will be offered by a team of professionals for High tech company creation. This summer school will also be available to any interested student from all over Europe and the US.

EU students: Preferably, European students will spend semester 1 in their home institution and semester 2 in one of the host institutions. Eventually, these students will stay over for the rest of the year doing the first year internship abroad and taking classes during the winter semester.

US students: For US students, choice will be open, and, as we already experienced in the UB1 – UCF agreement, master students will attend classes in year 2, eventually starting the master thesis in the European institution.

Conclusion

Building on the attractivity of the photonic research and development, we hope will strongly good students worldwide in our research areas, and especially in our lab and spinoff companies. Incentive from NSF and FIPSE for the US side as well as European institutions and Ministries of higher education are helping us to support students and researcher for their mobility but we are presently working on a more sustainable scheme to ensure long life to this photonics graduate school.

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Thematic course design for an undergraduate photonics engineering course

Invited Paper

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ABSTRACT

The traditional approach to undergraduate engineering course design is to first present underlying theoretical concepts in the course curriculum and then subsequently apply these theoretical concepts to system-level applications. A traditional photonics engineering course, for example, first reviews electromagnetic field theory, addressing essential concepts from geometrical and wave optics followed by an investigation of the interaction of photons with materials. Building upon these fundamental principles, the students then study the operating principles and design considerations of photoemitters, photodetectors, optical waveguides, and optical modulators. Individual devices are then combined in the design, construction and testing of a system – an example being a fiber optic communication link. This approach is often frustrating for the students because it is the applications that motivated them to study the subject and in many cases they have lost focus and interest well-before the applications are covered. This challenge can be overcome by deliberate course design where relevant thematic applications are introduced early in the course and routinely revisited as a referent. This approach has been shown to effectively motivate student-centric, inquiry-based learning.

This thematic course design framework was applied to an undergraduate photonics engineering course,1,2 at the U.S. Military Academy at West Point where an emphasis was placed on inquiry-based investigation of a wavelength division multiplexing communication system introduced during the first lesson of the course and subsequently revisited throughout the remainder of the course. The underlying theory necessary to understand foundational concepts, device behavior and subsystem operation was presented in a just-in-time fashion.

Key Words: photonics engineering, thematic course design, inquiry-based learning.

1. INTRODUCTION

Many undergraduate courses in engineering programs are structured to present underlying theoretical concepts first in the course curriculum and then subsequently, after covering the necessary theoretical constructs, introduce system-level applications. A traditional photonics engineering course, for example, first reviews electromagnetic field theory, addressing essential concepts from geometrical and wave optics followed by an investigation of the interaction of photons with materials. Building upon these fundamental principles, the students then study the operating principles and design considerations of photoemitters, photodetectors, optical waveguides, and optical modulators. Individual devices are then combined in the design, construction and testing of a system – an example being a fiber optic communication link.

Additionally, concept reinforcement within individual courses and among courses in the curriculum is frequently not deliberate. Students often fail to understand the importance of linkages within and among courses and subjects, and instead view their education as a series of disjoint and unrelated topics and courses. Making conceptual linkages and transferring knowledge from one context to another is a particularly important skill to teach students and, as importantly, is an effective teaching technique. Learning new information is more effective and efficient if the new information is framed within a known context and in fact, deduced from an established knowledge base. Many of the most accomplished and
successful scientists and engineers understand new concepts by relating them to foundational theories and framing the new concepts within the context of their own knowledge and experience. In a course like photonics engineering, earlier courses in chemistry, physics, electromagnetic fields and waves, signals and systems, and solid state electronics must all be leveraged to make the most effective use of time, extend previously developed foundational concepts to new applications, and deliberately reinforce those concepts.

Both of these challenges can be overcome by deliberate course and curriculum design. The first can be overcome by designing courses around a system-based application and the second by deliberate integration of the curriculum. The system-based application can be introduced early in the course and used effectively to motivate student-centric, inquiry-based education. Integration of the curriculum begins by identifying common foundational themes within and between courses, and highlighting these to students as the topical coverage warrants. Deliberate integration of the curriculum is accomplished by not only identifying the foundational themes through conceptual abstraction, but also, by design of common exemplars. We have begun deliberate curriculum design where topical linkages and recurring thematic examples are used to demonstrate course-to-course disciplinary linkages and reinforce foundational concepts. Curriculum integration will not be addressed in this paper. However, one example of a deliberate curriculum integration theme which we have developed strives to unify the development of topics such as resonance, filtering, stability, transmission line behavior, and spectral characteristics of lasers in courses such as signals and systems, basic electric circuits, controls, electromagnetic fields, and photonics from mathematical models and analysis techniques associated with second-order linear system response describing damped harmonic oscillators.3

This paper first introduces the original course design for an upper-division, undergraduate photonics engineering course and then describes the restructured course and the assessment of student results across the two different course designs.

2. ORIGINAL COURSE CONSTRUCT

Photonics Engineering is an upper-division undergraduate course taken by electrical engineering majors at West Point. The course began as a traditional introductory photonics engineering elective course in the electrical engineering curriculum. The course syllabus from academic year 2001 is shown in Figure 1. The text used for this course was and continues to be Fundamentals of Photonics by B. E. A. Saleh and M. C. Teich. This course followed the traditional approach of theory – devices – applications. In the beginning of the course theoretical constructs were covered including a review of linear system theory, electromagnetic fields and waves and some circuit analysis and electronics. This was followed by geometrical optics, wave optics, electromagnetic optics and an introduction to Fourier optics. Once this foundational material was covered, devices were introduced including lasers and light emitting diodes, modulators, photodetectors, and optical waveguides. At this point in the course, the students were able to synthesize the previous course material and address systems including fiber optic communications, imaging, and image processing applications. The early laboratories in this course were independent, self-contained laboratory exercises focused on verification of fundamental physical principles similar to those found in a traditional physics course that covers similar material. Since the geometrical optics and polarization laboratory was the first physical optics laboratory in the course, the objectives were twofold. First, students were to become familiar with basic optics laboratory hardware and laser safety procedures. Secondly, they were to become familiar with lenses, waveplates, linear polarizers and simple optical systems and verify the predictions of geometrical optics. The purpose of the diffraction and interference laboratory was to become familiar with diffraction gratings, pinholes, and optical slits and verify the predictions of optical diffraction and interference. Laboratory VI on lesson 36 of a 40 lesson course was the first time the students began assembling subsystems into a functional application of a fiber optic communication system.
In academic year 2004 we deliberately restructured our photonics engineering course to integrate a thematic application approach. We also moved from a traditional lecture-style approach to an inquiry-based approach to student-centered learning. This course restructuring required a substantial restructuring of the course syllabus to accommodate a logical approach to inquiry-based learning. The restructured course syllabus for academic year 2006 is shown in Figure 2. The course text remained *Fundamentals of Photonics* by B. E. A. Saleh and M. C. Teich. One could argue that the traditional approach to course design can be described mathematically as

\[ \text{Theory} \rightarrow \text{Devices} \rightarrow \text{Systems}. \quad (1) \]

In contrast, this new approach can be described as

\[ \text{Applications} (\text{Devices(Theory))} \]. \quad (2) \]
After considering the topical coverage of the course and relevant disciplinary applications, this rationale led us to develop an optical communication system-based thematic application, shown in Figure 3. Here, an emphasis is placed on an inquiry-based investigation of an optical communication system which is introduced during the first lesson of the course and subsequently used as the educational vehicle throughout the remainder of the course. In keeping with the rationale of Equation (2), the underlying theory necessary to understand foundational concepts, device behavior and subsystem operation is presented in a just-in-time fashion. The goal of this methodology is to motivate student interest and learning throughout the course and develop inquiry-based techniques.

<table>
<thead>
<tr>
<th>Lesson</th>
<th>Topic</th>
<th>Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Course Introduction, Transmitter: Optical Sources</td>
<td>None</td>
</tr>
<tr>
<td>3</td>
<td>Optical Perceptron I: Pattern Recognition, Fiber-Optic Interconnected</td>
<td>pp. 611-620</td>
</tr>
<tr>
<td>4</td>
<td>Laser I: Photon-Atom Interactions, Transition Rates and Lifetimes</td>
<td>pp. 621-634</td>
</tr>
<tr>
<td>6</td>
<td>Geometric Optics I: Solution to Wave Equations</td>
<td>pp. 651-652</td>
</tr>
<tr>
<td>7</td>
<td>Optical Perceptron II: Spatial/Temporal Properties &amp; Subsystem Models</td>
<td>pp. 667-674</td>
</tr>
<tr>
<td>9</td>
<td>Class Drop</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Laser IV: Laser Output Characteristics, Laser Interactions</td>
<td>pp. 709-715</td>
</tr>
<tr>
<td>11</td>
<td>Electronic/Magnetics I: Introduction to Electromagnetics</td>
<td>pp. 158-174</td>
</tr>
<tr>
<td>12</td>
<td>Laboratory I: Basic Diffraction</td>
<td>pp. 180-186, 192-194</td>
</tr>
<tr>
<td>13</td>
<td>Laboratory II: Ray Optics</td>
<td>pp. 195-202</td>
</tr>
<tr>
<td>14</td>
<td>Geometric Optics I: Reflection &amp; Refraction, Metallic Materials</td>
<td>pp. 212-215</td>
</tr>
<tr>
<td>15</td>
<td>Geometric Optics II: Imaging</td>
<td>pp. 23-28</td>
</tr>
<tr>
<td>16</td>
<td>Laboratory I: Geometric Optics</td>
<td>Lessons 1-13</td>
</tr>
<tr>
<td>17</td>
<td>Geometric Optics I: Transmission Through Optical Components</td>
<td>pp. 29-100</td>
</tr>
<tr>
<td>19</td>
<td>Optical Transmission &amp; Optical Materials</td>
<td>pp. 251-260</td>
</tr>
</tbody>
</table>

Figure 2. Photonics engineering course syllabus for academic year 2006.

An interesting and effective addition to this restructured course was the addition of a fiber optics voice and data kit as Laboratory I. In this laboratory, students build a self-contained fiber optics kit. At this stage in the course they have not covered the necessary course material to fully-understand the
components or subsystems. The purpose is to provide yet another example of a more compact, albeit simpler, commercially packaged optical communication system. At the end of the course, the students then revisit this project and write a short report that is intended to synthesize the course material and give them the opportunity to then describe all of the components and subsystems in this kit according to the knowledge they acquired in the course.

The course was structured to progress through the transmitter subsystem and address optical sources, optical modulation, and optical multiplexing in sequence followed by coverage of the channel subsystem and finally the receiver subsystem accounting for optical demultiplexing and optical detection.

The optical communication system used as the educational vehicle is a fully-functional wavelength division multiplexing (WDM) optical communication system shown in Figure 4. Each of the three lasers was a different wavelength and both direct modulation and acousto-optic modulation were used in the transmitter subsystem. Multiplexing was accomplished using mirrors and beam splitters. The transmission channel subsystem was comprised of a free-space component and an optical fiber. Demultiplexing in the receiver subsystem was accomplished using a diffraction grating and optical-to-electrical conversion was accomplished using photodetectors. This WDM system was functional throughout the entire course and was brought into the classroom for the introduction of each new subsystem block of instruction to motivate the application and inquiry-based questioning. The WDM system was also available and operating during each of the laboratories.

Study of a particular subsystem began by showing the students the specific functioning element or subsystem and then allowing students to ask questions about the associated devices of the operational system. Subsequent lessons were then dedicated to answering the student questions and developing the
theory necessary to quantify or qualify the answers. An example of this inquiry-based approach is described using Figure 5 as the inquiry vehicle.

Student questions prompted and guided the subsequent answers and further topical investigations:

1. How do you convert electrical power into optical power? Gain Medium
2. How is the optical power constrained in space? Resonator Cavity
3. Why does the optical power flow in a well-defined direction? Electromagnetic Fields
4. What properties of the optical beam can be changed? Physical-Mathematical Analysis

To begin to answer Question 1, we considered the following:

a) Power transferred into the gain medium by a variety of energy transfer processes:
   - Thermodynamic
   - Ionization of atoms
   - Absorption of photons

b) Gain medium properties
   - Characteristic responses of constituent atoms

From these discussions we identified the necessary underlying principles and theory:

a) Principles:
   - Quantized energy levels
   - Classical model for individual atom response

b) Theory:
   - Lineshape function (characteristic color of laser)
   - Transition strength (size of “target” to absorb a photon)
   - Spontaneous emission lifetime (likelihood to emit a photon)
   - Density of modes

Special emphasis was placed on reinforcing concepts with device-specific laboratory exercises. Whenever possible, the linkages were established with material from previous courses. Although this approach sometimes presented difficult concepts early in the semester, requiring a level of abstraction with unanswered questions, the same material was covered in the restructured course as in the previous traditional course.

4. ASSESSMENT.

Based on an analysis of assessment tools over a four-year period, the academic performance of the student remained unchanged; the evaluation of knowledge and skill outcomes compared to course objectives reflected a similar level of comprehension for both the traditional and system-based instruction. Despite a reduction in course content, and sometimes incomplete theoretical development, the students were able to perform at an appropriate academic level, especially when asked to integrate photonic devices in operational systems.

Student understanding of the theoretical course concepts is easily assessed in quizzes and traditional written examinations. The linkages between the theoretical constructs, devices, and system applications are traditionally assessed in the student laboratory report submissions. We have taken additional measures to reinforce this learning component by adding several oral laboratory reports throughout the
semester and by making the final system-level project and oral assessment. In this way the students have the opportunity to demonstrate their design project and the instructor has the opportunity to directly assess the student's understanding of the course material in the context of the design project application.

Perhaps even more important than academic performance was the increase in the student excitement for the material and the intellectual curiosity of the students. At the beginning of the semester, the average student was reluctant to ask questions or comment on the observed characteristics of the operational WDM system. By the end of the semester, the intellectual maturity of the student increased to the point that several lessons became free-flowing discussions of the topic.

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6. REFERENCES


Evolution of Photonics Education at the Australian National University

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ABSTRACT

This paper tracks the evolution of photonics education and training at the Australian National University (ANU) from its tentative beginnings in 1971 in the doctoral and masters postgraduate research arena and in 1989 in the undergraduate teaching arena through to its substantive role in 2009 and onwards. In addition it addresses various offshoots to national and international outreach activities and support for emerging photonics qualifications at other institutions, as well as photonics conference evolution.

Keywords: Photonics, optical fibres, lecture courses, photonics degrees, outreach, science schools, photonics conferences

1. Introduction

Optics has long been a strong tradition of research and development in Australia, partly enhanced by the country’s strategic location in terms of astronomical access to the southern night sky and partly due to its high international standing and reputation for research and expertise in areas such as holography and the production of precision optical devices, and more recently in optical fibres, devices and applications. With regard to the latter, names such as Beattie Steel and Hariharan spring to mind. It is only since the mid-1960’s when photonics began to make its presence felt in Australia that a whole new research and production industry evolved that has fluctuated with normal market pressures, including the great dot-com boom in the 1990’s and the subsequent bust in 2000. Now towards the end of the first decade of the 21st century, progress in photonics has reverted to the more normal increase that continues to follow Moore’s Law of doubling in demand for bandwidth about every 9 months.

For a country of its size and with a population of only 20 million, Australia has punched well above its weight in terms of photonics research and development, photonics education and training, and photonics commercialisation and exporting. Commensurate with the exponential growth in photonics activity, a parallel growth in photonics education and training occurred in the tertiary education sectors, including a significant number of major universities, TAFE’s (Technical and Further Education) in the six states and the equivalent in the Australian Capital Territory (Canberra), as well as the incorporation of basic fibre light-guiding into secondary school physics curricula. Indeed, several named photonics degrees were launched by various institutions in the heady 1990’s but have now been rationalised. A small number of commercial photonics training companies also appeared and there was an impressive level of outreach activity stemming from universities and photonics-based independent research groups that also spread to some south-east
Asian countries through Australian Government financial support. This has now subsided to more realistic proportions.

Another factor in the photonics education and training equation is the Australian Conference on Optical Fibre Technology (ACOFT) that emerged in 1984 out of an existing series of optical fibre workshops started in 1977 by Professor Toni Karbowiak. This annual conference has become the keystone for the reporting of photonics research progress in Australia and New Zealand and has attracted an impressive array of co-located leading international photonics-based conferences to the our shores, as well as incorporating workshops and photonics schools. This conference is now in its 34th year and is well set to continue far into the future.

2. Research Training

The first photonics research training in Australia started in the Department of Electrical Engineering at the University of New South Wales (UNSW) in 1966 with the arrival of Professor Toni Karbowiak from STL in the UK. Indeed the very first PhD student was the late Professor Pak Chu who went on the take over the leadership of the Optical Communications Group when Professor Karbowiak retired and later when Professor Chu retired from UNSW he moved to the City University of Hong Kong to head the Opto-Electronics Group. At ANU, the Department of Applied Mathematics in the Research School of Physics of the Institute of Advanced Studies hosted the first photonics research group in the early 1970’s under the leadership of Professor Allan Snyder. This theory group rapidly expanded and I had the pleasure of becoming a member in 1973. A large number of Ph.D’s was produced together with a small handful of masters degrees by research, the latter normally occurring because of a change in circumstance inhibiting progress towards a doctorate.

A culmination of the voluminous research output from this group appeared in 1984 as the book entitled “Optical Waveguide Theory” written by Professor Snyder and myself. It has since appeared in Russian and Chinese editions, is still in print after 25 years and is generally regarded as the classic on the subject. A second book appeared in 1996 entitled “Silica-based Buried Channel Waveguides and Devices” written by Professor François Ladouceur and myself, and is based on a combination of theory and experimental development using plasma deposition and etching processes, the latter undertaken in collaboration with Professor Rod Boswell at ANU.

3. Photonics Lecture Courses

The first short lecture course in guided photonics was given in the Department of Physics at ANU in 1989 and has since expanded into two full third-year/masters lectures courses, one of which covers all the fundamentals of the physics of guided wave photonics with a focus on application to long-distance optical transmission systems covering fibres and waveguides and associated light-processing devices. The second more recent course established in 2007 addresses the application of guided wave photonics to non-telecommunications areas including sensing, security, architecture, transport, biophotonics including endoscopy and dosimetry, astronomy and the emerging area of nanophotonics.

The lecture material in these courses has evolved with sufficient detail to minimise reliance on existing photonics texts that are either very expensive, too advanced or provide insufficient physical background and explanation.
Both courses have a well-developed laboratory component comprising around 6-7 experiments that are continually upgraded. The first course experiments embrace: (i) multimode fibre propagation characteristics; (ii) single-mode fibre and bend loss; (iii) constructing and testing a single-mode fibre communication link; (iv) optical time domain reflectometry (OTDR); (v) fibre couplers, connectors and wavelength division multiplexing (WDM); (vi) erbium-doped fibre amplifiers, and (vii) pulse dispersion in single mode fibres. Experiments (i) to (v) are hands-on while experiments (vi) and (vii) are PC-based using Australia-developed software from VPI. For the second course, the laboratory experiments include: (i) optical fibre refractometry; (ii) Fabry-Perot sensor; (iii) fibre gyroscope; (iv) optical fibre lighting and energy use; (v) fibre Bragg grating sensor; and (vi) optical time domain reflectometry (OTDR) sensing.

Digital optical communications laboratory experiment

In addition to these traditional lecture/laboratory courses, a half-course was introduced some years ago that is devoted to photonics work experience and places students with local photonics companies in Canberra for at least 30 hours of hands-on practical experience. There is no formal examination involved but the course requires a detailed work log and an essay covering the background to the area of photonics undertaken. Encouragingly, several students who have taken this course have gone on to work with the company involved on either a part-time or full-time basis.

All of the above courses are available to both engineering and physics students, with the majority of engineering students comprising Master of Engineering students from overseas. Masters students are expected to complete an essay assignment and give a presentation in the two major courses instead of further assignments. Guided wave photonics has also appeared to a lesser extent in other physics courses including first- and third-year courses, and guest lectures have been given in some other undergraduate engineering courses.

ANU was also instrumental in helping to establish photonics courses at other Australian universities and institutions. The bulk of an inaugural photonics lecture course was delivered by ANU personnel over a 2-month in the School of Electronic and Computer Science at Curtin University in Perth, WA, during 1997. Similarly ANU personnel together with Sydney University people delivered a theoretical and experimental component of a masters degree at the Australian Telecommunications Research Institute (ATRI), also at Curtin University. Closer to home, ANU played a leading role in the establishment of an Advanced Diploma in Photonics Technology at the Canberra Institute of Technology in 2003.
4. Undergraduate Photonics Degrees

The exponential increase in photonics activity in Australia in the 1990’s lead to the establishment of special degrees at a number of Australian universities and TAFE’s to take advantage of demand. Macquarie University in Sydney was probably the first entrant into this field and set up an undergraduate degree B.Optoelectronics that involved the local TAFE for the optical transmission systems training part of the degree. ANU’s response was to establish three new photonics degrees, two in physics and one in engineering. The engineering degree was labelled as a B.Photonics Systems but was not successful and was withdrawn a few years later. A B.Photonics degree was introduced by the (then) Department of Physics and has only been recently withdrawn as it attracted nothing like the expected number of students.

5. Masters Degrees by Coursework

The one remaining conventional photonics degree at ANU degree is the Master of Photonics (M.Photonics), a 1-year degree also introduced by the (then) Department of Physics. This has been in existence for about 10 years, and although it attracts a healthy number of applicants, only 1 or 2 take the degree each year, the reminder probably deterred by the relatively high level of ANU fees compared to their own country. The degree requirements are currently being revised to reflect available and evolving courses at ANU and the increasing interest in, e.g. photovoltaics integrated into guided wave photonics to increase efficiencies and reduce manufacturing costs. Apart from 6 lecture courses, there will be a research project in photonics undertaken with a group in the Research School of Physics and Engineering and, for the remaining course will be chosen by the student in consultation with the degree convenor.

There is also a photonics component to a distance-learning Master of Contemporary Science (M.Contemp.Sc) degree. This degree was developed to enable schoolteachers, in particular, to come up to speed with recent developments in various areas of science. The current photonics unit is derived from the first photonics course in fibre optics described above, and plans are afoot to add a second unit based on the second course. In addition, students can undertake a supervised research component for which it is necessary to spend significant time at ANU in the case of laboratory-based projects.
6. Photonics Prizes

An incentive for students to take the ANU photonics courses was the introduction of the Wanda Henry Prize in 1998. Dr Wanda Henry was the first woman to receive a PhD in guided wave photonics at ANU and went on to postdoctoral work at the University of Arizona at Tucson and at Kings College, Cambridge University, where she was a college fellow.

Kallista Stewart (left) receives the inaugural Wanda Henry Prize from parents Bob and Margaret Henry in 1998

She took up a permanent position in the Department of Electronic Engineering at La Trobe University in Melbourne in 1994 but sadly passed away in 1996 at the age of 35. In view of her great enthusiasm and strong support for photonics throughout her brief career, a number of prizes were established in her memory. One of these is at Aldridge State High School in Queensland, at the annual Australian Conference on Optical Fibre Technology (ACOFT) and at ANU, in addition to a Bursary at La Trobe University.

7. Photonics Teaching Kits

Minilab II showing the laser outputs for ray tracing experiments
The Department of Quantum Science also manufactures and markets the Minilab that is a comprehensive kit-in-a-box that enables a wide range of basic experiments to be undertaken in optics, photonics, quantum optics and electronics. The photonics component covers optical fibre basics, such as light launching and excitation, bound rays, attenuation and dispersion using ray tracing, as well as digital modulation, splicing, wavelength multiplexing and simple fibre sensors.

At present a more compact, simpler and more portable purely photonics kit is being developed and tested in the field for use in years 10-12 school laboratories by Sandy Box, a retired ACT science teacher with many years experience, as part of the research component of her Master of Contemporary Science degree at ANU.

8. Outreach

![Siemens Science Experience students at the ANU solar dish](image)

Photonics outreach has matched the peaks and troughs in the photonics industry in Australia but now seems to have settled down to a moderate but steadily increasing level of activity. In the

![Montage of Singapore school visit to ANU](image)
1990's and early 2000's, a number of companies were eager to be appraised of the new technology and a variety of brief introductory professional courses were tailor-made to order by ANU researchers and teachers. ANU photonics is also promoted through the annual National Science Festival held in Canberra and individuals make give occasional presentations to local schools and other organisations.

From 1991 to 2004, photonics in both lecture and hands-on form was also presented as part of the annual ANU-managed Siemens Science and Engineering Experience in the ACT for year 9 students. The Experience was designed to help these students make better-informed decisions about science and engineering courses for years 11 and 12 at college and on to university. Overseas groups regularly visit from Singapore for intensive few-day Science Schools with age groups as young as year 8.

8. Australian Photonics Cooperative Research Centre

The Australian Photonics Cooperative Research Centre was established in 1992 based on major Commonwealth Government funding and ran for 13 years until funding was exhausted. The Centre consisted of an amalgamation of collaborating universities, including ANU, and commercial partners to foster the development, application and commercialisation of photonics research. In addition to the strong research focus, the Centre also fostered a range of photonics teaching and training initiatives. One of the early ideas was the establishment of a number of scholarships exclusively for suitably qualified women postgraduate research students.

Another development was the introduction of Photonics Schools held over a few-day period prior to the annual Australian Conference on Optical Fibre Technology. The purpose of these Schools was primarily to broaden the photonics knowledge of research students beyond their only more narrowly focused doctoral research projects. In the event these Schools attracted other participants from government and industry, including the legal profession, the latter probably a reflection on the large number of patents being generated. Each School ran over a period of 2-3 days and comprised guest and regular lectures on different aspects of photonics, including contracts and patents. A half-day hands-on session was a popular component of the Schools.
Later Photonics Schools based on the above model and supported with Australian Commonwealth Government and local funding were run successfully in collaboration with tertiary institutions in Sweden, Singapore, Korea and China.

Later in the CRC’s history, a company – the Photonics Institute - was set up at the Canberra Institute of Technology to help integrate and plan the increasing level of photonics education and training activities. Part of the Institute’s remit was the development of a number of photonics modules that could be used by CRC-associated and other institutions for their internal teaching purposes. It also became involved in supporting the introduction of photonics into school curricula in a number of states, as well as into national training schemes. Most regrettably, the achievement of many of these goals was frustrated by the unplanned cessation of virtually all the CRC’s activities in 2005 caused by financial problems.

9. Future Developments

It is a challenge to try and predict with reasonable certainty how photonics education and training at ANU will evolve over the next few years. The basic teaching courses outlined above have a sufficiently strong base and demand to ensure their continued presentation for the foreseeable future. However, ANU has moved to a collegiate structure that has resulted in closer integration between the traditional undergraduate photonics teaching areas in the former Faculties and the graduate photonics teaching areas in the Research Schools. This amalgamation should in principal lead to enhanced involvement of researchers in photonics teaching, but current organisational and financial constraints may frustrate its rapid achievement.

10. Acknowledgements

I am grateful to Andrew Papworth who oversees the photonics teaching laboratories at ANU for providing material for this paper and to Dr Kate Wilson for financial support to help attend ETOP. Dr Anna Wilson, President of the ACT Branch of the Australian Institute of Physics (AIP), secured financial support from the AIP to help with the development of the new photonics kit for use in Canberra high schools.
Should Optics be taught to Optometry students?

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Abstract

Though developed out of physics and optics, the optometric profile in the UK has shifted towards a healthcare professional. As a result, optometry students are now stretched between numerous courses as diverse as microbiology, legal aspects related to practice, mathematics, vision or pharmacology. The importance of optics is still affirmed by regulating bodies and universities worldwide, but many students, particularly those with a relatively weak background in mathematics and physics, question the relevance of this teaching and engage reluctantly with this topic. In order to evaluate the importance of optics as part of the optometry curriculum, to improve the satisfaction of our students and to best suit their needs as future Optometrists, we first reviewed the place of optics in the optometry curricula across Europe. It appears that there are two main divisions: some have adopted a biomedical focus, well illustrated by UK universities while others have adopted a more optics/physics emphasis as in some German program. In addition to this review, we carried out a survey among Manchester Optometry alumni asking them how relevant they consider the classic teaching in optics (geometrical, physical and visual optics) to be to their subsequent career. The results of this survey will be discussed in detail. It appears that though predominantly favourable and against a reduction in the amount of optics taught, a relatively large percentage is in favour of a reduction and consider that what they learnt during their studies has not been useful to them professionally (over 20% for geometrical optics). In this context, a solution could be to increase the profile of the different professional opportunities available to graduates (optics, marketing, customer service, etc.). The simplest solution is however to take advantage of the wonderful potential of relevant optometric situations for the teaching of the fundamental optical principles. To conclude this presentation, we give a number of examples of how optometric applications can be used to introduce all the main optical phenomena.

Introduction

The history of Optometry is strongly related to the history of Optics. Philosophers of Antiquity speculated not only about the nature of light, but also about how vision is carried out in the body (e.g. Empedocles’ extromission theory). The origins of modern Optometry are however usually traced back to the 19th century when technological progresses and increased demand for vision testing led to a distinction being made between dispensing and refracting opticians [1].

Nowadays, according to the college of optometrists (UK), “optometrists are primary health care specialists trained to examine the eyes, to detect defects in vision, signs of
injury, ocular diseases or abnormality and problems with general health”. This means they should develop a broad range of competencies such as the ability to use diagnostic drugs to aid ocular examination, to assess symptoms and signs of neurological significance, to fit contact lenses or to advise on and to dispense the most suitable form of optical correction taking into account durability, comfort cosmetic appearance and lifestyle”. To acquire these competencies, optometry students have thus to follow a rich curriculum, covering a wide range of topics including: general medical science, visual ergonomics, optics, bioethics, binocular vision, pharmacology, visual psychophysics, neurophysiology, and legal and professional aspects of Optometry.

In this context, students sometimes fail to see the relevance of their education in Optics and engage reluctantly with this topic. This problem is aggravated by the fact that most students see Optics as a difficult subject. This last outcome is not completely surprising as most students are accepted with A levels in Biology, Chemistry and a 3rd topic, usually Mathematics, but very rarely Physics.

In order to evaluate the importance of optics as part of the optometry curriculum, to improve the satisfaction of our students and to best suit their needs as future Optometrists, we first reviewed the place of optics in the optometry curricula across Europe, then carried out a survey among Manchester Optometry alumni asking them how relevant they consider the classic teaching in optics (geometrical, physical and visual optics) to be to their subsequent career.

**Optometric Education in Europe**

Important changes took place in Optometric education in Europe in association with the Bologna declaration and the optometrists profile in several countries (e.g. Spain, Portugal) evolved towards the UK model. The practice of Optometry in Europe is however still surprisingly diversified [2, 3]. The profession is not always officially recognised (e.g. in France), and even in countries where the practice of Optometry has a legal status, regulations present important variations.

In Germany for instance, the clinical / bio-sanitary components represented traditionally a relatively smaller part of the course than in the UK, letting a more important place to Optics related subjects. The professional profile is thus different, more directed towards the development and fabrication of visual aids or related to the Optics industry. On the opposite side, the UK model emphasizes on the biomedical / healthcare, and UK optometrists can perform some medical acts legally restricted in other countries (e.g. using diagnostics drugs). As a consequence, the part of Optics in the curriculum is reduced to accommodate topics such as ocular pathology and pharmacology.

Institutions and regulating bodies throughout Europe tend to affirm however the importance of Optics, and the European Council of Optometry and Optics (ECOO) has chosen for the European Diploma in Optometry to retain the highest standard, combining the strong physics/optics focus of some German Universities’ program with the clinical focus of the UK model.

Optics is thus still seen as core to the formation of Optometrists but, in some countries, it does not represent anymore the backbone of the profession. For this reason, we decided to carry out a survey among Manchester Optometry alumni to know how
relevant they consider the classic teaching in optics (geometrical, physical and visual optics) to be to their subsequent career.

Survey – The point of view of Optometrists

The survey was carried out with the software SelectSurey.net among optometrists alumni of the University of Manchester / UMIST who had graduated at least four years ago (oldest respondents had graduated in 74). This duration was chosen so that this survey reflected the point of view of experienced optometrists (at least 3 years).

The content and answer rate of the survey are represented in Table 1. As stated previously, the purpose of the survey was to help re-assess the importance of the quality and quantity of the teaching in optics. The various aspects of optics are usually divided in three components: geometrical (G.O.), physical (P.O.) and visual optics (V.O.) and it is the division followed at the University of Manchester. For each one, we presented the same set of four statements:

- What I learnt during my studies has been useful for me professionally.
- The education I received was appropriate for my career.
- The current amount of geometrical optics taught (~24h) should not be reduced.
- I enjoyed the teaching I received.

Responses were given using a standard five-level Likert item ranging from "strongly agree" to "strongly disagree".

The participation rate was good with 37 respondents (i.e. almost 33%). The results of the survey were globally very positive. A majority of alumni (>59%) gave a positive answer to all these questions with Visual Optics clearly the most appreciated topics: 78-94% of positive answers (i.e. “strongly agree” and “agree”) and the only one with a majority of “strongly agree”.

For Physical Optics, the prevailing answer shifted to “agree” but results were still highly positive with 75-91% of positive answers.

The most negative answers were obtained for Geometrical Optics. Although the rate of positive answers is still high (59-67%, with a dominance of “agree”) the first 2 questions, regarding the usefulness of the course and its relevance to a career in Optometry, attracted 11 negative answers (“disagree” and “strongly disagree”) compared to 0 for P.O. and 1 for V.O. There is also a surprising 21.63% who did not found that what they had learned had been useful and 40.55% (“neutral” and “disagree”) who do not object to a reduction in the teaching to less than 24 hours, compared to 24.32% for P.O. and 16.21% for V.O.

V.O. is the unit which is the most clearly related to Optometry and the one which relies the less on mathematics. Its positive appreciation could therefore be expected.

The positive answers for P.O. are a bit more surprising but may reflect the fact that P.O., despite being challenging for students with a very limited background in Physics, is stimulating (new concepts (EM wave, polarisation, etc.) are introduced, explanations of natural phenomena are presented) and correspond well to the optometrists’ need in an increasingly technological environment.
The relatively negative results for geometrical optics are the most surprising. G.O. is often used to introduce numerous fundamental concepts (focal plane, image plane, conjugated points, light rays, etc.) which are necessary to teach P.O. and V.O. It is also a topic that can appear as dry and too abstract when compared to V.O., and without the novelty and challenge of P.O. Its limited appreciation probably reflects the desire to acquire a practical knowledge which relates closely with real life applications.

In addition to the series of questions, respondents had the possibility to provide some comments. These comments confirm the answers given to each questions, and underline the importance of Optics for Optometrists. It was stated that refraction and optics are the core strengths of Optometrists, strengths shared unequally with other eye-care professional and should therefore not be dismissed. A background appreciation of optics is important to better understand the visual difficulties met by the patient and provide the optimum correction. It is also useful to demonstrate their professional knowledge to patients if they ask questions (e.g. anti-reflection coatings), as well as to make sense of claims related to commercial instruments. Respondents however stressed that the teaching in Optics should be updated, made more concise and remain focused. Critics about teaching in subjects such as psychophysics, Fourier analysis were recurrent, as well as the place of mathematical ability in tests.

Conclusion

Even in the UK where the Optometrist profile is one of the less physics-oriented in Europe, the importance of Optics is still affirmed by regulating bodies and optometrists themselves. The question is then how to best deliver a teaching in Optics so as to provide the students with the skills set by the ECOO.

The scope of the profession tends to expand towards the detection, diagnosis and management of ocular diseases, and it is not possible to stretch further the course without increasing its duration. One solution could be to broaden the professional profile of optometry further than the healthcare sector. In addition to a common formation, students could choose different ECTS credits (optics, marketing, customer service, etc.) depending on their professional project, and each University could modulate their teaching by providing optional courses in agreement with its professional surrounding. Several respondents to the survey actually suggested that education in different topics such as business administration or pathology would be useful. The career prospects may however be low in some cases and this solution would have to comply with decisions associated with the ECOO and Bologna declarations.

The simplest solution is probably to modernise the teaching in Optics to best suit the needs of Optometry students. If Optometry progressively distanced itself from Optics, the teaching in Optics for optometrists may have stayed too traditional as can bee seen from the few books dedicated to the subject. The survey showed that this teaching needs to be relevant to optometrists’ daily activities and directed towards real life applications. Fortunately, Optometry offers a wonderful potential to introduce all the main optical phenomena and a number of examples are presented in table 2. A sound background in optics is important for the optometrist to understand many recent technological advances (e.g. aberrometer, multifocal implants) [4, 5] and to advise the patients contemplating refractive surgery. It is up to us to brush up our courses to
engage with the students and make sure that optics remains a core strength of Optometrists.

References


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   http://www.aneca.es/media/150364/libroblanco_optica_def.pdf


### Table 1

1. Regarding Geometrical Optics (i.e. light as rays, Snell's law, construction rays, thin lenses, cardinal planes, etc.):

<table>
<thead>
<tr>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
<th>Response Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>What I learnt during my studies has been useful for me professionally.</td>
<td>29.73% (11)</td>
<td>32.43% (12)</td>
<td>16.22% (6)</td>
<td>16.22% (6)</td>
<td>5.41% (1)</td>
</tr>
<tr>
<td>The education I received was appropriate for my career.</td>
<td>18.92% (7)</td>
<td>56.76% (21)</td>
<td>16.22% (6)</td>
<td>5.41% (2)</td>
<td>2.7% (1)</td>
</tr>
<tr>
<td>The current amount of geometrical optics taught (~24h) should not be reduced.</td>
<td>27.03% (10)</td>
<td>32.43% (12)</td>
<td>27.03% (10)</td>
<td>8.11% (3)</td>
<td>5.41% (2)</td>
</tr>
<tr>
<td>I enjoyed the teaching I received.</td>
<td>27.03% (10)</td>
<td>40.54% (15)</td>
<td>24.32% (9)</td>
<td>5.41% (2)</td>
<td>2.7% (1)</td>
</tr>
<tr>
<td>Total Respondents</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Regarding Physical Optics (i.e. the wave nature of light, interferences, anti-reflections coatings, diffraction, polarisation, etc.):

<table>
<thead>
<tr>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
<th>Response Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>What I learnt during my studies has been useful for me professionally.</td>
<td>40.54% (15)</td>
<td>51.35% (19)</td>
<td>8.11% (3)</td>
<td>0% (0)</td>
<td>0% (0)</td>
</tr>
<tr>
<td>The education I received was appropriate for my career.</td>
<td>29.73% (11)</td>
<td>56.76% (21)</td>
<td>13.51% (5)</td>
<td>0% (0)</td>
<td>0% (0)</td>
</tr>
<tr>
<td>The current amount of physical optics taught (~24h) should not be reduced.</td>
<td>32.43% (12)</td>
<td>43.24% (16)</td>
<td>18.92% (7)</td>
<td>2.7% (1)</td>
<td>2.7% (1)</td>
</tr>
<tr>
<td>I enjoyed the teaching I received.</td>
<td>29.73% (11)</td>
<td>51.35% (19)</td>
<td>10.81% (4)</td>
<td>5.41% (2)</td>
<td>2.7% (1)</td>
</tr>
<tr>
<td>Total Respondents</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Regarding Visual Optics (i.e. optics of the eye, correction of ametropia, aberrations, optical vs neural constraints on visual acuity, optics of ophthalmic instruments and lenses, etc.):

<table>
<thead>
<tr>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
<th>Response Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>What I learnt during my studies has been useful for me professionally.</td>
<td>56.76% (21)</td>
<td>37.84% (14)</td>
<td>5.41% (2)</td>
<td>0% (0)</td>
<td>0% (0)</td>
</tr>
<tr>
<td>The education I received was</td>
<td>56.76% (21)</td>
<td>35.14% (13)</td>
<td>5.41% (2)</td>
<td>0% (0)</td>
<td>2.7% (1)</td>
</tr>
</tbody>
</table>
appropriate for my career.

The current amount of visual optics taught (~24h) should not be reduced. I enjoyed the teaching I received.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Illustration in the context of Optometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometrical Optics</td>
<td>Correction of ametropia, telescopes for low vision patients</td>
</tr>
<tr>
<td>Interferences</td>
<td>Anti-reflection coatings</td>
</tr>
<tr>
<td>Michelson interferometer</td>
<td>Time-Domain OCT</td>
</tr>
<tr>
<td>Young's fringes</td>
<td>Instruments for assessment of visual acuity pre-cataract surgery</td>
</tr>
<tr>
<td>Polarisation</td>
<td>Polarising sunglasses, Haidinger brushes</td>
</tr>
<tr>
<td>Birefringence</td>
<td>Instruments to assess the integrity of the Retinal Nerve Fibre Layer</td>
</tr>
<tr>
<td>Waveguide</td>
<td>Photoreceptors</td>
</tr>
<tr>
<td>Aberrations</td>
<td>Myopia, wavefront sensor (Hartmann-Schack), Wavefront Guided Laser surgery, aberrations of lenses, relation between spherical aberration and depth of field in the context of intraocular implants and presbyopia</td>
</tr>
<tr>
<td>Chromatic aberrations</td>
<td>Duochrome test</td>
</tr>
<tr>
<td>Diffraction</td>
<td>Multifocal lenses, resolution, Rayleigh criterion</td>
</tr>
<tr>
<td>Photometry</td>
<td>Lighting</td>
</tr>
<tr>
<td>Optical design</td>
<td>Example of different optical designs that can be found among the animal kingdom (pinhole eye, compound eye, etc.)</td>
</tr>
<tr>
<td>Laser</td>
<td>Refractive surgery, pancoagulations, Nd:Yag posterior capsulotomy</td>
</tr>
</tbody>
</table>
Development of an Automated Modern Undergraduate Optics Laboratory using LabVIEW

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ABSTRACT
We report here the development of an automated modern optics laboratory for undergraduate students. This developed modern optics laboratory have automated experiments on optoelectronic device characterisation, optical instrumentation, CCD based optical experiments and advanced applications in optics. In the device characterisation section, Voltage-Current (V-I) and Optical Power-Current (P-I) characteristics of various optoelectronic devices like LEDs, Laser diodes and photo diodes have been automated. In the optical instrumentation section, development of PC based optical power meter have been reported whose functionality can be tailored as per the need of the designed experiment. In the CCD based optical experiments section, CCD has been integrated for fringe capture and analysis by studying the diffraction pattern of a pinhole. In the advanced applications in optics section, molar absorptivity of NiSO₄ has been calculated. Further work is in progress to develop heart rate monitoring system, non-evasive jaundice studies from the skin, CCD based real time spectrometers as well as elaborate studies on interference, diffraction and polarisation. The automation of this laboratory has been done by integrating various sensors (photodetectors, CCDs, Current and others) with data acquisition cards connected to PC and one of the most widely used world wide scientific graphical programming software LabVIEW. The purpose of the laboratory is to invoke student interest by exposing them to various modern tools in comparison to very conventional as well as boring existing optics laboratories. The use of this scientific graphical programming software will help in performing various real time measurements and calculations with ease. The automation of the experiments will also save great amount of experimentation time and procurement of costly equipments dedicated to each experiment thus providing an efficient way to carry out studies with reduced financial constraints and better manoeuvrability.

Keyword List: Modern Optics Laboratory, Computer Interfacing, Automation of Experiments

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INTRODUCTION

Optics is a branch of physics that deals with light. It is related to a number of phenomena from the lovely sight of rainbow in the sky to the laser light in a laboratory. Applied optics is related to different applications of optics. Lasers and their applications have added new dimensions to the study of optics. Laser in its different incarnations such as a doctor's scalpel doing bloodless surgery, booming laser-guided missile in space, weed-killer in undulating crops and as a tool in the optics laboratory has made optics and applied optics the most feted frontier of science.

The need for enhanced undergraduate laboratory teaching aids has been identified for better understanding of basic concepts to students. Although there are currently a number of interesting and powerful educational products in the market, they are typically produced in the developed countries and are sometimes inappropriate for applications in the developing countries. They are also often very expensive. This paper describes an automated modern optics laboratory configuration and a set of tools designed and implemented at the undergraduate level. The laboratory encompasses a personal computer (PC) station and a set of inexpensive hardware tools for data acquisition and control to make learning for students innovative.[1],[2]

The optics laboratory consists of four sections: Optical Instrumentation, Opto-Electronic Device Characterization, CCD based Optical Experiments, and Advanced Applications in Optics. The four sections of this automated modern optics laboratory have been discussed as under:

Section I: Optical Instrumentation

Optical instrumentation has made the overall expansion of optics and applied optics feasible. Primary working range of radiation in undergraduate laboratories is available from the infrared (IR, 730nm - 13µm) through the visible (380nm-780nm) region. So the instrumentation must respond to this range of radiation.

The developed optics laboratory comprises of an important instrument to measure optical power. An optical power meter is a device which converts light power to a measurable current or voltage that is proportional to the optical input. The optical power meter is used to monitor the power of the laser generating the optical signal, optics experiments based on various types of lasers in the undergraduate and postgraduate physics laboratory, to measure the loss through the transmission medium, to test the receiving electronics, optical communication industry, etc.

Theory

Optical power meters comprise of a photo-detector which generates an electrical current proportional to the optical power of an input optical beam, a Current to Voltage (I/V) amplifier (trans-impedance amplifier) which converts the output current of this photo-detector to a voltage, a variable gain amplifier which amplifies the output voltage of this I/V amplifier, and an A/D converter which converts the output voltage of this variable gain amplifier to a digital signal. Optical power meters generally do not discriminate wavelengths, rather they measure light intensity or optical power independently or substantially independently of wavelength.

In this paper, we report the development of a computer-based optical power meter which is a low-cost system containing a photo-detector and a USB based data acquisition card from National Instruments (NI-DAQ USB 6008). It offers all the features of standalone box type optical power meters in addition to scalability to higher number of channels, advanced data analysis, and continuous collection of optical power measurements.

Experimental Set-up

When interfacing with a photo-detector, the quantity that must be measured is current. A trans-impedance amplifier has been employed to measure the current as it is the most suitable method that yields the detectivity, signal-to-noise, and accuracy that is expected from a semiconductor photo-detector. The
advantage that the trans-impedance amplifier has over almost any other amplifier configuration is that it does not bias the photodiode with a voltage as the current starts to flow from the photodiode. Typically, one lead of the photo-detector is tied to the ground and the other lead is kept at virtual ground by means of the input of the trans-impedance amplifier. The resultant bias across the photo-detector is then kept at virtually zero volts, a condition that helps minimize dark current and noise, and helps increase linearity and detectivity. Effectively the trans-impedance amplifier causes the photocurrent to flow through the feedback resistor, which creates a voltage, \( V = iR \) (\( i \) is the current generated by photodiode and \( R \) is the feedback resistor), at the output of the amplifier. Since the designed program knows the value of the precision feedback resistor, the current can be calculated with very good accuracy.

The experimental design of the optical power meter is as shown in Fig.1.

![Fig. 1: Experimental Design of Optical Power Meter](image)

The experimental set-up consists of two sections: Hardware and Software. The hardware section comprises of a photodetector, transimpedance amplifier and a NI USB-6008 DAQ Card as shown in Fig.1. The light from the source under study is incident on the photodetector which generates an output current associated with the detector responsivity. This current is then converted to an equivalent analog voltage using a transimpedance amplifier as explained above. The analog voltage is fed to the LabVIEW based software section using the DAQ Card. The developed setup also provides an advantage of using any detector in the laboratory without the manufacturer data.

The software section developed using Student Version of LabVIEW 8.5.1 works in two modes: Calibration and Measurement. Prior to any measurement of optical power, the photodetector in the system is calibrated for accurate power measurements. The calibration routine in the software measures/calculates the responsivity for the photodetector in use. Responsivity is expressed as current/optical power (A/W) and is usually provided by the manufacturer of the photodetector. However, the developed software eliminates the need of the manufacturer data for calibration.

The calibration routine in the software incorporates this feature in 3 different modes: Single Wavelength Calibration, Multiple Wavelength Calibration and Standard Detector Calibration. The three modes have been described elsewhere.\[3\]

After the calibration of the detector is over, the software enables the options for optical power measurement. On clicking the button, “Measure Optical Power” on the software, the software asks the user to input the wavelength of the source for which optical power is to be measured. Using the results in the calibration section, the software now calculates the optical power for the source under study. At every click for power measurement, the software measures the optical power 100 times and displays them on a waveform chart in the front panel of the software. This data is useful to study the stability of optical detector and the source of light over time. The average value of the optical power is indicated by a numerical indicator on the panel. The software is also capable of displaying optical power in all the commonly used units such as Watts (W),
milliwatts (mW), microwatts (μW), nanowatts (nW), picowatts (pW) and dBm. The various screenshots and the supporting program are as shown in Fig.2 (a)-2(c).

**Results**

The developed system has been checked using a standard He-Ne laser at 632.8 nm of known optical power output of 2 mW. The responsivity of the photodetector used in the setup is 0.412 A/W. The standard He-Ne laser source output beam was directly positioned onto the photodetector. The developed system estimates the optical power output for the laser as 1.95482 mW. Also, to check the linearity of the system, we put a 50/50 beam splitter in the beam path of the He-Ne laser so as to reduce the output power falling onto the detector to half i.e.1mW. The recorded value on the power meter is 0.97738 mW. Hence the response of the system is linear.

In order to check the calibration at other wavelengths, we used a diode laser of 670 nm having an optical power output of 3 mW. After calibration as per the datasheet of the photodetector, the power recorded on the optical power meter is 2.92 mW which is near the actual power.

Therefore, the developed optical power meter is quite reliable and accurate. One important feature of the system is that it shows the time based waveform recording besides the numerical value of the power. Therefore, output stability of the source over a period of time can be displayed.
SECTION II: Opto-Electronic Device Characterization

Light Emitting Diodes (LEDs) and laser diodes are the most widely used optical sources for optical communication and relevant studies. A laser diode works in two modes, spontaneous and stimulated emission. However, a light emitting diode works on the principle of spontaneous emission only. Use of these devices for various applications involves correct biasing conditions. The regions of operation can be identified by studying the two most important characteristics, i.e., device current vs. device voltage (I-V) characteristics and optical output power vs. device current (P-I) characteristics.

We have developed an automated device characterization unit for study of various optical devices. This unit helps to study I-V characteristics for LEDs, Laser Diode, Photo detectors or any other optical device. The laser and LEDs being the light sources, the P-I characterization unit focuses on their study only. Several laser parameters and characteristics can be ascertained by study of its P-I curve. The device under test is just to be connected between the test points and all the measurements are done automatically by the developed system.

Theory

Like all diodes, both these diodes are inherently non-linear devices with respect to voltage and current. After applying a very small voltage, current flows easily through a diode without any significant increase in voltage. LEDs and Laser diodes operating in the forward region act in similar manner. However, they are unique because they emit a coherent optical beam as current is driven through the device. So the relationship between current and the light output is important.

At first, a significant amount of current seems to produce no light, and then the light output increases rapidly after a threshold point of current is reached. Below this point, any light emitted from the device is the diodes spontaneous emission. The population inversion is not great enough here to create stimulated emission, but still the holes and electrons are recombining. The emission is spontaneous, the light generated is low, and the light is incoherent and in all directions. Stimulated emission starts at the threshold current value. Determination of threshold current is especially important for modulated lasers. For efficient high-speed operation, diode lasers are biased around the threshold current for rapid switching response. At higher temperatures, threshold current increases to higher value and hence more current is needed to turn on the laser for a given amount of output optical power.[4],[5],[6]

Experimental Set-up

The automated characterization module was built using Student Version of LabVIEW 8.5.1 and its compatible Data Acquisition (DAQ) card, NI USB-6008 for interfacing. The experimental set-up and its working for the two different characteristic studies are explained as under:

1. I-V Characteristics: The block diagram for the I-V characteristic study is shown in Fig. 3.

![Fig. 3: Experimental Set-up for I-V Characterization of Optical Devices](image)

The Device Under Test (DUT) is placed between the test points and the characteristic curve is acquired and plotted for the device by LabVIEW along with DAQ card which provides for all the parameter acquisition. The Email: amit_andc@yahoo.co.in, Ph. 911126412547, Fax 911126294540
Analog Output Channel 0 (AO0) of the DAQ card is used to supply voltage to the DUT in steps of 0.01 Volts and the corresponding device voltage is read using Analog Input Channel 0 (AI0). The difference in the two voltages is then used to calculate the current flowing through the series resistor, R which is same as the device current in this case. This current is plotted with respect to the voltage read from AI0 thus generating the I-V characteristic curve for the DUT. The I-V characteristic curve is fitted with the equation (1)

\[ I = A(e^{\frac{V}{VT}} - 1) \]  

Equation (1) when compared with the diode equation (2) is used to determine important parameters such as reverse saturation current, \( I_0 \) and \( \eta V_T \) where \( \eta \) is the ideality factor and \( V_T \) is the equivalent thermal voltage.

The device characteristic is simultaneously stored in a datalog file which can be analysed anytime later for further study. The results obtained from the I-V characteristics for an LED, a laser diode and a photodiode are shown in Fig. 4(a)-(c). Figure 5 shows a part of the graphical software code designed in LabVIEW.

2. P-I Characteristics : The experimental set up for P-I characteristic study is shown in Fig. 6.
The P-I characteristics of an LED/Laser diode is obtained by varying the current flowing through the device using Analog Output Channel 0 (AO0) for the DAQ card. The current in the device is measured by acquiring the device voltage at Analog Input Channel 0 (AI0) in differential mode. The light emitted by the device is detected by the photo detector aligned in front of the LED/laser diode. The voltage developed at the output of the detector corresponds to the optical power output of the device under study. This voltage is sent to the developed module at Analog Channel 1 of the DAQ card in differential mode. This voltage is calibrated in terms of optical power at the beginning of routine. The calibration of the detector may be done either in online or offline mode. The online mode helps the user to calibrate an unknown detector with a standard light source before acquisition of P-I characteristics. When working in offline mode, the calibration factor calculated earlier can be loaded from a datalog file for all calculations and acquisition of characteristics.

The P-I characteristics of an LED and a laser diode are shown in Fig. 7(a)-(b). The analysis of the results predicts an increase in optical power for an LED with current. However, the light emission is spontaneous in case of an LED as compared to a Laser diode which exhibits similar P-I characteristics for current values below threshold. Above this current, the output optical power of a laser increases linearly thus verifying the stimulated emission in this region.

The software code for the study of P-I characteristics is illustrated in Fig. 8. The software converts the photo detector output to its corresponding optical power using its calibration factor. This optical power is plotted with respect to device current and simultaneously stored in a datalog file for future analysis and study.

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Through the analysis of LEDs and laser diode, the difference between the light emission processes in two devices can clearly be shown. The results obtained suggest that luminous intensity in spontaneous region for the laser diode is less than that of the light emitting diode. This effect is well explained by the fact that for lower forward bias current, the number of holes and electrons injected is small. As a result, the gain in the device too small to overcome the cavity loss. Also the region after the threshold current value for laser diode follows a smooth curve without any kinks or abruptness in the characteristics. The differential slope efficiency for this region is constant at all points in the curve. Both these results indicate that the quantum efficiency of the laser diode used is excellent and the internal defects in the laser are minimum.

**SECTION III: CCD Based Optical Experiments**

When a laser beam passes through a pin hole, the distribution of light shows a bright maxima surrounded by a number of secondary minima of decreasing intensity. The diffraction pattern is in the form of concentric circles where there are bright areas between the dark concentric rings. The phenomenon of diffraction can be studied under two heads, namely Fresnel and Fraunhofer diffraction. Fraunhofer diffraction is a special case of Fresnel diffraction when the source illuminating the aperture and the observation screen is located at infinity. When a lens is placed after the aperture, the diffraction pattern studied at the back of its focal plane, the diffraction is called as Fraunhofer diffraction. We study the Fresnel diffraction in the present experiment.\(^7\), \(^8\)

**Theory**

The working formula for calculating the diameter of the pin hole is as follows. Let the diameter of the pin hole be \(d\) and the screen is placed at a distance \(b\) from the pin hole, then the radius of the \(n\)th dark ring is given as

\[
x_n = \frac{nbh}{d}
\]  

(3)

When the laser light falls on the pin hole, one can see the appearance of many concentric circles. There are bright areas separating the dark concentric rings. The dark ring at the centre of the diffraction pattern is the central maxima and adjacent to it are different orders. The distance between the central maxima and the first order maxima can be used to calculate pin hole diameter using the equation (4)

\[
d = \frac{nbh}{x_n}
\]

(4)

**Experimental Set-up**

The experimental set up for the CCD based pin hole Fresnel diffraction study is shown in Fig. 9.

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Fig. 9 : Experimental Set-up for Single Slit Diffraction Study

Fig. 9 describes the experimental set-up used for pin hole diffraction studies using a linear CCD sensor. The diffraction pattern is generated when a beam of laser passes through the pin hole. This pattern is made to fall on a linear CCD image sensor which has 1024 elements with inter-pixel separation of 7.8 µm. Thus, the total length of the array is 7.9872 mm, which corresponds to 5.2 ms on the time frame of an oscilloscope. Each pixel data is then acquired by a LabVIEW based graphical code through Tektronix 1012B Digital Storage Oscilloscope (DSO). The analysis of this data reveals a diffraction pattern exhibiting maxima and minima points within the pattern which is stored in a text file simultaneously for further analysis. The spacing between two maxima or minima can easily be computed by the placing the cursor at the desired points and pressing the “Calculate Distance” button on the software routine as shown in Fig. 10(a) and 10(b). These distances are stored in an array and displayed on front panel of the software every time the distance is calculated by the user.

The distance between the central and the first order maxima as calculated from the fringe pattern is further used to calculate the pin hole diameter. The calculated value from the experimental data for a pin hole of 175µm is 170µm.

The diffraction pattern obtained using CCD is in accordance with the theoretical patterns. The diffraction patterns obtained help the students understand the variation in light patterns with ease. In the conventional optics laboratory, students calculate the distance between two maxima points on the concentric ring pattern for diameter calculations. However, the actual pattern shape is never visible which makes it difficult to relate the results with theory and to understand the basic concept of diffraction. Thus the developed automated...
system is an improvement over earlier experiments carried out in the laboratory along with increased accuracy and reliability in results.

SECTION IV : Advanced Applications in Optics

Applied optics is the application of the optics to the broad realm of practical problems in industry, engineering and science. The invention of optical devices like the laser, optical fibers and solid state detectors has led to a wide range of new technologies. The laboratory developed aims at using optics for multidisciplinary studies like Lambert Beers law study in chemistry, heart rate monitoring and jaundice studies in the medical field.

This section describes one of the applications of optics in the area of chemical education by studying Lambert Beers law. In chemistry, the Lambert-Beer law is an empirical relationship that relates the absorption of light to the properties of the material through which the light is travelling. Beers law can be applied to the analysis of a mixture by spectrophotometry, without the need for extensive pre-processing of the sample. An example is the determination of bilirubin in blood plasma samples. The law is widely used in infra-red spectroscopy for analysis of polymer degradation and oxidation. This law also describes the attenuation of solar or stellar radiation as it travels through the atmosphere.[9]

Theory

Substances that appear to have color absorb light at wavelengths that are visible. The color perceived is due to the wavelengths that are not absorbed. It is the light that is either transmitted or reflected that is sensed by the eye. Fig. 11 shows a beam of monochromatic radiation of radiant power $P_0$ directed at a sample solution. Absorption takes place and the beam of radiation leaving the sample has radiant power $P$.

![Fig. 11: Light Absorption in a diluted solution](image)

The amount of radiation absorbed defined as absorbance, $A$ which may be measured using equation (5).

$$A = \log_{10} \left( \frac{P_0}{P} \right) \quad (5)$$

Lambert Beers law states that the absorbance, $A$ of a dissolved substance is a linear function of its concentration, $c$. The distance the light travels through the material, $l$, and the molar absorbivity, $\varepsilon$, determine the slope of the linear plot as given by the equation (6).

$$A = \varepsilon c l \quad (6)$$

The Lambert-Beers law is valid only for diluted solutions. The limits for its validity differ for different materials. As a general rule, every material showing absorption of up to 0.5-0.6 still obeys the Lambert-Beer Law.

In the developed set up, we have reported the behavior of the linear absorption increase of Nickel Sulphate (NiSO₄) with increasing concentration in order to determine its molar absorbivity at a given wavelength within its absorption area. The studies have been carried out for various solutions.

Experimental Set-up

Fig.12 shows the experimental set up for Lambert Beers Law study. A light beam of red laser with wavelength of 640 nm was made to pass through a cuvette containing a solution of nickel sulphate. The amount of light

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transmitted out of the solution was made to fall on a photodetector and its output voltage was acquired using an Analog Input Channel AI0 of the DAQ card in differential mode through LabVIEW.

The process was repeated for solutions of different concentrations and the data stored in a data log file. The path length for the cuvette was also stored in the data file for absorbivity calculations. The photodetector output was converted into the corresponding optical power and the absorbance was calculated for all set of concentrations. The absorbance vs. concentration curve was simultaneously plotted for each concentration value of the solution and fitted linearly as depicted in fig. 13(a)-(b)

The linear variation of the plot verified the Lambert Beers Law. The data points were curve fitted linearly and the average absorbivity calculated for different solutions.

**CONCLUSIONS**

1. The developed modern automated optics laboratory is an improvement over the conventional optics laboratory. The experiments which could not be performed earlier like diffraction pattern studies can now performed with ease and accuracy. Also, the results obtained with the automated system are more accurate and precise.

2. The modern optics laboratory is being envisaged to meet higher goals and the work is in progress for developing new experiments like heart rate monitoring system, non-evasive jaundice studies from the skin and advanced interference, diffraction and polarization studies. The development of optical

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instruments like CCD based Spectrometer and integrated Optical Energy-Power Meter is also under execution.

3. The developed laboratory will invoke student interest by exposing them to various modern tools in comparison to very conventional as well as boring existing optics laboratories. The automation of the experiments will also save great amount of experimentation time and procurement of costly equipments dedicated to each experiment thus providing an efficient way to carry out studies with reduced financial constraints and better manoeuvrability.

4. The use of the scientific graphical programming software helps in performing various real time measurements and calculations with ease.

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REFERENCE CITATIONS


The Undergraduate Optics Course at Millersville University

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ABSTRACT: For many years, there was no stand alone course in optics at Millersville University (MU). In the fall of 2007, the Physics Department offered for the first time PHYS 331: Fundamentals in Optics, a discovery based lab course in geometrical, physical and modern optics. This 300-level, 2 credits course consists of four contact hours per week including one-hour lecture and three hours laboratory. This course is required for BS in physics majors, but is open also to other science majors, who have the appropriate background and have met the prerequisites. This course deals with fundamental optics and optical techniques in greater depth so that the student is abreast of the activities in the forefront of the field. The goal of the course is to provide hands-on experience and in-depth preparation of our students for graduate programs in optics or as a workforce for new emerging high-tech local industries. Students learn applied optics through sequence of discovery based laboratory experiments chosen from a broad range of topics in optics and lasers, as the emphasis is on geometrical optics, geometrical aberrations in optical systems, wave optics, microscopy, spectroscopy, polarization, birefringence, laser generation, laser properties and applications, and optical standards. The peer-guided but open-ended approach provides excellent practice for the academic model of science research. Solving problems is embedded in the laboratory part as an introduction to or a conclusion of the experiment performed during the lab period. The homework problems are carefully chosen to reflect the most important relations from the covered material. Important part of the student learning strategy is the individual work on a final mini project which is presented in the class and is included in the final grading. This new course also impacted the department’s undergraduate research and training programs. Some of the individual projects were extended to senior research projects in optics as part of the senior research and seminar courses, PHYS 492 and PHYS 498, which are required for graduation for all physics majors. The optics course also provides basic resources for both research and training in the classical and modern optics of high-school students and K-12 teachers. The successful implementation of the optics course was secured by a budget of about $60,000.

Keywords: optics, laboratory course, optics education

1. INTRODUCTION

Optics, the study and manipulation of visible light, has always been an important sub-discipline in physics, and clearly, it contributes to the most important technologies of the 21st century. Optical devices and laser applications are already an inherent part of our daily life. In recent decades, the use of optics has transcended the traditional devices such as cameras, microscopes, and binoculars and has merged with atomic physics and nanotechnology. The development of the laser and the use of optical cable for communication initiated a new technological revolution. The euphoria for internet connectivity and the huge amount of information upload daily via the internet impose rapidly rising demands for higher bandwidth and faster speed which drives the incessant growth and development of fiber optic communications [1]. Every single student in our classes has a cell phone and a CD player, but few know what an optical fiber is and how a laser works.

Understanding the nature of light, its propagation and interaction with matter is essential to physics and hands-on experiences greatly enhance that understanding. For more than 20 years, there was no single course at MU dedicated to optics at any level, although optics was woven into some courses and laboratories such algebra
and calculus based PHYS 132 or 232. Following the recommendation in the five-year department review report, the Physics Department decided to expand its undergraduate physics curriculum and to increase its expertise in this important sub-discipline. The first step that the department took in this direction was to hire two specialists in experimental optics and solid state physics, who are also the authors of this paper. This immediately resulted in an increased number of undergraduate research projects in optics such as measuring the speed of light in water, observation of surface plasmon resonance effect in thin silver and gold films, applications of laser pointers in the secondary physics education, measuring the light momentum, holography in thin films of silver halogenide and holographic recording in lithium-neobate crystals [2]. After careful study of the experience of the optics programs at New Jersey Institute of Technology (NJIT) [3, 4], North Dakota State University (NDSU) [5] and Indiana University of Pennsylvania (IUP) [6], the authors of the paper developed a new rigorous lab-based optics course. This was offered for the first time at MU in fall 2007. Since then, the course is offered every fall semester. A budget of about $60,000 provided by the Dean of the School of Mathematics and Science secured the state-of-the-art laboratory equipment for the course. The equipment is also being used by physics students and faculty for their research in the field of optics, as well as to evoke an interest in top high school students in optics and science careers. With an addition of another advanced optics course in future, the Department will be able to offer a new option in BA physics with optics. The optics course provides the basic resources for both research and training in modern optics. It promotes learning, teaching and training of students, faculty and K-12 teachers.

The purpose of this paper is to report on the progress of the new course in optics that is currently offered every fall at MU. The course goals, objectives, contents, equipment, assessments and progress are also discussed.

1. Who are we?

Millersville University (MU) is one of the 14 universities within the Pennsylvania State System for Higher Education (PSSHE). Founded in service to a rural nineteenth century Lancaster Pennsylvania, twenty-first century Millersville University is a vibrant public liberal arts university in a vital economic region. MU promotes intellectual development through a comprehensive range of meritorious baccalaureate and master programs offered to more than seven thousands undergraduates and about a thousand graduate students. Millersville has earned its place among US News & World Report's top public universities in the North and is recognized for its academic excellence in Martin Nemko's book, "How to Get an Ivy League Education at a State University." [7]

All resources, time, funding, and energy of the MU Physics Department are focused on doing one thing extremely well: Undergraduate Physics. We challenge thoughtful students, providing the opportunity and incentive for all to achieve their fullest. The Department offers high-quality four-year undergraduate degrees of BS and BA in Physics (option in computer science, meteorology, nanotechnology, philosophy and polymer science), and BS in Education, as well as two co-operative engineering programs. The first is a 3/2 Program - three years at MU and two at Pennsylvania State University (PSU) or University of Southern California, after which students get two degrees, BA in Physics and BS in Engineering. The second co-operative program is a 4/2 Program with PSU which offers BS in Physics and MS in engineering degrees. The BA with Nanotechnology option is also a co-operative program with Penn State. A student takes the basic physics courses of a B.A. degree at Millersville, and after spending a semester at the Penn State Nanofabrication Facility learning the specialized techniques of nanotechnology, receives a BA degree in Physics with a Nanotechnology Option. The department of physics is one of seven departments in the School of Science and Mathematics and consists of seven full-time and one permanent part-time faculty. At any time we have about 60 physics majors. On the average, nine students graduate every year from our department. We have low student/faculty ratio (15/1) and all labs are taught by Ph.D. faculty using hands-on experiments and not simulations. Many upper level elective courses in Physics have 5-12 students. Because we do not have a graduate degree program, advanced projects are integrated into the curriculum and are focused on the undergraduate student.

Millersville is conveniently located in the heart of Susquehanna Valley, almost equally distant from Philadelphia, Baltimore and Washington DC, and at about three hours drive from New Jersey and New York, an area of abundant advanced research centers and high-tech industries providing more opportunities for employment and graduate studies while keeping vital connections to the local community. The driving distances to Pittsburg, State College and Rochester facilitate the contacts with the Northpointe Technology Center in Freeport, Penn State Technology Park and The Institute of Optics, University of Rochester.
Millersville University has the most successful science programs of any school within the PSSHE system. The Physics Department, in particular, has generated over the last ten years many more Baccalaureate degrees than any other PSSHE University. However, we cannot be complacent. Technologies and their societal relevance change and we must adapt with them. This optics course is an important component in maintaining the currency of our programs and retaining our ascendant position within the PSSHE system.

2. THE NEW OPTICS COURSE (PHYS 331) AT MU

2.1 Goals and Objectives

The importance of optics is described in the syllabus of the course. Optics and laser systems, and their applications are an inherent part of our daily life – from classical optical systems, such as microscopes and telescopes, to CD and DVD players, cell phones, iPods, laser pointers, laser bar scanners, sophisticated devices for measurements and control, material processing systems, etc. Optics and lasers have direct implications in chemistry, biology, medicine, residential life and industry. Optics, the science of dealing with the propagation and manipulation of light, has always been an important sub-discipline in physics, and is crucial to advancement in science and technology. Understanding the nature of light, its propagation and interaction with matter is essential to constantly emerging newest technologies. Hands-on experience in optics and photonics are greatly appreciated in the modern industrial job market.

The goal of this lab-based course is to give students a detailed look at classical and modern optics, to provide hands-on experience at a rapidly growing field and in-depth preparation for graduate programs in optics, or for realizations as a workforce at high-tech industries.

The main objective of the course is to provide physics majors and other science students with hands-on experience and in-depth preparation for graduate programs in Optics, Optoelectronics, Optical Engineering, or as a workforce for new emerging high-tech local industries, via broader and deeper knowledge of basic concepts and principles of optics and optical techniques. The course introduces the basic optical systems and techniques in greater depth so that the student is abreast of the activities in the forefront of the field. Students are required to participate in a multidisciplinary project, complete a report and give a PowerPoint® presentation in class. After successful completion of this course, students will be able to:

1. Comment on basic concepts and principles of geometrical, physical and modern optics.
2. Discuss the nature of light, its propagation and interaction with matter.
3. Describe basic optical phenomena, the principles of lasers and their applications.
4. Discuss the Maxwell’s electromagnetic theory of light and derive simple relations from the basic optics laws.
5. Handle and align optical elements and set-up basic optical experiments.
6. Operates optical devices and equipment.
7. Handle and align a laser cavity.
8. Measure basic parameters of laser light.

2.2 Course description

PHYS 331 Optics is 300-level of two credit hours and is taken by students typically in their fifth semester. This course is required for BS physics majors, but is open also to chemistry, biology, earth science, computer science and other majors, who have met the prerequisite requirements MATH 211 Calculus-II and university general physics PHYS 232 or PHYS 132. This optics course is very useful for chemistry majors since it provides basic knowledge of optics associated with the analytical part of chemistry. It is beneficial also for computer science majors, since knowledge of modern optics is essential for fiber optics communication and data storage. Microscopes and lasers are widely used also in biological experiments. The MU Biology and Chemistry Departments have a well-equipped microscopy center, including a Scanning Electron Microscope (SEM) and an Atomic Force Microscope (AFM), which is actively used by students and faculties for undergraduate research. Therefore, biology majors are encouraged to gain knowledge in optics before they handle the sophisticated instruments in this center.

The course enrollment is restricted only by prerequisites and lab equipment limitations. The initial budget ensured the equipment for four lab stations. The Department provided a large laboratory room dedicated only to
this course. Considering three students per station, the maximum enrollment in the course at this moment is limited to 12 students.

The optics course is designed for juniors and seniors whose background is one year of university physics and two years of calculus and differential equations. To facilitate their transition to the challenges of the new course, we put some review materials on the department website. The highest priority of our optics course is creative and critical thinking, and life-long learning. This determines our teaching strategies. We emphasize concept development and qualitative and quantitative analysis. Demonstrations, thought experiments, guided class and group discussions, especially about misconceptions concerning optics, case studies, and peer-guided problem solving are part of our interactive learning strategies. Students learn and experience applied optics through sequence of open-ended laboratory experiments and multidisciplinary projects. In order to enhance interactive learning and deeper understanding of the most important concepts and phenomena of optics, the laboratory exercises are designed as hands-on use of state-of-the-art equipment. This guided but open-ended approach provides excellent practice for the academic model of science research. The lab experiments are chosen from a broad range of topics in optics and lasers, as the emphasis is on geometrical optics, wave optics, microscopy, spectroscopy, polarization, birefringence, and properties of lasers. Both, the lab and lecture portions of the course are taught by PhDs.

The optics course consists of one-hour lecture and a three-hour lab. The laboratory portion is the critical and most important part of the course, since it provides the tools and experience that students can take back to their respective disciplines and projects. The laboratory part uses the discovery based approach in which students have to investigate a hypothesis by designing and realizing the experiments, predicting relations and results, and processing the data. Therefore, no laboratory experiment write-ups are handed out, but students have access to the devices and optical kit manuals. Additional materials over the Web may also be used.

Since the new course is open to different science majors, we offer multidisciplinary projects which enable them to successfully apply optics in their respective majors. The projects are offered in the beginning of the course to provide an early start and enough time for accomplishment. The projects are determined on the base of the student’s interests and background, current undergraduate research projects they are working on, prospective plans for graduate studies or eventual job placement. Some example of such projects offered are optical properties of thin semiconductor films or sculptured thin films, diffraction from thin films of self-assembled micron size polystyrene particles, image processing, fiber optics, interferometric measurements, digital holography, etc. Presentations can include theoretical background, live demonstrations, simulations, and experimental results.

2.3 Course content

The general physics courses encompass some concepts of electromagnetic waves and propagation of light: reflection, refraction, and total internal reflection, image formation with lenses and mirrors, fibers, dispersion, interference, diffraction, polarization, atmospheric phenomena, human eye, color mixing, shadows, eclipses. But all these basic optical phenomena are described usually in two chapters, sometimes just a paragraph for a topic with broad applications. The new optics course enriches and broadens this background with knowledge about aberrations of optical systems, microscopes and telescopes, cameras and photography, visual processing, light sources and detectors, quantum nature of light, lasers, laser applications, holography, birefringence, thin films and optical coatings, nonlinear optical phenomena, ocean optics, ultraviolet (UV) and infrared (IR) optics materials. Part of the lecture material is covered in the laboratory using just-in-time teaching method. Students from different science departments work on optics projects related to their discipline and have to make a PowerPoint® presentation to the entire class. Besides background learning on their own, this covers various topics that would not normally be included in the course.

The lecture portion of the course follows the main topics in the E. Hecht, Optics, 4th ed., Addison Wesley, 2002. Other classical texts are also recommended to the students and are possibly in use [8]-[12]. Course material is available to students also through the university’s Blackboard website. There is rich information posted on the websites of NJIT and NDSU which is also referred to the students. This, in addition, introduces our students to the facilities and curricula of these leading Optics programs.

We offer fourteen separate experiments completed in three-hour blocks. The lab portion of the course starts with an introduction to the safety standards of using optical and laser sources and systems. The basic equipment for most of the experiments is The Projects in Optics Kit of Newport Corp. This is a set of laboratory equipment
containing all of the optics and optomechanical components needed to complete a series of experiments that provides students with basic background in optics and practical hands-on experience in laboratory techniques. The kit comes with a very well written workbook [13], which serves as the main supplement to lectures and is available to students as a source of information for the lab projects. For the last experiment, an investigation of the Helium-Neon (He-Ne) laser cavity, students are challenged to build a He-Ne laser using the state-of-the-art MICOS' He-Ne laser kit. We are aware that the lab experiments and individual projects require careful guidance to secure the successful student’s performance and data interpretrations. We rely on the previous experiences of the science majors with our PHYS 232 general physics course which uses the peer-reviewed discovery based approach in the physics lab.

Table 1: PHYS 331 Optics Laboratory

<table>
<thead>
<tr>
<th>Lab projects</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 The laws of geometrical optics; Introduction to optical systems (handling and alignment of optical elements)</td>
<td>This is an introductory lab which makes the transition to the new course via summarizing the student’s previous experiences in optics from the general courses in physics and introduces the students to more complicated optical systems. Students get familiar with safety standards.</td>
</tr>
<tr>
<td>2 Reflection and refraction</td>
<td>Laws of reflection and refraction; Prisms: Dove prism, roof prism, retro-reflectors; total internal reflection; attenuated total internal reflection;</td>
</tr>
<tr>
<td>3 The thin lens equations, Imaging; Geometrical aberrations, telescope</td>
<td>Image formation, telescopes and binoculars, correction of aberrations, photodetectors and computer data acquisition with Vernier Software Logger Pro 3.</td>
</tr>
<tr>
<td>4 Optical systems</td>
<td>Expanding laser beams, Divergence. The experiment demonstrates the design of two types of laser beam expanders – the Galilean and the Keplerian. Students gain experience in alignment of laser beams.</td>
</tr>
<tr>
<td>5 Microscopy</td>
<td>Optical microscope, magnification and resolution limits, Scanning Electron Microscope (SEM), Atomic Force Microscope (AFM)</td>
</tr>
<tr>
<td>6 Diffraction of circular apertures</td>
<td>Fresnel and Fraunhofer diffraction. Students measure the diffraction effects of circular apertures and experience how the size of the aperture determines the resolving power of all optical instruments.</td>
</tr>
<tr>
<td>7 Single slit diffraction and double slit interference</td>
<td>Using a single “infinitely” tall slit, students witness the diffraction which takes place in direction perpendicular to the small dimension and investigate the interference pattern of two nearby slits, and diffraction grating properties.</td>
</tr>
<tr>
<td>8 The Michelson interferometer</td>
<td>Students build a Michelson interferometer and use it as a means to observe small displacements and refractive index changes.</td>
</tr>
<tr>
<td>9 Interference of light</td>
<td>Newton’s rings, thin-film interference. Students will use the same arrangement as in lab 8 to test optical components in monochromatic light (Twyman-Green interferometer).</td>
</tr>
<tr>
<td>10 Lasers and coherence</td>
<td>Students examine the frequency separation between the axial modes of a He-Ne laser with Michelson interferometer.</td>
</tr>
<tr>
<td>11 Polarization of light</td>
<td>The students use a He-Ne laser with three modes (two of the modes polarized orthogonally to the third mode) to get experience in the orientation and generation of polarized light, as well as mode sweeping.</td>
</tr>
<tr>
<td>12 Birefringence of materials</td>
<td>Students become familiar with uniaxial crystals, the extraordinary index of refraction and quarter-wave plates by using birefringence of a material to change polarization of light; students build an optical isolator and polarization rotator.</td>
</tr>
<tr>
<td>13 The Abbe theory of imagining</td>
<td>Students investigate the spatial frequency content of objects and how they could be used to control shape and quality of image.</td>
</tr>
<tr>
<td>14 He-Ne Laser Cavity</td>
<td>Students use MICOS’ state-of-the-art laser education kit to get familiar with optical cavity (confocal cavity, near concentric cavity), to build a He-Ne laser and to optimize its properties (intensity distribution, divergence).</td>
</tr>
</tbody>
</table>
3. PROGRESS

Five students in fall of 2007 and four students in fall of 2008 have successfully completed this course. Out of the nine students, seven were physics majors, one from Chemistry, and one from Biology Departments. After graduation, one of the students from the optics class continued in a Ph.D. program that actively involves optical measurements. The following words are taken from an unsolicited letter from one of the optics alumni: “I think the background and experience I got from your [Optics] course has helped me a great deal both in undergrad analytical chemistry and now as a grad student. Again I think it was an excellent class and highly recommend it to students who have any desire to work with analytical instruments in physics or chemistry.”

3.1 Individual projects

The following projects were completed: restoration of art holograms, interferometric thermometer, interferometric measurement of refractive index of sucrose solutions, construction of a hand-made photodetector, and longitudinal laser modes selection.

3.2 Senior projects

Few examples of senior research projects included in PHYS 492 and PHYS 498 are: Surface Plasmon Resonance (SPR) observation (Fig. 1), Laser pointers in high-school physics education (Fig. 2), Holography (Fig. 3), Diffraction from self-assembled structures of polystyrene microparticles, etc.

Figure 1. Undergraduate student research paper on Surface Plasmon Resonance.
Figure 2. Student research paper on applications of laser pointers in high-school physics education.

Figure 3. Student research paper on spectral calculations for columnar thin films deposited on periodically decorated substrate.
3.3 Lasers and their Application course

A new 400-level course “Lasers and Their Applications” was developed by one of the authors of this paper and was offered in spring of 2009. The main objective of the course was to make students familiar with the basic principles, characteristics and some of the applications of the lasers. The students learn the principles of laser operation, the nature of most common laser systems, feedback systems, resonators, modes, line shapes, broadening mechanism, Q-switching, semiconductor lasers, gas lasers, Dye lasers and some lasers applications. This course provides the foundation for further in depth studies at graduate level in the field of lasers. The details of the course will be published somewhere else.

3.4 Outreach

The successful start of the optics course was reflected in the School of Science and Mathematics PHYSICS Newsletter, fall 2008. The paper includes three pictures from the class of fall 2008 on total internal reflection (Fig. 4), a lecture on interference of light (Fig. 5) and alignment of a He-Ne laser cavity (Fig. 6). The authors of the paper were interviewed by Madelyn Pennino, a journalist at Intelligencer Journal, and the new Optics course was featured in her article “MU’s optics course - a study in success”, Intelligencer Journal, February 2, 2008. The experiments on “Laser Construction” and “Generating Surface Plasmons” performed in the class of fall 2007 were featured at the MU Physics homepage, as the “Experiment of the month”, December 2007 and April 2008, and the optical set-up of a Michelson interferometer from the class of fall 2008 is on the title page of the Physics Department brochure.

In general, most high school students receive little exposure to physics, and, consequently, to optics. As a result, few students are aware of the ample career opportunities in this field. In order to attract the student’s attention to this rapidly evolving discipline, we offer annual summer workshops for high school students. The first, Color Formation, is addressed to 8-9 graders (usually students with no exposure to physics), while the second one Physical Colors targets the junior and senior students (10-12 graders) who may have had taken physics courses. These two workshops are part of the educational and research activities of the Summer Science Training Program (SSTP) held for three weeks on the MU campus for a select group of local and regional high

Figure 4. Project: Total Internal Reflection and Surface Plasmon Resonance.
Figure 5. Lecture on interference of light.

Figure 6. Project: Alignment of a He-Ne Laser.
school students. The new optics course provides new opportunities to enrich the existing workshops and to expand our offerings with a workshop suitable for high school physics teachers.

Another way to promote participation of bright students in optical programs is mentoring high school student research projects. We sustain a continuous collaboration with a physics teacher at the Lancaster Country Day School supervising his student’s projects in optics and helping them to build optical experiments. We introduced the phenomena of surface plasmon resonance (SPR) to him and to one of his students and opened our lab for them to study SPR in porous gold samples [14].

4. EVALUATION

4.1 Assessment of student’s learning

Student’s learning and progress is assessed on a continuous base through the entire course. The continuous screening involves class and group discussions on thought-provoking questions, as the emphases are on student’s misconceptions and experimental missteps. The student’s preparedness and performance is reviewed, and the lab report for each lab experiment is graded on the basis of meaningful quantitative data, as well as qualitative interpretations. Three (two midterms and a final) exams are used for the lecture material. The exams include also questions on the laboratory experiments in order to assess the student’s understanding of the lab procedures and data analysis. The student’s individual work and self learning is assessed via the student’s individual projects and PowerPoint® presentations. The presentations are evaluated based on content, oral delivery, visual aids, and relevance.

4.2 Course evaluation

At the end of the course, students complete a questionnaire on various aspects of the course. Students evaluate their background preparedness for the course, qualitative lap of knowledge, preliminary competency in lab techniques, the effectiveness of the lab experiments and projects, what lab experiments meet the course objectives, the effectiveness of the instructor’s guidance, what should be improved in the lecture and lab portions of the course. The constructive students’ suggestions are the base for changes and improvement of the course.

5. THE IMPACT OF THE OPTICS COURSE

5.1. Undergraduate Research and Training in Optics

The new optics course impacted strongly the department’s advanced lab, undergraduate research and training program. A few research projects in optics were already offered to students for their two-semester senior seminar courses, PHYS 492 and PHYS 498, which are required for graduation for all physics majors. The optics teaching laboratory was incorporated also into the PHYS 451 and 452 advanced laboratories and the department’s undergraduate research. Some of the research projects were already mentioned above.

5.2. The impact on the other departments through the School of Mathematics and Science

The new course has inspired new projects and new opportunities for collaborations, such as the collaborative project between the authors of this paper and six other faculty members from Indiana University of Pennsylvania and Penn State at State College, PA. The course has increased the interdisciplinary work and joint activities among the departments of the School of Mathematics and Science.

5.3 The impact on the department’s curriculum

The Optics course was the basis for offering the course in lasers and their applications in spring 2010, which was already discussed in this paper. A possible advanced course in optics could deal with detailed introduction to basic optical standards and international standardization aspects of optical engineering, and laser safety standards, which will provide insight to terminology, requirements, interfaces, test methods, and product safety, that apply to complete optical systems, devices or components.
With an additional advanced optics course, the Department will be able to offer a new option in BA physics with optics. Therefore, the described efforts will provide new opportunities and enrichment of the already existing two cooperative programs between our Department and The Pennsylvania State University and University of Southern California.

5.4 The impact on the community

The optics course provides the basic resources for both research and training in modern optics. It promotes learning, teaching and training of students, faculty and K-12 teachers. Based on our experience with the course we could offer a summer training workshop for K-12 teachers in the following summers.

Our current percentage of female physics majors is typically between 10 and 20 percent. Most of our female students are enrolled in the BS in Education (Physics) program. Since optics is one of the most demonstrable parts of physics, we believe that the new optics course in combination with the BSE option will attract more female students to the field of physics and physics education.

We regularly host open house receptions for the campus community and students, parents and teachers from the local high-schools. The guests visit our optics laboratory and have the opportunity to speak with instructors and students involved in the optics course and to hear by word of mouth their experiences and future plans.

6. CONCLUSION

A rigorous lab based course in applied optics has been offered for the first time at MU in the fall of 2007. The course is required for BS physics majors, and is open also to all majors from the School of Mathematics and Science, who have met the prerequisite requirements. Enrollment is restricted only by prerequisites and lab equipment limitations. The primary goal of the course is to provide students with the theoretical background and hands-on experiences necessary to enable them to successfully apply optics in their respective majors. Students learn the fundamentals of applied optics through a sequence of hands-on laboratory experiments using state-of-the-art equipment and multidisciplinary individual projects. Because of the hands-on experience requirement the enrollment is limited to maximum 12 students per semester. Initially, the optics course is offered annually. Adapting our educational efforts to the future challenges of our students, college education and training in optics became high priority for the Physics Department at MU.

ACKNOWLEDGEMENTS

We acknowledge the support of the MU Physics Department, as well as the Dean of the School of Mathematics and Science, MU, for his encouragement and the financing of this project.

REFERENCES

[2] Some of the experiments are described on the MU Physics Department’s website at http://muweb.millersville.edu/~physics/
ABSTRACT

The Institute for Optical Sciences at the University of Toronto is an association of faculty members from various departments with research interests in optics. The institute has an extensive program of academic activities, for graduate and undergraduate students, as well as public outreach.

For undergraduate students, we have a course on holography. We provide opportunities for students to gain optics experience through research by providing access to summer research positions and by enrolling them in the Research Skills Program, a summer course teaching the basic skills needed in research.

For graduate students, we offer the Distinguished Visiting Scientists program, where world-renowned researchers come for a week, giving a series of 3 lectures and interacting closely with students and professors. The extended stay allows the program to run like a mini-course.

We launched a Collaborative Master’s Program in Optics, where students earn a degree from their home department, along with a certification of participation in the collaborative program. Physics, Chemistry and Engineering students attending together are exposed to the various points of view on optics, ranging from the pure to the applied sciences.

For the general public, we offer the Stoicheff Lecture, a yearly public lecture on optics, organized with the Royal Canadian Institute. Our institute also initiated Science Rendezvous, a yearly public celebration of science across the Greater Toronto Area, with lab tours, demonstrations, and other opportunities to learn about science and those who are actively advancing it. This year, this event attracted over 20,000 attendees.

KEYWORDS

Undergraduate education, graduate education, experimental methods, research skills, public outreach.

1. INTRODUCTION

The study of optics is a multi-disciplinary endeavour, requiring concepts of Physics and Engineering. Production of optical materials and devices also requires expertise in Chemistry and Materials Science. At the University of Toronto, the Institute for Optical Sciences (IOS) provides a common home for approximately 27 faculty members with an interest in optics from the Departments of Physics, Electrical and Computer Engineering, Chemistry and Materials Science and Engineering.
Besides the research of its individual members, the IOS is active in the following three areas: contract research services for other academic and industrial users; promoting entrepreneurship and transfer of technology, acting as a bridge between university research and the industry; as well as an extensive academic program, which is described in detail below. Over the past 4 years, the IOS has helped launch 8 start up companies and numerous others indirectly through the *Entrepreneurship 101* course we developed that is now independent from the IOS.

The main goal of the academic program at the IOS is to make student education more complete and more efficient by complementing the resources available to students in their home departments. In addition we are active in public outreach, demonstrating the importance of optics and science as a whole to the general public.

2. PROGRAMS FOR UNDERGRADUATE STUDENTS

At the undergraduate student level we focus on accessible methods to teach optics, stimulating the students’ creativity at the same time, and facilitating the students’ access to the research labs.

We have recently introduced a holography course *Holography for 3D Visualization*, as a very visual method to introduce students to the science of optics, and as a bridge between the art and science communities. The course emphasizes both the art and science of display holography, enrolling both art and science students, with collaborating instructors for these components. Besides learning the course material, the two very different groups of students learn to communicate and work with each other on common projects. Recording their own holograms gives students an excellent motivation to study the optics of interference and diffraction, making optics accessible to students who would not normally study it. More details about the course are presented elsewhere.

At a large research university, the academic community divides its time mainly between teaching and research. Undergraduate students are very well acquainted with the teaching aspect, through their courses, but most of them are quite unfamiliar with the research activities. This is in spite of the fact that most professors do work with some undergraduate students in their research projects during the summer. Many students, however, do not know about these opportunities, since they are almost never well announced. At the same time, professors are reluctant to admit a large number of undergraduate students, due to the necessary time investment to make them productive in the labs. We facilitate undergraduate student access to the research labs by responding to both issues raised above.

To reduce the necessary time required, on the part of each professor or senior graduate student, in order to train new students for work in the research lab, we are running a yearly summer course called the *Research Skills Program*. This is a non-credit series of seminars that summer students are encouraged to attend, running from May to mid-August. The goal is to cover the topics that are general enough to be needed by all, regardless of the exact research topic. We start off with a description of the scientific literature, and give examples of how to search it effectively. Then we continue with instructions on how to keep a lab book, the design of experiments, small signal and noise analysis, basic techniques in the optics lab, data analysis and interpretation, and patents. Emphasis in this course is also placed on effective technical communications, both written and oral. We consider the elements necessary to write a scientific paper and to produce a poster. Finally we give students the opportunity to practice formal and informal technical presentations. At the beginning of each class, two students are asked to give an informal 5-minute description of their work. In the second half of the course, students then give two formal presentations, in the style of a conference paper.

We normally get around 25 students attending the course each summer. In the absence of such a course, individual professors or graduate students would have to perform this training in much smaller groups (usually 1 or 2 students). Training in a larger class provides significant economies of scale. More importantly, however, the training is done in a more rigorous fashion, as opposed to the more ad-hoc instructions and explanations that undergraduate students receive from their supervisors. A further advantage is that we form a community among undergraduate students working on research. They are usually the most junior students
in each research group, and may feel overwhelmed and intimidated by the expertise of more senior researchers around them. This weekly course gives them the opportunity to exchange information with other students who are in a similar situation.

In order to facilitate access to the university research for those students who would not normally consider such an activity during the summer, we actively collect and promote research project descriptions. Starting in January and February, we collect from professors project descriptions that are suitable for undergraduate students. The availability of the projects is then announced on-line, and through email to most relevant undergraduate programs. We also collect the student applications and do a first round of screening before distributing them to the individual professors.

In many ways, learning through research, compared to learning in courses, requires a different attitude and skill set. Problems are no longer guaranteed to have solutions. If they do, they may have multiple answers, with no clear choice between competing advantages. Projects can take several years to complete. Our Research Skills Program and related activities are helping students with this change.

3. PROGRAMS FOR GRADUATE STUDENTS

The Institute for Optical Sciences has over 100 graduate students working on a variety of optics-related research topics in the labs of the professors associated with the institute. They are registered in either Master’s or PhD programs in one of the four departments mentioned above. The institute is helping these students by encouraging them to take a more inter-disciplinary approach to their education and allowing them to take credit for doing so; helping them make connections in the global scientific community; helping them take better advantage of the available research equipment; and forming a community among optics students.

In the fall of 2008, the institute has introduced a collaborative Master’s Program in Optics. At the University of Toronto, collaborative graduate programs are offered jointly by several departments. They study topics where no single department has the full expertise. This fits well with the way optics is covered at the university, where the Physics and Chemistry departments focus on the fundamental science of optics, while the departments of Electrical and Computer Engineering, and Materials Science and Engineering study the applications of optics in technology. These are the four departments that offer the collaborative program.

In this program, students first apply and register in their home departments and then additionally register in the collaborative program. Therefore, they must satisfy all requirements of the home program. The requirements of the collaborative program are that the thesis topic must be in optics, and that students take the seminar course Selected Topics in Optics Research. Upon completion, students receive the degree from their home department, with an additional notice on their transcript certifying the completion of the collaborative program.

The course required for the collaborative program consists of a series of seminars and student presentations. The seminars introduce brief practical topics that are useful for work in optics. Examples include best practices in the optics lab; numerical simulation tools for optics and electromagnetism; lens design and optical aberrations; signals and noise analysis. The remaining time in the course is devoted to student seminars. We invite senior graduate students to present their research topics. Given the diverse background of the students in the collaborative program, we keep the presentations to only 10 minutes. During each meeting we have 4 such presentations.

One of the many goals of the collaborative program is to create a community among the optics students at the University of Toronto. Coming from four different departments and two different faculties, these students do not have many opportunities to interact with each other. The collaborative program provides a setting where this can be done effectively. Students taking advantage of the resources available at the Institute for Optical Sciences will be exposed to multiple points of view on optics, and will acquire a more multi-disciplinary education. The certification of completion of the collaborative program gives them credit for this.
To connect the students in the global scientific community, we run a Distinguished Visiting Scientists program. We invite a number of world-renowned scientists to spend a week at the University of Toronto, giving a series of three lectures and interacting with the students and faculty. The extended stay allows the visitors to organize their lectures in the style of a mini-course, providing more in-depth technical detail than can be covered in a simple seminar. During the remaining time, the visitors will have open office hours where students can drop in with questions, and other meetings with graduate students and faculty.

Spending a full week in Toronto makes it possible for students to meet such world-class scientists personally, and to build their connections in the global optics community. Students regularly go to lunch or dinner with the visitors. This is in contrast to the standard 1-hour seminars, where speakers usually do not have time for more than a few meetings, mostly with other professors, and do not have much time to devote to graduate students individually.

One of the biggest challenges awaiting junior graduate students is the large number of instruments and experimental techniques that they must master in order to complete their work successfully. While some of the most common instruments and techniques are covered in undergraduate courses, most are never taught formally. Expertise is acquired slowly, from discussions with more senior students, and is often incomplete. Most standard graduate courses do not usually cover experimental techniques either, instead focusing on in-depth theoretical studies. This lack of familiarity with sufficient experimental methodologies increases the time to graduate and can often mean the difference between solving a problem or not. To help students acquire the necessary experimental skills of a successful optics researcher more quickly, the Institute for Optical Sciences together with the Department of Chemistry have launched a laboratory course, *Advanced Experimental Methods: Optics to Electronics*. The course is divided into three modules.

The first module consists of lectures complemented by simple experiments and measurements. Students learn how to use the standard data collection instruments, such as lock-in amplifiers and boxcar integrators, as well as an introduction to signal and noise analysis. They then perform various measurements of thermal and shot noise, and collect weak signals from a noisy environment. In the lectures on optics we cover topics on light sources and detectors, optical beam propagation and collection systems, along with standard techniques in spectroscopy, etc. Students practice by setting up spatial filters and interferometers, collecting fluorescence signals, and others.

In the second module, students are assigned projects that they must complete using the parts provided. Examples include assembling an ellipsometer from standard optical components, assembling a confocal Raman spectrometer, and setting up dynamic light scattering measurements. Here we encourage students to find the best solution by themselves with minimal guidance. As opposed to standard undergraduate laboratories, students must determine themselves the detailed procedure to follow. Some of the experiments are open-ended, with students encouraged to explore as many options as possible.

The remaining portion of the course is devoted to entirely open projects, where students propose an experiment and carry it through. The goal, again, is an independent exploration of various experimental techniques. Some students attempt to duplicate a complex setup from the recent literature. Others attempt new variations on existing techniques. During the last week of the course, students give presentations on their results. Examples of student projects are: building an optical parametric amplifier, measuring thermally-excited capillary waves, stabilizing an interferometer using a feedback loop and a piezo-electric transducer, or building an organic light-emitting diode.

4. ACTIVITIES FOR THE PUBLIC

In addition to the programs organized for our students, we organize two yearly events for the scientific literacy of the general public.

We organize the *Stoicheff Lecture*, named in the honour of Professor Boris P. Stoicheff, a preeminent spectroscopist. This is a one-hour public lecture on a particular topic in optics, delivered for the general public
by one of the experts in the field. The event is organized every December, in collaboration with the Royal Canadian Institute, the oldest scientific organization in Canada, and attracts an attendance of approximately 400.

The Institute for Optical Sciences also initiated *Science Rendezvous*, a yearly public celebration of sciences in Toronto. Its main goal is to help the public see the importance of science, and to serve as a culture transformation from a science averse society to one that actively embraces the sciences. The event now has the support and participation of most universities and research institutions in the Greater Toronto Area. Each institution organizes public demonstrations and hands-on activities, lab tours, and others. To gain some appreciation of the potential and impact of this event, see www.sciencerendezvous.ca.

At the University of Toronto, a number of science and engineering departments participate actively. Some of the optics-related exhibits and demonstrations are as follows: a show of holograms, ray and lens optics, spectroscopy of various light sources, laser shows, polarization and birefringence, index of refraction and index matching, gelatin optics and total internal reflection, optical communications, liquid crystals. Additionally, a number of optics-related challenges and puzzles were set up for the public. Among them were a laser beam security and alarm system and a hologram containing hidden information, as part of a competition set to emulate saving the planet – of course through the proper use of science.

In May of 2009, the event attracted 10,000 attendees at the University of Toronto, and 20,000 in the Greater Toronto Area. Beside the direct benefit of allowing the public to see and learn what goes on at their local universities, the event gave several hundreds of student volunteers the opportunity to showcase their work and to demonstrate their enthusiasm and excitement for science to a very wide audience.

5. SUMMARY

The Institute for Optical Sciences at the University of Toronto organizes a number of programs and activities designed to complement the courses and research performed in the departments of Physics, Electrical and Computer Engineering, Chemistry, and Materials Science and Engineering. Various programs are targeted at University students at all levels, ranging from introductory optics courses at the undergraduate level, to advanced experimental techniques at the graduate level, along with means to connect the students in both their local and global community. Additional programs aim to improve scientific literacy among the general public. Together, these programs improve the student experience at the University, and make students more efficient in their work, both now and in the future.

REFERENCES


A Holography Course in Toronto

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ABSTRACT

Holography is one of the most intuitive methods to teach optics, covering many concepts of introductory optics courses, in a visual manner. At the same time it provides a bridge between sciences and art.

For these reasons, the Institute for Optical Sciences at the University of Toronto in collaboration with the Ontario College of Art and Design (OCAD) has started an undergraduate course on holography. This course is unique from a number of perspectives. It is a collaboration between two Toronto post secondary education institutions. Also, it enrolls both science and art students, and teaches both the artistic and scientific aspects of holography. Besides the direct learning outcome of the course material, an equally important gain is for art and science students to work together on projects, learning from each others’ strengths.

The course is completely hands-on, with students given individual access to the holography studio (under the supervision of a teaching assistant) to complete the required projects in the course. The projects are complemented with lectures that cover the necessary concepts in holography, such as wave propagation, interference and diffraction. The students also receive an introduction to other uses of interference and diffraction. Since the course is taken by art as well as science students, the lectures are delivered very conceptually.

Students produced some stunning holograms as part of their projects and rated the course very positively with enthusiastic reviews.

KEYWORDS

Holography, undergraduate teaching, art and science, 3D visualization, computer graphics.

1. INTRODUCTION

Holography, as proposed in 1947 by Dennis Gabor, is the method of recording three-dimensional (3D) images with full parallax in a two-dimensional (2D) film. Even though holograms can be used to record very striking images, they are not well-known or understood outside the optics community. In addition, holography can be used to perform very high-precision measurements of mechanical strain and vibrations.

Holograms rely on the wave-nature of light. Recording of holograms involves interference between two light beams, with the resulting standing wave interference pattern recorded in holographic film as a diffraction grating. Playback of the resulting hologram happens through diffraction. Light diffracts off the periodic pattern recorded in the film, and “bends” to form the holographic image. Since the diffraction grating can be represented with a grating vector equal in magnitude to the difference in wave vectors of the two initial interfering waves, the grating will recreate all original rays of the image. In particular, the recording is done with a reference beam striking the holographic film directly, in addition to the light scattered by the object, with
the interference between these two beams forming the diffraction grating. For playback, a beam coming from the same direction as the original reference beam will diffract to recreate the original object. We can therefore assume that the hologram acts like a window with memory: during recording, the film records all rays traversing it. During playback, it recreates all these rays, in their original directions. Therefore, the object is reproduced at the original depth with full 3D information. Since the main phenomenon is the formation of standing waves, the interfering waves must be monochromatic sinusoids of a defined phase, and holograms are most easily recorded with coherent light produced by a laser.

As summarized above, holography involves most of the important concepts of optics and electromagnetism that are normally covered in undergraduate courses. This includes wave propagation, interference, diffraction, colour perception, optical coherence and laser operation. These concepts make holography a natural medium for the hands-on teaching of optics.

At the same time, holography is a very rich artistic medium, stimulating the creativity of art students. Owing to its recent introduction and stringent requirements, it is not as widely explored as some of the other new media. The combination of full parallax, along with the ability to record both virtual reality and real subjects gives considerable freedom.

Based on these unique properties, our goal is to use holography as a multi-faceted teaching tool of both science and art. Half the class is composed of science students, while the other half is composed of art students. The material covered and marking scheme employed is also divided between science and art. Two instructors are needed for these two components. As a result, our course teaches optics in a very hands-on and accessible manner to scientists and non-scientists alike, making this very important but not well-understood science available to a larger number of students. Of equal importance, however, the course teaches science and art students to work with each other and to learn from each other. Science students are required to take non-science breadth requirements, and art students must have a few science credits. These requirements, however, rarely lead to collaboration and dialog between these distinct student communities. Quite often, the courses offered as science credits for non-science students are not the same courses that students with science or engineering majors take, and the communities remain separate.

Our course, therefore, emphasizes and requires collaboration between art and science students. Projects are done in groups of two students. They require both an understanding of the physics of holography, and also an artistically creative concept for the subject to be recorded. Students are encouraged to form the teams with one art and one science student. They will then help each other, and learn from each other, establishing a very fruitful dialog between these two, normally separated, groups.

As mentioned above, holography involves concepts of interference, diffraction, optical coherence and lasers. Normally, these are taught in a very mathematical way, with the help of many equations. Given our diverse student background, however, we cannot use this standard approach in this course. Instead we teach these topics very conceptually, relying on the hands-on work in the lab and on geometrical constructions instead of the typical mathematical abstraction. This turns out to be one of the most challenging aspects of teaching the course.

The course, called *Holography for 3D Visualization* is one of several educational activities of the Institute for Optical Sciences. It was offered for the first time at the University of Toronto in the spring of 2008. In the spring of 2009 it was offered in collaboration with the Ontario College of Art and Design, which was responsible for the art component of the course, while the science component was delivered by the University of Toronto. The course is 13 weeks long, as is typical of our half-courses. It includes class-room lectures, lab demonstrations, computer labs for the production of 3D computer-generated images and projects for students to produce their own holograms. These are described below.
2. LECTURES

The lectures run for two hours per week, covering general concepts of optics, detailed concepts of holography, the history and art of holography, as well as the necessary concepts of laser safety and other areas of application of the concepts that students have learned.

The first lecture serves as a motivation for the course. Since few students have seen holograms before, we include a small in-class exhibition, with both professionally made holograms and student work from past years. Topics discussed include early studies on visualization, the history of holography, as well as opinions of artists in holography regarding the unique features of this artistic medium.

In the labs, described below, students will be using a Class IV laser, which poses significant dangers especially for eye safety. It is therefore mandatory that all students undergo laser safety training. This is the topic of the second lecture. The training is done by the University’s Laser Safety Officer. This is the only course at the University of Toronto where students are required to work with lasers above Class II. Therefore, a special training package was developed for this course, based on elements of the standard training course for researchers who use lasers in their work. This is a compulsory lecture – for safety reasons, those who do not complete the training are not allowed to continue in the course.

The following two lectures are devoted to general topics in optics that are necessary for holography. These are: ray and wave optics; interference and diffraction; polarization of light; light emission and lasers; coherence. Given the diverse student background, we teach these in a conceptual manner, with equations reduced to a minimum. At the same time, we emphasize the understanding of the underlying physical concepts. For interference and diffraction, however, we found equations to be essential. Since these phenomena are at the core of the recording and reconstruction of holograms, we need to be able to calculate angles and wavelengths correctly.

With a solid understanding of interference and diffraction we are now ready to apply them to holography. We first prove the following: If two plane waves \((a\) and \(b\)) interfere and the resulting standing wave pattern is recorded in holographic film we form a diffraction grating. After development we place the film back in the original position, and continue to shine wave \(a\) on it. This wave will diffract into wave \(b\). Alternatively, we can shine wave \(b\) onto the film, which will diffract into wave \(a\). We can then repeat this procedure with wave \(a\) as before, but wave \(b\) as a superposition of many rays that form a complex image. After recording, as long as we can recreate wave \(a\) in the original direction, it will diffract into the many rays \(b\) that form the image. This leads to the conclusion that the hologram is a window that records all rays going through it, and plays them back in the original position and direction. With this concept, questions regarding the recording of holograms can be reduced to geometrical optics problems, with relatively simple solutions.

We can now explore the different kinds of holograms, explaining the difference between master and transfer holograms, reflection vs. transmission holograms, and the various techniques to obtain white-light-viewable holograms. These concepts are very easily understood at this point, since the students have already seen how such holograms are recorded in the lab, and can link the lab experience with the theoretical explanations in the lecture.

The next topic to be discussed is the chemistry of holographic film and the development process. Here we connect to the chemistry of photography, which is very similar, given that both processes use silver halide emulsions. We also introduce non-silver processes for holography, with their advantages and disadvantages.

The remaining topics in holography are the production of holograms from digitally created computer graphics and colour in holography. Both are required for the later lab demonstrations and student projects. We discuss how to record master holograms from computer graphics as an extension of the multiple channel hologram, with many channels. We also mention alternative techniques such as the direct-write technique printing individual pixels (hogels) in the hologram, avoiding the master-transfer process. For the recording of holograms in full colours we discuss briefly the technique of recording holograms with 3 laser colours.
simultaneously, and the pre-swelling of emulsions with triethanolamine. We focus, however, on the full colour white light transmission hologram, since this will be used by students in their projects.

The lecture on digital and colour holography is complemented by a lecture on human perception of depth and colour. We discuss the clues used in human vision to give depth-related information. For colour perception, we describe the physiology of colour vision, along with its defects, and the various methods to quantize colours.

To close up the discussion of holography we describe other scientific uses of this phenomenon. We include holographic measurements and non-destructive testing, as well as applications in data storage, medicine and security. We also introduce emerging trends in holography. Finally, we discuss other areas of optics that are now accessible to our students, after acquiring an in-depth practical understanding of interference and diffraction. We discuss interferometers and their use in precision metrology, the operation of fibre Bragg gratings and their importance in fibre optic networks. As another example of interference, we describe the production techniques for fibre Bragg gratings.

3. LAB DEMONSTRATIONS

A very important aspect of our course is the hands-on approach to holography in the lab. Students assist in the recording of several holograms before we consider their theory in class. This serves as excellent motivation for the lectures. The lab sessions are 3 hours long, and are run roughly every second week.

The lab is equipped with a vibration-isolated table of 120 by 240 cm and a 1-Watt 532-nm continuous wave laser. We use a number of 1-inch mirrors to steer the beam. As beam expanders we use microscope objectives with spatial filters. To steer and collimate the expanded beam we use large-area (25 cm) flat and concave mirrors. In addition, for the recording of digital holograms, we have a laser screen and a moving slit assembly, both controlled by a computer. The laser screen uses the Liquid Crystal component of an LCD monitor, without its enclosure and with the backlight removed. It serves to place an image on the laser beam. The moving slit assembly serves to only expose a small area on the master plate, resulting in a multiple channel hologram with up to 150 channels. With such a high number of channels, the parallax of individual channels becomes unimportant and we can use the 2D image on the LCD screen as the subject. Half-wave plates are used to compensate the polarization of the laser beam after passing through the LCD screen. The holograms recorded in the labs measure 20 by 30 cm in size. This is a size that is compact enough to handle on the optical table described above, yet is large enough to accommodate the subjects that most students choose.

The first 3 meetings in the labs are devoted to the recording of holograms from real objects. We start with 3 small demonstrations of a transmission master hologram, followed by reflection and rainbow transfers, to show the simplicity of the process. In the following weeks we record again reflection and rainbow holograms (along with the requisite master holograms) this time focusing on the visual aspects and quality of the hologram. These holograms will be the subject of the students’ first project. As is typical in holography, the largest amount of time is spent setting up the table for each shot. We do this as a group activity, with the students taking turns aligning the various components.

The remaining two meetings in the labs are used for digital holograms. We start with a monochrome reflection hologram, to introduce students to the operation of the moving slit assembly, looking at how this process can be understood as an extreme version of a multiple-channel hologram. Because of time limitations in a 3 hours session, part of the table is already set up before the students arrive. Students are invited to provide their own digital files for this demonstration. In the last lab meeting, we record a white light transmission full colour hologram, as described in the lectures. Here again, we cannot perform all the steps during the lab session, and must prepare the master plate ahead of time.
4. COMPUTER LABS

For the second half of the course, the lab demonstrations and project focus on the recording of digital holograms from computer sources. This is a relatively new use of holography, which gives considerable freedom compared to the standard use of holography from real objects. Some of the advantages are: We no longer need to bring the subject to be recorded into the studio – all we need are the digital files. Also, we are no longer limited to life-size copies of real objects. Instead, we can represent subjects of any size. Finally, we are no longer limited to static objects. We can introduce motion in our subjects. In fact, digital holography opens the door to completely abstract subjects.

There are many ways to produce the necessary graphic files for digital holography. We use Autodesk 3DSstudio Max to compose the subjects for our digital holograms. This software, used mainly for 3D animation, is able to provide the correct view of a scene from any given angle, while also allowing for motion of the subjects. With this program we can define the scene with three-dimensional detail for the placement of all elements. We can compose the scene elements ourselves, from geometrical shapes, or we can use pre-made models for many types of subjects: people, animals, furniture, plants, etc. The resulting scene is exported as a stack of 2D images, representing the view from the different angles of the hologram.

Since most students do not have experience with 3D graphics and animation when taking this course, we provide computer lab sessions for them to learn this software. These sessions take place during the lab times, in weeks when no lab demonstrations are scheduled. Students start with very basic 3D graphics task, and then focus on the subject necessary for the production of the necessary files for their project.

3D computer graphics are used much more widely than in holography. The techniques learned here can also be used for video animation in other fields.

5. STUDENT PROJECTS

During the course, students are required to complete two projects. The main part of each project is the production of a hologram with a meaningful artistic content. As mentioned above, students work in teams of two, and are encouraged to form the teams with one art and one science student. These are the major hands-on activities of the course, where students do most of the work themselves.

Since students do not yet have the necessary experience to decide what subjects will not work for holography, they must first submit a proposal describing briefly the contents of the holograms and the motivation for choosing this subject. Examples of the pitfalls we try to avoid are: Subjects that emit light, such as candles or computer screens; subjects that will vibrate during the exposure; subjects that will deform during the exposure, for example due to evaporation; subjects that are too big for our holographic plates, since real object holography does not allow a change in size; subjects that give specular reflections of light onto the holographic plate. At the same time, we use the proposals to evaluate and give feedback on the artistic content, since this will be a large part of the evaluation. This is especially important since many of the students have not been evaluated on artistic creativity before.

Due to laser safety concerns and the complexity of recording holograms, the students are not allowed in the holography lab without supervision. They must reserve a time slot in the lab ahead of time, and at the same time book an appointment with the teaching assistant. The teaching assistant will make sure that most common problems resulting in defective holograms are avoided. As with other artist materials, students must buy the holographic plates that they use. Since there are few local suppliers of holographic materials, however, we provide the plates to the students.

Once all holograms are produced, we organize a critiquing session in the following lecture time. Students present their holograms to the entire class and receive constructive comments from their colleagues. The critique sessions become a highlight of the course, allowing students to celebrate their work and their results.
After the critiques, students are allowed to take the hologram home. In these sessions students present surprisingly successful holograms.

The first project involves real object holography. Students are required to produce either a reflection or a rainbow hologram. They will prepare the materials to be recorded ahead of time, and will bring them to the lab for shooting. Most students have spent considerable effort in selecting and building the correct composition for their project, a direct manifestation of the enthusiasm for the course. The biggest challenge here is to ensure that the subjects will not vibrate during exposure.

The second project for the students requires a full-colour digital hologram. Students prepare the files ahead of time, and submit them by the appropriate deadline. Since the process of recording the master holograms is quite time consuming and very mechanical, all master plates are recorded by the teaching assistant. Students are only involved in setting up the table for this purpose. When recording the transfer, however, students must determine the correct colour balance. Therefore, they will record this hologram themselves, under the supervision of the teaching assistant, as for project 1.

6. STUDENT EVALUATION

Evaluation of students in this course is trying to achieve a balance between the science and art components and also to encourage students to keep up with the lecture material. For the scientific aspects we have 3 assignments, based on lecture material, along with midterm and final examinations. Artistic aspects are tested with some questions on the midterm and final examinations, but mainly through the two projects. Here we consider three components: the proposal, the concept and premise for the hologram, and the execution of this concept.

7. CHALLENGES

In the introduction of this new and unique course we had to overcome a number challenges. The most important are mentioned here. Most of them are due to the combination of art and science into one course, and to the very hands-on nature of our approach.

When delivering the lectures, the biggest challenge was to present the material in a manner that is engaging and stimulating for both groups of students, even though these groups have very different backgrounds from previous courses and from personal interests. The science components need to be taught in a way that is challenging enough for science students, yet still accessible to art students. The same also holds for the art components. A related problem is that of student evaluations, especially when it comes to science questions. Science students have taken many more quantitative tests in the past, and are used to difficult questions that must be solved mathematically under time pressure. This is, however, not usual for art students. As a result, we avoid questions involving mathematics on the tests. Instead we focus on the conceptual understanding of the material.

A second set of challenges came from the complex equipment needed for holography. Due to cost, size and the requirement to work in a dark room, we can only have one holographic setup available, and students must take turns. Also, students can only work when the teaching assistant is available, which requires considerable time flexibility on the part of the assistant. Even though all students have the same deadline, some must record the hologram much earlier than others, since work cannot be done in parallel. Limited time slots in the lab also mean that students do not usually have the opportunity to retry a hologram, something quite unusual for the production of art: the hologram is recorded on the first try, and is presented as is. There is usually no time to correct minor problems. This also means that students only get one hologram, even though they work in groups of two. Most of the time both group partners would like to get a hologram. Additional copies of these holograms are recorded during the summer, when more time is available.

Finally, the cost of such a course must also be considered. The equipment used here is not usually seen in an undergraduate laboratory. The need for individual supervision of student work means that the class size must
be limited to a number much smaller than is typical for a second year course. This, however, means that students will have much more direct contact with the instructors, something of great value with today’s very large lower year classes.

8. OTHER STUDENTS INVOLVED IN HOLOGRAPHY

The entire holographic setup described here was assembled, tested and fine-tuned by a number of undergraduate students working at the Institute for Optical Sciences during the summers, since 2006. Since our holographic equipment is custom-made in house, the students had the very challenging task of making sure that everything works correctly. These students acquired not only a very deep understanding of optics and holography, but also problem-solving, debugging and time-management skills. Working closely with other students and staff, they were introduced to the University’s research activities, something that most undergraduate students do not experience. Most of these students are continuing to graduate studies in engineering or science.

9. CONCLUSIONS

In the course Holography for 3D Visualization, we have used the topic of holography to deliver a student experience that is unique from many points of view. We teach optics to undergraduate students with hands-on activities. By allowing students to record their own holograms, we provide an excellent motivation for students to learn optics and the properties of light, especially the phenomena of interference, diffraction, coherence etc. More importantly, however, we use holography to bridge the very distinct science and art student communities. The class has both science and art students and teaches both science and art. The very diverse student background provides a very rich learning experience with students learning both from the instructor and from each other. Art and science students working in teams to solve problems that involve both artistic and scientific challenges allows students to form a dialog with each other, and to learn each others’ strengths.

The course has now been offered for two years in a row. The holograms produced by students as part of their projects are stunning, both visually and conceptually. In both years, the course received unanimously positive reviews form students. The undergraduate students appreciated especially the opportunity to work in an optics lab, and the freedom to record their own holograms. Science and art students had surprisingly similar feedback at the end of the course. The student response to this course shows that there is a real need among undergraduate students for courses that emphasize hands-on work, and direct contact with the instructors and teaching assistants.

REFERENCES


**You can achieve anything - with a Laser**

*Ingenuity in the Design of the Impossible*

**Ray Davies**

Photonics Academy at OpTIC

**Abstract**

In the area of Photonics Research as to what can be achieved with Low Power Photonics Sources, such as a Class 2 HeNe Laser, a Laser Diode, or an ultra high intensity LED, the Photonics Academy at OpTIC possesses a highly impressive array of functional Prototype Designs. Each of these visually attractive Prototype Designs illustrates the Ingenuity in Design that has been achieved by students, in the range of 15 - 25 years of age, who have been engaged in personal opportunities to Investigate the potential application of Photonics concepts to, and within, a whole range of highly Innovative outcomes, that are clear demonstrations of many students’ individual Originality and Ingenuity in creating new ideas for the application of Low Power Photonics Concepts.

This Paper will highlight some of the highly Perceptive Prototype Design achievements of students in the application of Photonics principles, with these applications ranging from the Use of a Laser to identify the Letters of a Word in an ordinary book before translating them into Braille for a Visually Handicapped person, to the transmission of audio information over a distance; from a Book Page turning device for a paralysed person, to a pair of Laser Activated Mobile Feet; from a Mobile Guide Robot for a Blind person, to a five-Laser beam Combination Lock for a high Security application; from a Laser Birefringent Seismograph, to a Laser Speckle Activated Robotic Hand; and many, many more. All of the many functioning Prototype Design ideas that will be demonstrated have one characteristic that is common, namely, they are all designed with the intention to help improve the day-to-day experiences of other people, especially those who are impaired in some way. One of the most interesting challenges that can be presented to students is to apply Low Power Laser Photonics to help any visually impaired person within a whole range of activities, and several of the Prototype Designs will illustrate that particular type of student Ingenuity and Achievement via Perceptive Knowledge in Photonics.

**Key Words:** Achievement, Design, Data, Empirical, Imagination, Impossible, Information, Ingenuity, Insight, Investigative, Perceptive, Photon, Prototype, Op-Amp, Optoelectronics.

**Presentation**

1 **The importance of demonstrating visually attractive Photonics Concepts to students.**

The Following Photonics Concepts, and a small selection of Prototype Designs (all constructed by students), will be demonstrated:

1.1 Twin Linear Ronché Gratings and Moiré Fringes.
   1.1.1 PowerPoint demonstration of the effect of relatively changing the angle between two sets of Ronché Gratings.
   1.1.2 PowerPoint demonstration of the effect of the relative vertical displacement of one Ronché Grating with respect to the other stationary Ronché Grating.

1.2 Twin Circular Ronché Gratings and Moiré Fringes.
   1.2.1 PowerPoint demonstration of the relative horizontal displacement of one Ronché Grating with respect to the other stationary Ronché Grating.
   1.2.2 The optical analogy of Young’s Double Slit Interference Fringes.

1.3 Green Laser and x-y cross Diffraction Gratings.
   1.3.1 The 2-D images of multiple Laser Dot pattern with one x-y cross Diffraction Grating.
   1.3.2 The 2-D multiple Laser Dot pattern with two cross Diffraction Gratings – one rotating.

1.4 Laser Diode and Multimode Fibre Optic Laser Speckle.
   1.4.1 Audio demonstration of the changing optical fibre Laser Speckle pattern.
   1.4.2 Student Prototype Design for an innovative new Seismograph.

1.5 Automatic LED Oscillation Counting Device.
   1.5.1 Counter for oscillations of a cantilever over 1 second.
   1.5.2 Counter for oscillations of a cantilever over 4 seconds.

1.6 Five-Laser Beam Combination Lock.
   1.6.1 Five-Laser Beam sequence = x x x x 4.
   1.6.2 Alarm activated is 4 appears anywhere before final figure.

1.7 Laser and Fibre Optic Activated Robotic Hand.
   1.7.1 LED Activation by Control Hand.
   1.7.2 Opening and closing of Robotic Hand Fingers.
1.8 Laser Diode Diffraction Activated Robotic Finger.
1.8.1 Motion of Control Finger.
1.8.2 Replication of Control Finger Movement in Robotic Finger.

1.9 Light Seeking Mobile Robots

1.10 Laser Activated Mobile Feet

1.11 Laser Speckle Eye-sight Test

1.12 Blind Person’s Tea Cup Level Sensor

2 Additional Prototype Designs

Additional Prototype Designs may be viewed, by appointment, in visiting Unit 1, off The Street in OpTIC

3 Ingenuity in the Design of the Impossible

In the Photonics Academy at OpTIC, students are always asked to select one response from the following sequence of three questions:-

3.1 Who likes doing things which are – easy?
3.2 Who likes doing things which are – difficult?
3.3 Who likes doing things which are – impossible?

In the Photonics Academy at OpTIC, all the highly innovative Prototype Design outcomes materialize from a starting point that initially seems to be impossible. The impossible nature of the final outcome is always emphasized to the students, at the start of any Laser Photonics Design opportunity, and the ensuing challenge of attempting to achieve the impossible holds a great attraction for most students.

Impossible outcomes are purely outcomes that just remain in the future. When students are encouraged to focus their attention on to a specific Photonics concept, together with the “impossible” challenge of how that Photonics concept might be used for the benefit of Mankind, most students’ imaginative thinking seems to be activated to a very perceptive level of original analysis. Young students really do appreciate an opportunity to become involved with the focused engagement of their imaginative thinking, when they realize that any Prototype Design outcome, which they may devise, also may be of benefit to Mankind.

The achievement of the impossible simply means drawing the “impossible” future towards the “possible” present. This transitional drawing of the “impossible” future into the “possible” present always requires the gathering of the empirical evidence, through very precise and specific investigative observations. Once the investigative observations have become evident, an accurate analysis of the implications of all of the empirically acquired evidence quickly leads any student towards a realization that the “impossible” future is not all that far into the future, and that it is possible for such a student to reach out to grasp the “impossible” future, and then begin to draw the impossible towards the possible.

The essential ingredients of Perceptive Knowledge are Insight, Imagination, and Ingenuity, all of which qualities are forward looking characteristics of a well motivated, and an inspired, student.

In the experience of the Photonics Academy at OpTIC, to focus the attention of a student on to a specific Photonics concept, and then to offer that student an opportunity to achieve an impossible outcome that will be of benefit to Mankind, really does inspire a student to want to learn, want to acquire perceptive knowledge, and want to apply that knowledge to a highly innovative new application of that Photonics concept.

The creation of imaginative Prototype Designs from within Photonics certainly does inspire students towards a desire for an acquisition of knowledge which is both perceptive, as well as useful.

7 Conclusion

Perceptive Empirical Design enables students to achieve quite outstanding and impressive changes within Science, through their personal Ingenuity of the Design of the Impossible.

A student’s sense of Personal Achievement in developing an innovative and valuable Prototype Design, through his, or her, Ingenuity of the Design of the Impossible is of a very high quality factor.
The Concept of Perceptive Empirical Design

You can achieve anything - with a Laser

Ingenuity in the Design of the Impossible

Ray Davies

Photonics Academy at OpTIC

Abstract

In devising an effective approach for the Presentation of Information Data to any group of students, it has to be anticipated that the particular Style of Presentation that is chosen for conveying the new Information Data will influence the ensuing level of stimulation of the Response from each student. New Information Data forms the foundations for new Knowledge, but the ideal purpose of any Presentation is to promote the acquisition of Perceptive Knowledge. Any endeavour to promote Perceptive Knowledge involves considerably more cognitive processing procedures than just the initial delivery and reception of new Information Data. It always is necessary to activate the Awareness of a student as to the Usefulness of any Information Data which is being drawn to their attention for the first time. The Style of Presentation needs to bring into sharp Focus specific characteristics in the communication procedures that illustrate the Significance, the Relevance, and the Intrinsic Value of the new Information Data. However, the real importance of new Information Data lies less in the actual content of the Data itself, and much more in the Implications which are consequential to the existence of that Information Data.

This Paper will highlight an approach for the Presentation of Photonics Information Data in such a way as to augment a student’s acquisition of Perceptive Knowledge, by the provision of a coincident forum for Photonics Investigations, with the student’s own Imagination, Insight, and Ingenuity then being integrated with the Empirical Evidence to arrive at a proposal to create a new Prototype Design Idea. In providing opportunities for a student to create a highly Innovative Prototype Design, such a student’s attention is focused on the Usefulness of the original Information Data, challenged by the potential applications of the Information Data within an Investigative environment, and made aware of the impressive outcomes that are the result of Ingenuity that is prompted by a Design encounter. In such a Learning approach, a student is certain to acquire Perceptive Knowledge.


Presentation

1 The importance of an appropriate Light Sensing System

When the Photon energy from a source of Light is incident on the surface of an object, complex quantum state attenuations occur between the incident Photons and the orbital electrons of the surface material atoms, with one consequence being that some of that incident Photon energy subsequently is scattered outwards from that surface. Through these surface quantum interactions between the orbital electrons and the Photons, this scattered Photon energy has been encoded in such a way as to carry new Information Data away from that surface.

This scattered Photon Energy, which now has become encoded with new Information Data, carries that Information Data in three distinct categories, namely:-

- **Category 1**: The Intensity and Brightness characteristics of the scattered Light Energy Photons;
- **Category 2**: The Colours and Wavelengths characteristics of the scattered Light Energy Photons;
- **Category 3**: The relative Phase and Emission characteristics of the scattered Light Energy Photons.

To acquire any useful, and valuable, interpretation of this scattered Photon Information Data, an appropriate sensing system needs to be set up to receive this scattered Light Energy Photon Information Data.

When connected to suitable Optoelectronics circuitry, a Photodiode certainly will respond to the Category 1 Information Data. The human eye, and cameras of all types, normally will respond to both Category 1 and to Category 2 Information Data, whereas photographic Holography encompasses the Light Energy Photon Information Data from Category 1, Category 2, as well as Category 3.

In the Prototype Design work of the Photonics Academy at OpTIC, the first emphasis for students is always placed on their construction of a versatile Optoelectronics sensing system, normally incorporating a Photodiode, to detect the Category 1 characteristics of the Light Energy Photons. Since Low Power Laser Beams are normally being considered, Category 2 is not often an essential consideration, and the coherent nature of the Laser Beam Photons provides a useful opportunity for Category 3 characteristics to be merged into Category 1 characteristics, through the effectiveness of the frequently encountered Interference Patterns. Hence, to achieve a really effective outcome from any Prototype Design, a well designed Category 1 sensor is perfectly adequate for students to create.
2 The Photodiode and Operational Amplifier Circuit

The basic Optoelectronics circuit which is used within the Photonics Academy at OpTIC is shown below, for use with a TSL 250 (visible) or TSL 260 (Infrared) series of Photodiodes.

![Circuit Diagram]

Fig 1 – TLS Photodiode with Additional Variable Gain Operational Amplifier

The above circuit provides a variable Gain Output of up to 20 from the output of the Operational Amplifier. By changing the variable resistor Feedback value used in the above circuit, with the resistance ranging from 5kΩ to 1MΩ, a whole array of bright to even very low levels of Light Intensities can be detected. This circuit is extremely versatile, for it can be used to detect steady, as well as slowly changing, mainly d.c. potential differences, or, if the Pin 3 Input signal is applied through a capacitor, rapidly changing a.c. potential differences can be detected, dependent upon the selection of an appropriately fast response Photodiode.

3 The Concept of Perceptive Empirical Design

When the above Category 1 Light Energy Photon Information Data sensor has been constructed, tested, and its full range of versatility investigated by the students of the Photonics Academy at OpTIC, they are then in a position to commence their Perceptive Empirical Design, which eventually always leads to an Innovative Prototype Design outcome.

There are 10 Phases to the Concept of Perceptive Empirical Design, all with a strong focus on student investigations, student observations, and student imagination. Several years of experience in developing the Concept of Perceptive Empirical Design has provided a great deal of evidence to support the recurrent theme that students frequently do reveal imaginative Ingenuity in the Design of the Impossible.
Flow Diagram for the Concept of Perceptive Empirical Design

1 Laser Photonics Parameter Concept
   Visual Evidence
   Information Data

2 Information Data Implications
   +
   Imagination + Insight + Ingenuity

3 Investigative Scientific Method + Empirical Evidence

4 Discovery of New Information Data
   +
   Complications

5 Injection Tutorials
   +
   Quanta of Information Data + Implications

6 Design Specification + Model
   Optoelectronics + Optics
   Logic Control Brain
   Structural + Tweakability
   Reality Interface

7 Photonics Involvement
   Photonics Beam
   Beam Attenuation
   Beam Sensors

8 Initiative
   +
   Imagination + Insight + Ingenuity

9 Assembly
   +
   Test Procedures + Oversight Location

10 Perceptive Knowledge Achievement
   +
   Prototype Design
   Final Outcome Report and Presentation
5 The Effectiveness of Perceptive Empirical Design

In 1925, Sir J J Thomson (Awarded a Nobel Physics Prize for the Discovery of the Electron) said:--

"The Study of Light has resulted in achievements of

**INSIGHT**

**IMAGINATION**

and

**INGENUITY**

unsurpassed in any field of mental activity".

If students are encouraged to achieve personal qualities of **Insight, Imagination, and Ingenuity**, through the medium of Photonics, then any Educational Initiative that places Photonics clearly in the focal plane of any opportunities for students to become personally involved with empirical investigations and observations within Photonics is sure to inspire students towards their own personal desires to acquire perceptive knowledge.

Since 1994, a large number of 14-24 year old students, working with a very similar approach to the Perceptive Empirical Design techniques now used in the Photonics Academy at OpTIC, have designed and constructed well over 200 highly innovative and novel Lower Power Laser Photonics Prototype Design Projects, all of which use Photonics concepts in highly imaginative ways. Many of the students who have been introduced to Perceptive Empirical Design opportunities have been inspired to move towards higher education studies in academic disciplines of Science, Engineering and Medicine, which is evidence of some importance.

Two very frequent responses from Sixth Form Advanced-Level students, who have been introduced to the Teaching technique of Perceptive Empirical Design, have been:--

"Now I know about Photonics, why has no-one ever shown me before that Science is so interesting"

and

"Until meeting Photonics, I had completely mapped out my career intentions, but now I have encountered the potential of Photonics, I will have to start again to re-think all of my career planning"

The intention of introducing students to Photonics, through the technique and approach that we have called Perceptive Empirical Design, is so that students are introduced to 21st Century concepts in Light that will enable the students themselves, at a relatively early stage in their scientific development, to change the way in which Light, and Photonics, can be used in highly imaginative ways – which are ways they have designed and created as a direct consequence of their own investigations and perceptive deductions.

Literally within minutes of being introduced to a new Photonics concept, Perceptive Empirical Design students are asked to imagine new ways in which that particular Photonics concept might be used for the benefit of Mankind. This highly focused inspirationally demanding approach to students is in perfect harmony with Pierre Aigrain’s definition of Photonics, which he proposed in 1967, namely that:--

"**Photonics is the science of the harnessing of Light.**

Photonics encompasses the

**Generation of Light**,  
**Management of Light**,  
**Detection of Light**, through

**Guidance**,  
**Manipulation** and

**Amplification**,  
and,

most importantly,  
**the Utilization of Light for the benefit of Mankind**”.

The approach of Perceptive Empirical Design encourages a process of learning by students through their own Investigative Observations, together with the development of new designs that are based upon the implications of the acquisition of their own specific, precise, accurate and useful empirical observations and results.

Perceptive Empirical Design quite naturally leads on to the next phase of the story, namely, the students’ personal **Ingenuity of the Design of the Impossible**.
If soldering presents a complication for students, the following Prototype Board circuit is recommended.

The Left-hand Circuit is a Variable Gain Light Detector, using a Photodiode and Operational Amplifier. This circuit will indicate differing Light Intensity Levels.

The Right-hand Circuit is a Light to Dark / Dark to Light discriminator Light Detector, also using a Photodiode and Operational Amplifier, but with a Capacitor Input to the Operational Amplifier. This circuit discriminates between the Photodiode receiving Light by indicating if the Photodiode receives Light – then Dark, or if the Photodiode receives Dark – then Light. This discriminatory versatility is of immense value in many Photonics applications, particularly in Robotics.

7 Conclusion

Perceptive Empirical Design enables students to achieve quite outstanding and impressive changes within Science, through their personal Ingenuity of the Design of the Impossible.

A student’s sense of Personal Achievement in developing an innovative and valuable Prototype, through his, or her, Ingenuity of the Design of the Impossible is of a very high quality factor.
The Human Eye: A Model System For Teaching Optics

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ABSTRACT

The human eye treated as an optical system is an excellent model to teach various aspects of Optics. The range of topics treated can start from simple refraction upto quantum optics including detection of single photons. In particular, concepts and methods such as ray tracing, apertures and stops, field of view calculations, gradient index systems, non-centered systems, Fraunhofer and Fresnel diffraction, scattering, Fourier optics as well as aberrations (both Seidel and wavefront aberrations) and adaptive optics can be illustrated using various properties of the human visual system. A course such as this will be of interest to students from biological sciences as well natural science and engineering students who desire some “real world” applications. I have taught these aspects and will describe my experiences and a model curriculum utilizing this ansatz.

Keyword list: Optics, dioptrics of eye, biomedical optics, inter-disciplinary courses

INTRODUCTION

It is generally said that the eyes are the windows to the soul. I paraphrase this saying by stating that the human eye is the window to the world of optics. The eye offers a wonderful system for teaching at various levels of sophistication different aspects of optics. Traditional textbooks, i.e., introductory physics textbooks, such as those by Serway and Beichner, Halliday, Resnick and Walker or Giancoli often treat the eye as a model application and deal with concepts such as myopia (short-sightedness) and hyperopia (long-sightedness). Advanced courses devoted exclusively to optics, do not spend much time (if any at all) to the eye as an optical instrument. Even the classic book by Jenkins and White devotes about three pages in its chapter on optical instruments. The one exception is the book by Keating. In this book, the human eye is used throughout in both examples and problems. However, Keating’s book is rather specialized, and is meant to be used in optics courses taught in Optometry schools and colleges in the professional program.

The vertebrate, human eye is an excellent example of a decentered optical system which utilizes not only aspherical components, but also gradient index sub-systems. Because, it utilizes biological material, we can also expect it to exhibit significant chromatic aberration. The eye also has an iris which acts as an aperture stop. Image formation by the human eye can be treated as either as a thin lens system or as a thick lens system. The eye suffers from considerable high order aberrations, including (and not limited to) spherical, coma, meridional astigmatism, etc. Finally, the photoreceptors in the retina, the rods and cones, act as classic fiber optic elements, which exhibit waveguiding phenomena. As an optical system, we can define a point spread function and an optical transfer function for the eye and study the imaging characteristics as well as phenomena such as aliasing. The reader is referred to, for example, Atchison and Smith, for a detailed description of the optics of the eye.
It is possible, to devise a curriculum, based on the eye, that will teach various aspects of optics. A course based on this fundamental assumption, will be of interest to a wide variety of students, ranging from those in the biological sciences, biomedical engineering, biophysics and medical physics, as well as those in allied health sciences such as pre-optometry, ophthalmic nursing, etc.

THE EYE AND SOME EXAMPLES

Geometric Optics

Typical optics texts begin with a discussion of Fermat’s principle and the concept of wavefronts from which the concept of rays and ray bundles are generated. Following the introduction of the refractive index, we are led to the idea of refraction at an interface between two media. The cornea – air interface can be considered as the model for this; from this, it is possible to deal with total internal reflection. The eye example to use herein is the idea of the viewing of the “angle” which is used in a technique called gonioscopy. One can also use the fact that the photoreceptor captures the incident light and channels them to the site of absorption using the idea of total internal reflection. The crystalline lens is a gradient index medium, and it is possible to teach ray tracing through such media. The iris of the eye, which acts as an aperture, is a good example of both the entrance and exit pupils (image when viewed through the cornea and image when viewed from the retina, after being refracted by the crystalline lens). Curved surface refraction can be thought of as refraction at the various elements (surfaces of the cornea, surfaces of the crystalline lens). Additionally, instead of treating the eye as a thin lens system, we can treat it as a thick lens system and introduce Gaussian points, etc. Another reason to use the eye as a model system is the fact that we can introduce concepts of non-spherical systems (i.e., aspherics) and deal with astigmatic lenses – this concept is rarely taught in traditional optics courses. Because the eye is a decentered system, we can discuss concepts such as prismatic deviation introduced due to a light ray incident at some distance from the optical center (e.g., Prentice’s law). Spherical mirrors can be very easily illustrated by the example of Purkinje – Sanson images (light reflections seen due to reflections at various structures of the eye, namely the anterior corneal surface, posterior corneal surface, anterior lens surface and posterior lens surface). Here, the ideas of Fresnel losses can be introduced. In a more advanced course, it is possible to construct computational eye models and illustrate imaging characteristics by changing the parameters of the model. It is easy (and much welcomed by students) to use the ABCD matrix formalism in these exercises.

Physical Optics

Physical Optics ideas can be taught by using a number of different examples from the visual system. Interference and the Young double slit experiment has an immediate application in the eye – namely to measure what is known as the grating acuity. This is done by projecting two small coherent spots in the entrance pupil of the eye. These spots will now act as the double slit and produce sine-wave gratings on the retina. As in the traditional Young double slit, by varying the separation between the two spots, we can change the spatial frequency of the fringes and find the limit of vision. This can also lead to finding the contrast threshold for different spatial frequencies. As in the traditional interference experiment, here too, we can define the Michelson contrast, etc. This is just one example. From this, we can generalize and define the modulation transfer function (MTF) and the Optical Transfer function (OTF) and hence, study Fourier optics. Diffraction can be taught by studying imaging by different apertures - more specifically by circular apertures and showing how visual acuity varies depending upon the size of the aperture. When we talk about visual acuity, we are dealing with resolution ability and hence the Rayleigh criterion. Of course, other criteria could be used.

Polarization phenomena can be illustrated by using for example, demonstrations of Haidinger’s brushes. This entoptic phenomenon is due to the polarization properties of short wavelength sensitive photoreceptors in the retina. Light scattering can be illustrated by the presence of
floaters in the eye media and the presence of glare. As noted earlier, photoreceptors in the retina behave as classic fiberoptic properties and demonstrate waveguide modes.\textsuperscript{10}

Wavefront aberrations can be measured using, for example, Hartmann Shack sensors, and this is a major area of research in vision science\textsuperscript{11}. We can describe adaptive optics techniques and descriptions of wavefront aberrations using Zernike polynomials (as well as comparison with Seidel aberrations) using the aberration measurements of the human eye.

Quantum Optics

Photon statistics can be illustrated by analyzing the fact that a dark adapted human eye, under some conditions, needs only about 4-7 photons to give a response of “I see a spot of light” about 60\% of the time. In fact, one only needs the absorption of one photon by one photoreceptor to generate a neural response\textsuperscript{12}. There is also the presence of dark noise. More recently, it has been proposed that human vision can be used to observe entanglement\textsuperscript{13}.

DISCUSSION

In the above description, I have not dealt with various instrumentation and equipment used to study the visual system. These offer further examples to teach physics and physics concepts. Additional methods that can be taught include topics such as feedback control, optical engineering, and so forth. Various aspects of imaging science can also be introduced (optical coherence tomography, functional magnetic resonance imaging, etc.). An example of a course that uses the eye in a significant manner to teach physics/optics in particular and science in general is described by Falk, Brill and Stork.\textsuperscript{14} This course, at the University of Maryland, College Park, was taught to non-science majors.

I have taught physical optics and geometric optics courses using the eye as a model system. A caveat is that these courses were taught to professional Optometry students in their first, post-undergraduate, professional year. These courses form the bedrock for their future career as optometrists. However, other students, such as those majoring in physics have taken these courses. These courses, taught at both the University of Waterloo and at the University of Missouri – St Louis (where I was previously affiliated) were also accompanied by a laboratory. Many of the laboratory exercises used aspects of human vision. Because of the application oriented approach, there is considerable interest and my student evaluations have always praised the practical applications shown. I believe a course such as this, would be of great interest to various categories of students and not just limited to future optometry professionals.
REFERENCES

Teaching diffraction gratings by means of a phasor analysis

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ABSTRACT

Diffraction gratings play a very important educational role in describing wave properties of light. In this work we present a simple phasor technique to fully describe binary amplitude diffraction gratings with different slit widths relative to the grating period, as well as binary phase gratings with different phase shift. This analysis, which is directly derived from the Huygens principle, introduces a slit phasor to account for the diffracted orders relative intensity, and a grating phasor that accounts for the grating’s resolving power. The proposed phasor technique is mathematically equivalent to the Fourier transform calculation of the diffraction orders amplitude, and it can be useful to explain binary diffraction gratings in a simple manner in introductory physics courses. Experimental results probing this theoretical analysis are included with the use of a liquid crystal display.

Keywords: Diffraction gratings; Huygens principle; Phase matching; Diffraction’s efficiency; Phasor methods; Diffractive optics.
1. INTRODUCTION

Diffraction is a topic usually introduced in general physics courses and taught more extensively in more advanced optics courses in Physics and Engineering degrees. Diffraction gratings have been regarded as one of the most important instruments in physics and they are indeed an important educational tool for describing the wave nature of light. Usually, in general physics textbooks, they are analyzed on the basis of a direct application of the Huygens principle. The angular directions where the diffraction orders are generated are easily derived from the condition of constructive interference between the wavelets transmitted through the multiple slits of the diffraction grating.

However, as it is noted in some general physics textbooks, this simplified approach does not explain the relative intensities of the diffracted orders nor the grating’s angular resolving power, because the envelope associated with the slit width is ignored. The effect of this envelope function is so important that some diffraction orders may disappear, although they fulfil the former interference condition. For instance, the simplest binary amplitude diffraction grating, where the width of the slit is half the period of the grating, produces a diffraction pattern where all even diffraction orders are missing. A full quantitative analysis of diffraction gratings is usually taught in advanced optics courses based on the Fourier transform description of the multislit interference phenomena, characteristic of the Fraunhofer approximation. However, the use of Fourier theory to analyze diffraction problems is too advanced for introductory physics courses.

In this work we show a simpler method to fully describe binary diffraction grating patterns. The analysis is based on a phasor technique directly derived from the Huygens principle, where we take into account the phase contributions from all points at the slit aperture. The addition of all these contributions results in a slit phasor, whose length is directly related to the diffraction order amplitude. The contribution of all the slits leads to the so-called grating phasor which describes the grating’s resolving power. We study binary amplitude diffraction gratings with different fill factors (ratio between the transparent and opaque areas). When changing the grating’s fill factor the relative intensities of the different diffraction orders are modified, and the missing orders change.

While diffraction gratings are usually introduced considering amplitude gratings, phase-only diffraction gratings are much more attractive for technological purposes because of their much greater diffraction efficiency. Additionally, the recent advent of liquid crystal technology allows the realization of programmable phase-only gratings. In this work we also show how to extend the proposed phasor analysis to binary phase-only diffraction gratings. Within this intuitive formalism, the grating’s diffraction efficiency, which is an important quality parameter of a diffraction grating and is assimilated to the intensity of the positive first diffraction order, can be easily obtained. The proposed phasor analysis of diffraction gratings explains such properties in a physically very intuitive way, and provides an interesting teaching tool for undergraduate students in general physics courses, where diffraction is not studied on the basis of the Fourier transform.

A similar phasor analysis is considered in some fundamental physics textbooks in order to address specific diffraction problems. For instance, it is used to analyze the diffraction pattern of a single slit. In other texts, it is applied to multislit interference and it describes the increasing intensity and narrowing of the main peaks as the number of slits increases. However, to our knowledge, no general physics textbook shows the connection between the phasor analysis and the Fourier transform calculation. This connection is not shown, either, in more advanced optics books, where diffraction gratings are directly treated on the Fourier transform basis. In this work we demonstrate that the diffraction’s order amplitude calculated within our slit phasor formalism is mathematically equivalent to the one obtained by the Fourier transform calculation.

Finally, the proposed phasor analysis is illustrated experimentally in the case of binary amplitude diffraction gratings by using a ferroelectric liquid crystal display, which allows to very easily change the diffraction grating’s fill factor simply by changing the addressed image. The experiment agrees very well with the theory, and it is an illustrative optical demonstration.
2. PHASOR ANALYSIS OF BINARY DIFFRACTION GRATINGS

We consider diffraction gratings illuminated with plane wave monochromatic light with normal incidence and wavelength $\lambda$. The grating’s period is regarded to be high enough so that the scalar diffraction theory is valid, and we concentrate on describing the diffraction pattern generated in the Fraunhofer approximation.

For simplicity we start considering binary amplitude gratings as described in Fig. 1(a). The period $p$ is divided in two regions, with transmittances $t_1=1$ and $t_2=0$ and widths $d_1$ and $d_2$, respectively. The gratings period is constant $p=d_1+d_2$, but we consider different relative widths of the two regions. A fill factor parameter $a$ can be defined such that $d_1=ap$ and $d_2=(1-a)p$. The grating has $N$ slits and its extension is $A=Np$. Figure 1(b) shows the typical diagram used in introductory physics to explain the generation of the diffracted orders by these amplitude diffraction gratings. The angular directions associated to the diffraction orders are obtained from the constructive interference of the Huygens wavelets generated at each aperture. This condition requires that, for the angular direction $\theta_m$ where the $m$ diffraction order is generated, the path difference between the waves generated at the same point at consecutive apertures must be equal to an integer number of wavelengths, $m\lambda$. Therefore, for instance, points A and A' in Fig. 1(b) are in phase. This situation, leads to the very well-known diffraction grating law:

$$p \sin(\theta_m) = m\lambda. \quad (1)$$

However, the above condition does not explain the relative intensities of the different diffraction orders, in particular the vanishing of some orders.

![Fig. 1. (a) Diffraction grating transmittance $g(x)$ of a binary amplitude diffraction grating with period $p$, fill factor $a=d_1/p$ and width $A=Np$, being $N$ the number of slits. (b) Ray diagram at the diffraction grating plane, where $\theta_m$ is the angular direction of the $m$ diffracted order.](image)

2.1 The slit phasor: relative intensity of diffracted orders of binary amplitude gratings

Based on the Huygens principle, an intuitive phasor analysis which explains not only the angular direction of the diffraction orders but also their relative intensities, can be developed. The idea of this method is based on considering the phase mismatch of all the wavelets scattered in the diffraction order angular direction from all points in the slit aperture, and is illustrated in Figure 1(b). We consider the phase mismatch of the rays emerging from the slit aperture with diffraction angle $\theta_m$ at all points in the wavefront between A and C. Each
contribution can be represented by a phasor in the complex plane whose orientation is given by the phase state of the corresponding wavelet. The amplitude of the corresponding diffraction order is given by the magnitude of the phasor resulting from adding all these contributions. We call this phasor the slit phasor since it is directly related to the slit’s shape. Figure 2 shows the slit phasor diagrams for the zero (undiffracted) and the first four diffraction orders (see figure columns) of binary gratings with different fill factors (see figure rows).

Let us first consider the simplest binary amplitude diffraction grating, where the period is divided in two equal regions with transmittances 1 and zero (fill factor $\alpha=1/2$). For the zero diffraction order, there is not a phase difference between the transmitted rays, and all the phasors are aligned, being the total length equal to $1/2$, corresponding to the mean half-intensity transmission in a single period. For the first order ($m=1$), the difference in path lengths between rays A and B is $\lambda/4$, and between ray A and ray C is $\lambda/2$ (Fig. 1(b)). Consequently, the phase at point A is zero, while the ray crossing at point B contributes with a phase $\pi/2$, and the ray crossing at point C contributes with phase $\pi$. Therefore, these rays are represented in Figure 2 by a phasor parallel to the positive real axis (ray A), parallel to the positive imaginary axis (ray B) and parallel to the negative real axis (ray C). The summation of all the phasors contained between A and C results in a total phasor along the positive imaginary axis, whose square modulus gives the intensity of the diffraction order $m=1$ for the diffraction grating with fill factor $\alpha=1/2$.

Let us now consider the diffraction order $m=2$. Now, ray $A'$ in Fig. 1(b) contributes to the wavefront with a phase $4\pi$, (the path from the grating is $2\lambda$). Rays A, B and C follow paths $0$, $\lambda/2$ and $\lambda$, and therefore they contribute with phases $0$, $\pi$ and $2\pi$ respectively. Then, the phasor contributions fill the whole complex plane and the total summation is cancelled. This explains why the second diffraction order has zero intensity. For $m=3$, the phasors related to rays A, B and C have phases $0$, $3\pi/2$ and $3\pi$. Therefore, all the phasors
contributing to the third diffraction order are contained in one and a half complex plane and the density of phasors is smaller than for \( m=1 \), namely, it is one third of that value. Hence, we expect the intensity of the third order \( I_3 \) to be one-ninth of \( I_1 \). Finally, in the case of \( m=4 \), the total phasor contributions fills twice the complex plane and the total summation is cancelled. This is why the fourth diffraction order has zero intensity.

We now consider the diffraction grating with fill factor \( a=1/3 \). In the ray diagram of Figure 1(b) the path for ray C is now \( m\lambda/3 \). The corresponding phasor diagrams are shown in the second row of Figure 2. The rays contributing to the first order are those between A and C in Figure 1(b) whose difference in path length is \( \lambda/3 \). Therefore, the contributing phasors have phases from zero to \( 2\pi/3 \) and they result in a non-zero total phasor with squared modulus \( I_1 \). For \( m=2 \), ray C corresponds to a phasor with phase \( 4\pi/3 \), and the density of phasors is reduced by one half. Hence, the expected relative intensities between the second and first diffraction order is \( I_2/I_1 = 1/4 \). For \( m=3 \), the difference in path length between rays A and C in Figure 1(b) is \( \lambda \), and they correspond to phasors with phases zero and \( 2\pi \). Therefore, all the contributing phasors are contained in the whole complex plane and their summation is exactly cancelled. This explains why now the third order is missing. For \( m=4 \), the phasor distribution is similar to the case \( m=1 \), but the phasor density is one fourth. Therefore their intensity ratio is \( I_4/I_1 = 1/16 \).

Finally, we consider the diffraction grating with fill factor \( a=1/4 \). For the first diffraction order, only the first quadrant in the complex plane is filled. For diffraction orders 2 and 3 the phasors are distributed in two and three quadrants of the complex plane. In this case, the phasors are distributed along the whole complex plane for the fourth diffraction order, and therefore this is now the vanishing order.

For the correct evaluation of the diffraction orders intensity, it is required to calculate the density of phasors \( (D) \) when these are distributed on an angular sector. Since for the zero diffracted order all the slit phasors are aligned, the total phasor length is equal to \( a \). When considering the \( m^{th} \) diffracted order, the phasors are uniformly distributed in an angular sector \( ma2\pi \), and therefore:

\[
D = \frac{a}{ma2\pi} = \frac{1}{m2\pi}.
\] (2)

2.2 Connection between phasor and Fourier analysis

Here we demonstrate that the slit phasor analysis above described provides the exact solution of the diffraction orders amplitude derived from the Fourier transform analysis. In our approach, this amplitude is given by the total slit phasor length. In the Fourier transform analysis, this amplitude is given by the diffraction’s grating Fourier expansion coefficient of the corresponding order. A detailed comparison between the phasor and the Fourier transform approach is developed in a previous work. We show below that these quantities have an equivalent mathematical expression. This demonstration is interesting for educational purposes, since it is usually not included in general physics textbooks - because it is too advanced -, nor in more advanced optics books, where diffraction gratings are described only on a Fourier transform basis.

The relative intensities of the diffraction orders are not affected by the grating’s extension provided the number of slits is large. Therefore we can assume an infinitely extended diffraction grating, and use the Fourier expansion series to obtain the value of the Fourier coefficients \( G_m \) corresponding to the amplitude of the \( m^{th} \) diffraction order. They can be calculated as:

\[
G_m = \frac{1}{p} \int_{-p/2}^{p/2} g(x) \exp \left( im \frac{2\pi x}{p} \right) dx = \frac{1}{m2\pi} \int_0^{ma2\pi} \exp(i\theta) d\theta = \frac{i}{m2\pi} (1 - \exp(ima2\pi)),
\] (3)

where the function \( g(x) \) describes the grating’s transmittance, being \( g(x) = 1 \) when \( x \in [0,ap] \), and zero in the rest of the period, and where the change of variables \( \theta = m2\pi x/p \), has been applied. Let us note that the
The integrand term is the phasor \( \exp(i\theta) \), which is integrated from 0 to the maximum value \( m\alpha 2\pi \). This depends on the diffraction order \( m \) and the fill factor \( \alpha \), exactly as the phasors described in section 2. On the other hand, the factor \((m2\pi)^{-1}\) exactly corresponds to the density of phasors mentioned in the previous subsection. The intensity of the diffraction orders is then given by:

\[
I_m = |G_m|^2 = \frac{\sin^2(m\pi\alpha^2)}{m^2\pi^2}.
\]

The limit \( m \to 0 \) of this expression is equal to \( \alpha^2 \), in agreement with the phasor of length \( \alpha \) at \( m=0 \).

Therefore, the above discussion demonstrates that the phasor analysis described in Section 2, which was derived from physical considerations, leads to the same expression for the diffraction orders amplitude as the Fourier series analysis. Table I summarizes the intensities of the first diffraction orders for different fill factor values. We can see that all the conclusions previously derived from the slit phasor analysis are confirmed from this exact Fourier calculation.

<table>
<thead>
<tr>
<th>Fill factor</th>
<th>( I_0 )</th>
<th>( I_{-1} )</th>
<th>( I_{1} )</th>
<th>( I_{-2} )</th>
<th>( I_{2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha=1/2 )</td>
<td>1/4=25.0%</td>
<td>1/( \pi^2 )=10.1%</td>
<td>0</td>
<td>1/9( \pi^2 )</td>
<td>0</td>
</tr>
<tr>
<td>( \alpha=1/3 )</td>
<td>1/9=11.1%</td>
<td>3/4( \pi^2 )=7.6%</td>
<td>3/16( \pi^2 )=1.9%</td>
<td>0</td>
<td>3/64( \pi^2 )=0.5%</td>
</tr>
<tr>
<td>( \alpha=1/4 )</td>
<td>1/16=6.2%</td>
<td>1/2( \pi^2 )=5.1%</td>
<td>1/4( \pi^2 )=2.5%</td>
<td>1/18( \pi^2 )=0.6%</td>
<td>0</td>
</tr>
</tbody>
</table>

Table I: Relative intensities of the first diffraction orders for binary amplitude gratings with different fill factors.

### 2.3 Extension to binary phase gratings

The phasor analysis can be easily extended to binary phase-only gratings with a relative phase shift \( \phi \) between the two levels in the grating. For the sake of simplicity we consider these levels of equal width (\( \alpha=1/2 \)). Figure 3 shows the profiles of both the binary amplitude and binary phase grating. The transmittance profile for the latter is \( g(x)=t(x)\exp[i\phi(x)] \) (\( t \) denotes the amplitude and \( \phi \) the phase), which in the centered basic period (\( x\in[-p/2,+p/2] \)), is defined as:

\[
g(x) = \begin{cases} 
\exp(i\phi) & \text{if } x \in \left[-\frac{p}{2},0\right] \\
1 & \text{if } x \in \left[0,+\frac{p}{2}\right] 
\end{cases}
\]

(a) Binary amplitude grating

(b) Binary phase grating

![Transmittance profiles of the binary amplitude and binary phase gratings.](image)

Thus, there are now two different regions in the diffraction grating’s period that contribute to the diffraction pattern, and provide different distributions in the phasor diagrams. The region \( x\in[0,+p/2] \) is equivalent to that of an amplitude diffraction grating, whose phasor distribution was analyzed in Fig. 2. But the
region $x \in [-p/2,0]$ now contributes with another set of phasors. Figure 4 illustrates the phasor diagrams of the binary phase grating, for the same diffraction orders considered in Fig. 2. The two regions in the grating are distinguished with phasors in two colours, blue for the region with phase $\phi$, and red for the area with zero phase.

Figures 4(a) and 4(b) illustrate, respectively, the case of arbitrary phase shift $\phi$, and the important particular case of $\phi=\pi$ radians. Let us first analyze the undiffracted zero order. In this case all the phasors in the same region contribute with the same phase, oriented with phases zero (red phasors) and $\phi$ (blue phasors). Since the two regions in the grating have the same size ($a=1/2$), the length of the corresponding phasors is the same (equal to 1/2), and the amplitude of the resulting phasor is the given by

$$G_0 = \frac{1}{2}(1 + \exp(i\phi)).$$

The intensity at this order is therefore $I_0=|G_0|^2=\cos^2(\phi/2)$. For $\phi=\pi$, the two phasor contributions are aligned in opposite directions and they cancel each other, thus leading to a null intensity.

(a) Binary phase grating with arbitrary phase $\phi$

(b) Binary phase grating with phase $\phi=\pi$

Fig. 4. Slit phasor diagrams for diffraction orders $m=0,1,2,3,4$, of the binary phase grating. Red phasors correspond to the region with zero phase and blue phasors to the region with phase $\phi$.

For the other diffraction orders ($m \neq 0$), these phasor contributions are folded according to Eq. (3). Red phasors fold in the positive sense (counterclockwise), while blue phasors fold in the negative sense (clockwise) because they correspond to negative values of $x$. Since $a=1/2$, the folding range is the same for the two regions, and increases with $m$ as $[0, \pm m\pi]$, being the starting angle 0 and $\phi$ respectively. For $m=2$, both phasor contributions cover the whole complex circle, resulting in a null global phasor which indicates the zero intensity at this order. This is a consequence of the fact that the two regions in the grating have the same width, and the fill factor is 1/2.

Let us now focus on the odd diffraction orders, and particularly on $m=1$. Now the phasors cover a wide, but not full, sector of the complex plane. The amplitude of the global phasor can be calculated by applying Eq. (3), which now results in
\[
G_m = \frac{1}{p} \int_0^p \exp(i\phi) \exp\left(\frac{im 2\pi x}{p}\right) dx + \frac{1}{p} \int_0^{+p/2} \exp\left(\frac{im 2\pi x}{p}\right) dx = \\
(1 - \exp(i\phi)) \cdot \frac{1}{m2\pi} \int_0^{n_m} \exp(i\theta) d\theta,
\]

where, once again, the change of variables \(\theta = m2\pi x / p\), has been applied. Equation (7) shows how the same distribution of phasors of the amplitude grating contribute with two starting angles, 0 and \(\phi + \pi\). When \(\phi = \pi\) the distribution of phasors corresponding to each region exactly overlap, thus producing a multiplicative factor 2 in the resulting total phasor when compared with the amplitude grating (and therefore a multiplicative factor 4 in the intensity). In the case \(m = 3\), the linear phases cover a much larger angular sector. In fact, what was covered in an angular sector of \(\pi\) radians for \(m = 1\), is now covered in a range of \(3\pi\) radians. Those phasors covering the angular sector of \(2\pi\) radians cancel each other, and only the rest contribute to the global phasor. The result is a phasor diagram for \(m = 3\) equivalent to that for \(m = 1\), but now the density of phasors has been decreased by a factor of 3. The integration in Eq. (7) leads to

\[
G_m = (1 - \exp(i\phi)) \cdot \frac{i}{m2\pi} (1 - \exp(im\pi)).
\]

The corresponding intensity values are:

\[
i_m = 4 \sin^2\left(\frac{\phi}{2}\right) \cdot \frac{\sin^2(m\pi/2)}{m^2\pi^2},
\]

Table II gives the intensity values of the first four diffraction orders. The intensity of the positive first diffraction order is the grating’s diffraction efficiency. The phasor analysis of phase diffraction gratings allows to obtain this important quality parameter in a physically intuitive way. As it is expected, we obtain that the diffraction efficiency is maximum for a \(\pi\)-phase grating.

<table>
<thead>
<tr>
<th>Case</th>
<th>(i_0)</th>
<th>(i_{+1})</th>
<th>(i_{+2})</th>
<th>(i_{+3})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arbitrary (\phi)</td>
<td>(\cos^2\left(\frac{\phi}{2}\right))</td>
<td>(\frac{4}{\pi^2} \sin^2\left(\frac{\phi}{2}\right))</td>
<td>0</td>
<td>(\frac{4}{9\pi^2} \sin^2\left(\frac{\phi}{2}\right))</td>
</tr>
<tr>
<td>(\phi = \pi)</td>
<td>0</td>
<td>(\frac{4}{\pi^2} = 40.5%)</td>
<td>0</td>
<td>(\frac{4}{9\pi^2} = 4.5%)</td>
</tr>
</tbody>
</table>

Table II: Intensity of the first diffraction orders of a binary phase diffraction grating with phase shift \(\phi\).

3. THE GRATING PHASOR: RESOLVING POWER

The slit phasor analysis in Section 2.1 deals only with the interference condition of the Huygens wavelets generated by a single slit in the angular direction corresponding to the diffraction order. Now we address the phasor analysis for a different subject: the grating’s angular resolving power. For that purpose we analyze Fig. 5(a), where some rays leaving the grating with a slight angular separation \(\Delta\theta\) from the diffraction order angle have been drawn. We evaluate the phase condition of the Huygens wavelets interference in this angular direction.
We consider a non-zero diffraction order angle \( \theta_m \). Therefore, the slit phasor associated to each slit in this angular direction is not zero. The key point to derive the angular resolving power is to consider the interference from the multiple slits that constitute the grating. Since the angle \( \Delta \theta \) is very small, we can consider that the slit phasor is approximately still valid also for the angle \( \theta_m + \Delta \theta \). Each slit contributes with the slit phasor derived in the previous section. The so called grating phasor is generated by the addition of all the slit phasors oriented in accordance with the interference between the wavelets emerging from the same point of successive slits. As an example we consider points A and A' in Fig. 5(a). Now the propagation distance from the slit plane (point S) to the point A' is

\[
SA' = p \sin(\theta_m + \Delta \theta),
\]

(10)

The small angle approximation can be applied to \( \Delta \theta \) to obtain that \( \sin(\theta_m + \Delta \theta) = \sin(\theta_m) \cos(\Delta \theta) + \cos(\theta_m) \sin(\Delta \theta) \approx \sin(\theta_m) + \cos(\theta_m) \cdot \Delta \theta \). Taking into account the grating equation (Eq. (1)), the previous equation becomes

\[
SA' = m \lambda + p \cos(\theta_m) \cdot \Delta \theta,
\]

(11)

Wavelets from successive slits do not interfere exactly in phase, but the phase between them is equal to \( m2\pi + 2\pi p \cdot \cos(\theta_m) \cdot \Delta \theta / \lambda \). We define the angular phasor mismatch as:

\[
\phi = \frac{2\pi p \cos(\theta_m) \Delta \theta}{\lambda},
\]

(12)

This quantity represents the angular separation in the phasor diagram between slit phasors from successive slits. Figure 5(b-d) illustrates the situation, where \( n \) labels the slits and \( N \) is the total number of slits. Figure 5(b) corresponds to the diffraction order angle \( \theta_m (\Delta \theta = 0) \). In this case all slit phasors from successive slits are always in phase, thus contributing to a grating phasor with a large modulus that explains the diffraction order. When \( \Delta \theta = 0 \) there is a phase mismatch \( \phi \) between successive slits, given by Eq. (12). The global grating phasor resulting from the addition of all these slit phasors with phase mismatch \( \phi \) (Fig. 5(c)) has a smaller modulus than the one where \( \Delta \theta = 0 \) (Fig. 5(b)), thus explaining the reduction in intensity as \( \Delta \theta \) increases. The first zero intensity angle (which defines the angular resolution \( \Delta \theta_r \) of the grating), is obtained when all the \( N \) individual slit phasors are distributed in the whole complex plane, leading to a zero global
grating phasor, as shown in Fig. 5(d). This situation is obtained when the condition \((N+1)\phi=2\pi\), which is simplified to \(N\phi=2\pi\) because the number of slits is in general very large \((N>>1)\). Taking into account this condition and the definition in Eq. (12), the angular resolution is obtained as

\[
\Delta \theta_r = \frac{\lambda}{N_p \cos(\theta_m)} = \frac{\lambda}{A \cos(\theta_m)},
\]

This angular separation determines the grating’s resolving power in spectroscopic applications. The smaller \(\Delta \theta_r\), the greater the resolving power of the grating is.

Two spectral lines with wavelengths \(\lambda \pm \Delta \lambda/2\) are considered resolved if the maximum of one wavelength coincides with the minimum of the other, i.e., their angular separation is \(\Delta \theta_r\). The grating’s resolving power \((R)\) is defined as \(R=\lambda/\Delta \lambda\). The chromatic dispersion \(\Delta \lambda\) is related to the angular resolution \(\Delta \theta_r\) and can be derived from Eq. (1) as

\[
\Delta \lambda = \frac{p}{m} \left(\sin\left(\theta_m + \frac{\Delta \theta_r}{2}\right) - \sin\left(\theta_m - \frac{\Delta \theta_r}{2}\right)\right) \approx \frac{p}{m} \cos(\theta_m) \cdot \Delta \theta_r,
\]

where the small angle approximation has been used again for \(\Delta \theta_r\). Therefore, considering Eqs. (13) and (14), the resolving power is deduced to be:

\[
R = \frac{\lambda}{\Delta \lambda} = \frac{\lambda}{Z \cos(\theta_m) \Delta \theta_r} = mN,
\]

This very well known result shows why a larger-size grating has higher resolution, and it has been derived here directly using the grating phasor analysis.

4. EXPERIMENTAL DEMONSTRATION

The properties described in the previous sections can be easily demonstrated by means of a liquid crystal (LC) microdisplay. LC devices have been used as programmable diffractive screens, and also for pedagogical demonstrations. As an example, we will show the change in the vanishing diffraction orders as the fill factor changes. The binary modulation provided by ferroelectric LC displays (FLCD) makes them particularly useful to implement binary diffraction gratings. FLCDs are binary modulators that provide at the output two orthogonal linearly polarized states depending on the addressed voltage. In this case, the two grating levels are controlled through the standard PC computer video signal.

Here we use a reflective ferroelectric LC on silicon display from CRL-Opto, model RXGA1.5C, with an active area of 12.3 mm \(\times\) 9.2 mm with 1024\(\times\)768 pixels. The pixel pitch (distance between pixels) is 12.0 \(\mu\)m \(\times\) 12.0 \(\mu\)m, being the pixel size 11.4 \(\mu\)m \(\times\) 11.4 \(\mu\)m (thus the fill factor is about 90%). The FLCD is illuminated with a collimated linearly polarized plane wave of a He-Ne laser, with wavelength \(\lambda=632.8\) nm. One linear polarizer is placed on the reflected beam, in order to act as an analyzer and operate the FLCD in the binary amplitude modulation scheme. The reflected beam is propagated a distance of about 2 meters in order to observe the diffraction pattern in the Fraunhofer approximation regime. Finally, we use a CCD camera to record the intensity patterns of the diffracted field.

Figure 6 shows the binary images that are addressed to the FLCD and the corresponding experimental diffraction pattern. The three images shown in Fig. 6 are binary amplitude gratings, with fill factor values \(\alpha=1/2\), 1/3 and 1/4, respectively. White pixels refer to areas where the reflected light is transmitted through the analyzer. Black pixels refer to areas where the reflected light is being absorbed by the analyzer. Therefore, the display acts as a binary amplitude diffraction element with transmission values 0 and 1 at the black and white pixels of the addressed image.
The experimental diffraction patterns show the typical diffraction orders, and their intensities follow the expected behaviour described in the previous sections. Namely, for the binary grating with fill factor $a=1/2$ all even orders in the diffraction pattern are cancelled. For the gratings with fill factors $a=1/3$ and $a=1/4$, it is the $\pm 3$ orders and the $\pm 4$ orders the ones that are cancelled, respectively. In these experiments the DC zero order has been slightly over exposed in the CCD camera in order to easily observe the other diffraction orders.

5. CONCLUSIONS

Using interference considerations on the basis of the Huygens principle, we have developed a phasor technique which provides a complete description of binary diffraction gratings in the Fraunhofer approximation. We have shown how this physically intuitive phasor technique describes, by means of the so called slit phasor, the diffractions amplitude and vanishing orders in the diffraction pattern of binary amplitude gratings with different ratios between the transparent and opaque areas. Also, defining a grating phasor, we have obtained the grating's resolving power. By applying this formalism to phase-only binary gratings, we have been able to describe the intensity of the diffracted orders and the diffraction efficiency, which is a key quality parameter of the grating.

Such properties of binary amplitude and phase diffraction gratings cannot be addressed in a general physics course, where diffraction gratings are usually explained from the direct application of the Huygens principle. Within this principle only the angular directions of the diffraction orders are described, but not their relative intensities, nor the grating’s angular resolving power and diffraction efficiency. A full description of binary diffraction gratings is usually addressed with the Fourier optics theory in advanced optics courses, which is too complicated for general physics courses.

Thus, in this work we have shown that a simple phasor approach provides a full description of binary diffraction grating patterns in the Fraunhofer approximation. We have also demonstrated that the diffraction’s order amplitude calculated within this phasor formalism is mathematically equivalent to the one obtained by the Fourier transform calculation. The proposed phasor analysis is more intuitive than the Fourier transform
approach, and is appropriate for less advanced courses. It also represents an alternative approach to the problem which can be useful for understanding the physical phenomena.

Finally, an illustrative optical demonstration of these effects has been performed by using a ferroelectric liquid crystal display, which allows to very easily change the diffraction grating’s fill factor simply by changing the addressed image.

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REFERENCES

Students Misconceptions about Light in Algeria

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ABSTRACT

Physics education research has shown that students have difficulties in learning essential optics concepts. Therefore, in this present work we deal with student's conceptions in geometrical optics field. Our objective is to show the Algerian students misconceptions. We proposed to 246 students in first year university (aged 18–21) a closed questionnaire where most of its questions were already used by other researchers. The misunderstandings identified were compared with those in literature. The results show that our students have the same misconceptions, related to the propagation of the light, the vision, the refraction and the reflexion, as the students in other countries (Andersson, Çiğdem ŞAHİN, Galili, Goldberg, Viennot,…).

We investigate new students “misconception” concerning the propagation of the light in the vacuum.

KEYWORDS

Misconception, Geometrical optics

1, INTRODUCTION

Light is an essential feature of everyday life. It is a key component of many modern technologies and is used as the primary tool in many sciences ranging from astronomy to zoology. Without some familiarity with the properties of light, students are not expected to fully grasp modern science.

The field of optics is a complex area for the students and many studies has shown students’ difficulties in learning optics see for example (Guesne 1985; Galili, Bendall and al. 1993; Galili and Hazan 2000; Tao 2004). The greatest number of these studies is concerns geometrical optics at the primary and secondary school.

There exists important evidence on the fact that the students at the university often have the same conceptual difficulties and of reasoning about optics that those largely divided by younger pupils (McDermott and Al, 1996). However, the studies at university level have been relatively rare. That is why we have chosen this level in our studies.

A lot of data about conceptions and representations regarding the phenomena of physics have been accumulated.

For Tiberghien ( 1997) A conception is seen as a hypothetical set of statements, skills, procedures attribute to one or more students in order to account for students' behaviour in a set of given situations. Other studies (eg: Goldberg & McDermott, 1983) concluded that students did not use concepts systematically, and the particular situation determines the conception that is relevant. Many student conceptions were misconceptions and that these misconceptions were difficult to change through regular instruction.

Students come to science classes with opinions and intuitions about physical phenomena derived from prior learning, either in the classroom or from their interaction with the physical and social world (Bransford et al., 1999). Furthermore, these beliefs or opinions are sometimes different from the scientifically accepted ideas presented in the classroom.

Terms such as misconceptions, preconceptions, alternative frameworks, children’s science, naive conceptions and so forth; are used to describe such beliefs (Pınarbaşi and Canpolat, 2003).
Arons (1990), for example, prefers ‘preconceptions’. He argues that the misconception is to be removed through asserting the correct notion. Viennot (1979) prefers ‘intuitive notions' that reflect vagueness in student ideas rather than ideas which are well articulated. HUBBER (2005) uses ‘alternative conceptions’ for student’s conceptions after teaching.

In the present paper we prefer using the word “misconception”. It may be an appropriate term to use if only because the student may be judged right or wrong, although a misconception can be utilized as a ‘teaching aid’(Stuart Rowlands, 2007). Also for the reason that, Misconceptions are produced when people integrate new information, learnt at school, with previously held information resulting in the new knowledge being reinterpreted to correspond with everyday experiences (Duit, 2002; Duit, 2006). Vygotsky (1997) referred to the possibility that even if adults have successfully developed scientific concepts, their earlier everyday concepts may survive alongside.

About the main features of misconceptions research carried out some findings (Duit, and Al, 2003, Driver, 1989; Mortimer, 1995; Eve Kikas, 2003):

- Misconceptions of students in different countries and region are frequently similar to each other;
- Students' misconceptions are often strongly held, difficult to change through regular instruction;
- Culture, religion and language can cause the formation of some misconceptions;
- Misconceptions and the scientists’ explanations can be used together in interpreting scientific phenomena;
- Misconceptions may develop after a formal teaching.

For better learning and understanding of scientific concepts, it has been recommended that before the beginning of the instruction, the students’ misconceptions should be taken into account by teachers (Smith and Al., 1993). It must be interesting to take in consideration the misconceptions about light to elaborate a new teaching strategies because the traditional teaching strategies employed were not always successful in changing these conceptions.

In light of the studies and ideas outlined above, this study aims to reveal university students’ misconceptions in Algeria about optics phenomena. Therefore, questions to be sought for the responses are:

1. What are the misconceptions of Algerian first year university students about optics phenomena?
2. Are there any differences between students’ misconception about light in Algeria and other countries?
3. Are there any changes in students' misconceptions after 30 years of research about light and optical phenomena conceptions?

2, AN OVERVIEW OF PREVIOUS RESEARCH STUDENT’S MISCONCEPTIONS OF LIGHT

Many studies have sought student’s views and knowledge about light, vision and optics phenomena at different ages, grades and different countries during the past 30 years (Pfundt and Duit 1994, Galili, I. and A. Hazan 2000, Goldberg and McDermott (1983). The Studies of postinstruction students have revealed a persistence of student’s misconceptions even after formal learning of optics.

We present here only the student’s misconception at the university level before instruction and at secondary level after studying optics.

2.1 Light propagation

In a study by (Langley, Ronen et al. 1997), students’ preconceptions were tested and they found that students didn’t indicate direction in their representation of light. Significant number of students in the Western Australian study believed that the distance light travels is depends on its energy. (Fetherstonhaugh 1990).

Goldberg and McDermott (1987) established that the students at the university designs such as a luminous object which has a determined form, sends parallel rays. That the rays are parallel implies obligatorily that this is the privileged direction; and it is generally a horizontal direction.

In physics, Shadows are formed when light is stopped by objects, but students think that shadows can be conceived as an image, or as something belonging to an object (Anderson B, Bach F; 2005). There is a need to see light as an entity in space for being able to give an explanation of the formation of shadows (Galili and Hazan 2000).

2.2 Vision
Most of older students in study of Bendall, Goldberg et al. (1993) have the idea that the eye plays an active role while the object ‘looked at’ has a passive role. Students think that the eyes send out something making it possible for us to see. (Andersson, B. and F. Bach (2005), Palacios, J. and Al. (1989))

Heywood (2005) presents three categories of representations in students’ reasoning how we can see an object. Visual representation where students’ focus is on looking and seeing, the eye looking at the direction of the object. Light representation, where students’ reasoning is concerned with where light is travelling. The third category is a dual representation, students’ using both visual representation and light representation. Most of the student’s misconceptions about vision have been founded in history. Ibn-el Heythem has been the first who has revealed the function of eye and light. Ibn-el Heythem rejected the idea that the eye diffuses light. He also asserted that light beams come from the object and then to the eye.

2.3 Image
The students’ difficulties with light as an entity in space is pointed out as a problem in image construction by (Heywood 2005). Image undergoes a deconstruction to a collection of points, each being transmitted by means of single light ray.

For Galili and Al (1993), the image construction is complex and one difficulty for students is to use multiple rays and point to point mapping simultaneously.
Concerning how students think about images in plane mirrors and lens, Goldberg & McDermott (1986) indicated that a significant number of students believed that an observer can see an image only if it lies along his or her line of sight to the object, and that an image would be in different positions for different observers. They thought that the image of a rod placed in front of a mirror would move to the right if they moved to the left, they would be able to see more of themselves in a mirror by moving further away and the image of an object could be projected onto a screen without lens.

Goldberg and McDermott (1983) also reported that many students predicted that half the image would disappear when half of a lens was used to form the image. The same misconceptions are shown by Galili, and Hazan (2000):

- The image stays in the mirror whether it is observed or not;
- The image moves from the object towards the mirror, where it stays;
- A half-lens produces a half-image. The rest of the image (rays) is blocked;
- When the screen moves towards or away from the lens the image will become bigger or smaller but remain sharp.

The students explain this by their understanding of geometric image construction rather than reasoning about cones of light being partially stopped by the cover.

The misconceptions are listed in Table 1.

<table>
<thead>
<tr>
<th>Table 1: Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Misconception</td>
</tr>
<tr>
<td>➢ Each point on a luminous object emits light in one direction.</td>
</tr>
<tr>
<td>➢ Light travels further at night than during the day.</td>
</tr>
<tr>
<td>➢ Light is not conceived as moving from one point to another with a finite speed.</td>
</tr>
<tr>
<td>➢ Shadows can be conceived as an image, or as something belonging to an object</td>
</tr>
<tr>
<td>➢ A shadow is a ‘reflection’ (reproduction) of an object.</td>
</tr>
<tr>
<td>➢ The stronger the source of light, give the bigger the shadow.</td>
</tr>
<tr>
<td>➢ The bigger the source of light, give the smaller the shadow.</td>
</tr>
<tr>
<td>➢ Objects are seen because they are bathed in light.</td>
</tr>
<tr>
<td>➢ Light travels from the eyes to the object.</td>
</tr>
<tr>
<td>➢ We can see because light travels to your eyes and then from the eyes to the object.</td>
</tr>
<tr>
<td>➢ An individual's eyes see the shape of an object.</td>
</tr>
<tr>
<td>➢ Shiny objects reflect more light than dull objects.</td>
</tr>
<tr>
<td>➢ Light is not necessary to see since we can see a little in a dark room.</td>
</tr>
</tbody>
</table>
Light always passes straight through transparent material (without changing direction).

An observer can see more of his or her mirror image by moving further back from the mirror.

The mirror image of an object is located on the surface of the mirror.

To be seen in a mirror, the object must be directly in front of the mirror or in the line-of-sight from the observer to the mirror.

The image of an object placed to the side of a plane mirror does not exist for any observer.

A plane mirror forms real images.

The convergent lens increases the speed of the light

Blocking part of the lens surface would block the corresponding part of the image.

An image can be seen on the screen regardless of where the screen is placed relative to a lens.

To see a larger image on the screen, the screen should be moved further back.

The size of an image depends on the size (diameter) of the lens used to form the image.

Images can be in two places.

Lenses are not necessary to form images.

3. METHODOLOGY

The participants in the study were 246 first year university students (age from 18 to 21). All of them had studied optics in secondary school.

From a survey of literature, it is found that most works on misconceptions about optics have employed interviews and/or open-ended questionnaires. Little research has used multiple choice tests. In our work, the paper multiple choice test was chosen as most appropriate for investigating a sample of 246 students and to diagnose students' misconceptions.

We utilized questions which had been used in previous studies of the light preconception (where their validity and effectiveness had been proved).

Our questionnaire comprised 12 questions, 10 of which are selected and partially modified from the studies investigating students' conception about vision, propagation of light, and imagery in reflection and refraction (Guesne, E. (1985), Viennot L. (1996), Fetherstonhaugh, (1990), Goldberg, F M. and McDermott L. C, (1983), CHUNG-CHIH CHEN, (2002),) and 2 of them (questions 2 and 3) redefined by the researchers (see table 2).

The test was taken by the students in a regular class environment, prior to the optics teaching for that year, under the condition of no time limit.

Table 2: Questionnaire description.

<table>
<thead>
<tr>
<th>Question</th>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>-Q1</td>
<td>Vision</td>
<td>-Utilised the alternative frameworks for seeing identified by Guesne 1985</td>
</tr>
</tbody>
</table>
4, RESULTS AND DISCUSSION

We present our results in four different sections: about conceptions around vision, propagation of light and image.

4.1 Vision:
Less than 50% (45%) have a scientific concept about vision: to be able to see the object, light coming from the light source to the object which reflects it and then light goes into the eye.

Significant numbers of students believed that light comes from eyes to the simple (26%). This idea founded the Grek scientists. A similar number of students (20%) thought that to see we don’t need any material link between eyes and the objects observed. The objects are seen because they are bathed in light. This understanding of vision represents the initial stage in a succession of models of rising complexity that an individual adopts in the course of knowledge development (Gallili, 2000).

4.2 Propagation of light
In the following situation, we have asked student about what happen if there is vacuum (no air) inside of the camera obscure. The answers of this question are in table 3 (see figure 1).

<table>
<thead>
<tr>
<th>Table 3: Light propagation in the vacuum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Answer</strong></td>
</tr>
<tr>
<td>-no change</td>
</tr>
<tr>
<td>- disappears</td>
</tr>
<tr>
<td>- a spot of light</td>
</tr>
<tr>
<td>- no answer</td>
</tr>
</tbody>
</table>

Almost half of the questioned students (44%) in Algerian university (before optics course) believe that the air is necessary for propagation of light. Also Sexena (1991), in its research to identify that Indian students conceptions in optics (16 are 20 years old), affirms that for many subjects the light cannot penetrate in a completely empty room (vacuum).

Significant number of students (21) thought that light propagates in only one direction (horizontal) under the conditions where the air does not exist.

In other questions (q3 and q4) there is a mask with a small triangular hole between a small bulb and screen (Woslait.K and McDermott 1998). The students are asked about the appearance of the image in the normal condition and under the condition where air does not exist.

The results obtained in this case confirm the presidents’ results. Under the normal condition (presence of air) more than 48% give a good answer (triangle on the screen). But, when the air doesn’t exist 36% of the students think that image disappears and approximately 21% of students believe we will see a small spot on the screen.
The new students misconception that we have found is that the light propagate in the horizontal direction when the air doesn’t exist.

4.3 Shadow
In this item we ask students about the shadow of a ball (obstacle) between bulb and screen. If the light source is very small, 37% of students think that the obstacle will blocks all the light and we will see a black screen. In the case where the source of light is very large (bigger than the obstacle), the screen becomes completely enlightened.
For 46% of the questioned students, the shadow exists on the screen in the case where the source of the light has the same dimension as the obstacle. It seems that students holding the views corresponding to the Shadow Image scheme do not predict partial shadows (penumbra) (Gallili 2000).

4.4 Image formation
With an aim of knowing the students misconceptions about the formation of the images by reflection, we put questions about the image of the sludge which is on a table in front of a plane mirror.
Obviously, student’s schemes of knowledge may not conform to scientific conceptions and may represent alternative interpretations of reflection. The students’ misconceptions are listed in table 4 along with their percentage frequency of occurrence.

Table 4 Students’ misconceptions

<table>
<thead>
<tr>
<th>Students response</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>-The image of the sludge in front of a plane mirror is on the mirror surface</td>
<td>43%</td>
</tr>
<tr>
<td>-The image of the sludge in front of a plane mirror is in front of mirror.</td>
<td>35%</td>
</tr>
<tr>
<td>-The image of sludge placed in front of a mirror would move to the right if they moved to the left.</td>
<td>41%</td>
</tr>
<tr>
<td>-There is no image if the sludge is not in front of mirror.</td>
<td></td>
</tr>
<tr>
<td>-The image of sludge placed in front of a mirror would move to the right if the observant person moved to the left.</td>
<td>31%</td>
</tr>
<tr>
<td>-If distance of the sludge from the mirror is increased the image would be smaller</td>
<td>40%</td>
</tr>
</tbody>
</table>

Most of the student’s misconceptions about the formation of image by using the convergent lens were shown in other studies. (MaCdermott, 1996)
When the screen moves towards or away from the lens, many students (31%) considered that the image will become bigger and sharp. A similar number of students (32%) thought that the image given by lens will become smaller but remain sharp.
When half of a lens is covered, 45% of students believed that only half of the image of object appears on screen. The rest of the image is blocked. And significant number of students (28%) thought that the image will have the half of dimension.
22% of students thought that covering a centre of lens produces a half-image. But, for 43% of the questioned students, the image disappears. They think that the centre of the lens is responsible of image formation. In optics courses (or manual), we always found the light rays which passed from the centre of lens.

5, CONCLUSION
No change in students’ misconceptions after 20 years of research concerning light and optical phenomena. Misconceptions, which have been found in earlier studies, were also determined in this study.
We also have found a new misconception. We can summarise these results as follows:
- Light propagates in the horizontal direction when the air doesn’t exist.
- The centre of the lens is responsible of the image formation.
The misconceptions about optics phenomena are resistant to change with scientific knowledge (Cigdem. Sahin, 2008). Furthermore, this study offered to the teachers an opportunity to get acquainted with how they can study their pupils’ preconceptions in optics as a part of their daily practice.

6, REFERENCES


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Optical phase measurement emphasized

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ABSTRACT
In undergraduate optics laboratory, one thing that is not easily achieved is quantitative measurement of optical phase. The reason is that optical phase measurement usually requires expensive interferometers. We demonstrate measurement of relative optical phase shift upon total internal reflection. Total internal reflection, though known by every student of optics, is remembered by 100% reflection at an interface when angle of incidence is greater than the critical angle, that is, it seems all the same beyond the critical angle. This is not entirely true if one considers the optical phase, which keeps changing upon total internal reflection as the angle of incidence is varied. Furthermore, for linear polarization states perpendicular to or in the plane of incidence (s- and p- polarization), optical phase changes differently upon total internal reflection. Therefore, a linearly polarized beam composed of both s- and p- polarization undergoing total internal reflection becomes elliptically polarized. We show how to determine relative optical phase change between s- and p- polarization states through analysis of the outgoing elliptically polarized beam. Such optical phase change can also be theoretically calculated using Fresnel equations.

1. INTRODUCTION
For any harmonic signal, amplitude and phase information are both essential. For example, in communication applications, amplitude, frequency, and phase modulation schemes are all well established methods. In optical communications, however, intensity modulation is mostly used. Although phase modulation at optical frequencies is straightforward, it has never become a preferred method. The main reason for this is that direct phase detection at optical frequencies is extremely difficult, whereas intensity detection through photodiodes is straightforward. The difficulty for direct phase detection stems from the fact that one optical cycle is a few femtoseconds ($10^{-15}$ second). Photodetectors that can respond in such a short amount of time have not yet been invented. Furthermore, in a typical optical communication system phase may constantly vary. Consider, for example, a semiconductor laser, a piece of optical fiber, and a photodetector. Unless the optical fiber is in an ultrastable condition, that is, neither temperature fluctuations nor vibrations occur in the environment, phase will constantly fluctuate due to temperature and stress induced changes in refractive index and length of the optical fiber. Consequently, detection of absolute phase at optical frequencies is impractical.

Although measurement of absolute optical phase is both very difficult and impractical, there are many optical devices that work based on optical phase changes, that is, relative optical phase. There are many interferometric devices that can measure relative optical phase through interference of two beams that are originally split after being emitted from a source. Among many types of optical sensors, those utilizing phase change as their working principle are usually superior to sensors based on optical intensity measurement.

In optics curriculum, numerous qualitative demonstrations of interference phenomena can be performed. Students, including those taking only introductory physics classes, can be easily shown the interference pattern through a double slit arrangement. Typically, a laser beam impinging on two narrow slits that are separated by a fraction of a millimeter results in an interference pattern on a screen. In optics laboratory classes, more advanced experiments, such as Michelson interferometer or Fabry-Perot interferometer are possible. In all these cases, most of the time, the student experience is limited to fringe counting, that is, more of a qualitative approach is utilized rather than a quantitative description of optical phase.
An important phenomenon where optical phase manifests itself is total internal reflection. There are, for example, sensors dependent on relative phase shift upon reflection from an interface. Fresnel rhomb is an optical component that works based on optical phase shift upon total internal reflection. In typical experiments involving total internal reflection, students are asked to send a laser beam to a prism, and observe the reflected and refracted beams as the angle of incidence is varied. Of course, beyond the critical angle, one observes total internal reflection, which is simply 100% reflection, and the transmitted beam disappears. If the prism angles are known and measurement of the angle of incidence is carried out, then the critical angle can be determined. If the reflectance—ratio of the reflected to the incident optical power—at, for example, glass-air interface is measured, one can verify Fresnel equations. In all such experiments, however, one merely deals with optical power measurements, and optical phase changes are omitted. Students may leave the lab thinking that beyond the critical angle, total internal reflection is nothing but 100% reflection. This is not true. In fact, total internal reflection is a very interesting phenomenon with many subtle aspects. One of these subtleties is continuous change of optical phase upon total internal reflection. To study the optical phase change upon total internal reflection, one needs to perform a complete analysis using Fresnel equations.

Optical phase change can be measured interferometrically. There are, however, multiple challenges that need to be faced in a typical interferometer setup. First, the setup needs to be on a sufficiently heavy optical table, and one needs to keep the arms of the interferometer stable. Such stringent conditions may make it difficult to emphasize quantitative characterization of optical phase in an undergraduate laboratory.

We propose in this paper a simple experiment emphasizing optical phase change based on measurement and analysis of elliptically polarized state of light that is formed upon total internal reflection. We present the relevant theory on elliptically polarized light and Fresnel equations, and demonstrate both qualitative and quantitative experiments that demonstrate optical phase shift upon total internal reflection.

2. THEORY

2.1. Elliptically polarized light

If electric field vector of an electromagnetic wave sweeps an ellipse, it is said to be elliptically polarized. For a plane wave traveling in the $z$ direction, and if $x$ and $y$ axes represent horizontal and vertical directions, respectively, the electric field vector of an elliptically polarized beam can be written as:

$$\vec{E} = E_{0_x} \cos(kz - \omega t + \phi_x) \hat{i} + E_{0_y} \cos(kz - \omega t + \phi_y) \hat{j}$$

Elliptical polarization is the most general expression of polarization state. Linear and circular polarization states are special cases. If $\phi_x = \phi_y$, we obtain linear polarization. If $|\phi_x - \phi_y| = \pi/2$ and $E_{0_x} = E_{0_y}$, then we obtain circularly polarized light. More information on polarization can be found in any standard text in optics, such as ref. 2. Elliptically polarized light can be analyzed with various methods.

2.2. Fresnel equations and optical phase shift

Fresnel equations result from Maxwell’s equations solved at an interface. Reflectance depends on both the angle of incidence and the polarization state of the incident beam. A well-known effect illustrating the polarization dependence is of Brewster angle: For a light beam linearly polarized parallel to the plane of incidence—p-polarized or TM (transverse magnetic)—the reflected beam diminishes at a certain angle (Brewster angle or polarization angle); for a light beam linearly polarized perpendicular to the plane of incidence—s-polarized or TE (transverse electric)—there is always some reflection as the angle of incidence is varied.
The reflection amplitude coefficients—ratio of reflected electric field to incident electric field—are needed to describe the amplitude and phase changes upon reflection at a dielectric interface. The reflection amplitude coefficients $r_s$ and $r_p$ for s- and p-polarized light, respectively, can be expressed as:

\[
\begin{align*}
    r_s &= \frac{\cos \theta_i - \sqrt{n_t^2 - \sin^2 \theta_i}}{\cos \theta_i + \sqrt{n_t^2 - \sin^2 \theta_i}} \\
    r_p &= \frac{n_t^2 \cos \theta_i - \sqrt{n_t^2 - \sin^2 \theta_i}}{n_t^2 \cos \theta_i + \sqrt{n_t^2 - \sin^2 \theta_i}}
\end{align*}
\]  

(2)

(3)

where $\theta_i$ is the angle of incidence, $n_u = n_i/n_t$, and $n_i$ and $n_t$ are the refractive indices of the incident and the transmitted media, respectively. Using reflection amplitude coefficients, we can calculate reflectance by simply the product of an amplitude coefficient and its complex conjugate. Reflectance at air-glass interface for both external ($n_i < n_t$) and internal ($n_i > n_t$) reflection cases are shown in Fig. 1. Note that for internal reflection, the reflectance is constant at 100% beyond the critical angle.

As a light beam is reflected at a dielectric interface, not only does the reflectance depend on its state of polarization and the angle of incidence but also does the phase of the reflected beam. If $n_i < n_t$, reflection amplitude coefficients are real, and amplitude phase shift is either 0 or $\pi$. If, on the other hand, $n_i > n_t$, phase shift is 0 or $\pi$, or it varies continuously between 0 and $\pi$ in the case of total internal reflection, where reflection amplitude coefficients are complex. (Fig. 1) In order to calculate the phase shift upon reflection we can simply calculate the argument of the amplitude coefficients. The relative phase shift $\Delta \phi$ can be written as a function of $\theta_i$ and $n_u$ as:

\[
\Delta \phi = \arg(r_p) - \arg(r_s).
\]

(4)

Fig. 2 shows the relative phase shift for total internal reflection at air-glass interface. This figure summarizes the goal of the experiments to be presented in this paper, that is, we will experimentally demonstrate the validity of the curve in Fig. 2, which shows that relative phase shift $\Delta \phi$ varies between 0 and about 45° giving rise to elliptical polarization.

2.3. Calculating transmission of an elliptically polarized beam through a linear polarizer

A linear polarizer in Jones calculus can be described as follows:

\[
P = \begin{pmatrix}
    \cos^2 \alpha & \cos \alpha \sin \alpha \\
    \cos \alpha \sin \alpha & \sin^2 \alpha
\end{pmatrix}
\]

(5)

where $\alpha$ is the angle between the horizontal (parallel to plane of incidence) and the polarization transmission axis. As shown in Fig. [exp1], if we send a linearly polarized beam $P_0$ to the prism, then it becomes elliptically polarized ($P_1$) upon total internal reflection. We can express $P_0$ and $P_1$ as follows:

\[
\tilde{P}_0 = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 1 \end{pmatrix}
\]

(6)

\[
\tilde{P}_1 = \frac{1}{\sqrt{2}} \begin{pmatrix} e^{i \Delta \phi} \\ 1 \end{pmatrix}
\]

(7)
If the elliptically polarized light $\vec{P}_1$, then, goes through a linear polarizer, the polarization vector out of the polarizer $\vec{P}_2$ can be obtained by applying the linear polarization matrix (Eq. 5) on $\vec{P}_1$ (Eq. 7):

$$\vec{P}_2 = \frac{1}{\sqrt{2}}(e^{i\Delta\phi} \cos \alpha + \sin \alpha) \begin{pmatrix} \cos \alpha \\ \sin \alpha \end{pmatrix}$$

(8)

If one measures the intensity through the polarizer as the polarization axis is turned between $\alpha = 0^\circ$ and $\alpha = 360^\circ$, the intensity of the transmitted beam will be given by:

$$I(\alpha) = I_{\text{max}} |\vec{P}_2|^2 = \frac{I_{\text{max}}}{2} [1 + \sin(2\alpha) \cos(\Delta\phi)]$$

(9)

3. EXPERIMENT

3.1. Qualitative demonstration of optical phase change upon total internal reflection

Before any quantitative measurement, we can qualitatively show that there is indeed some optical phase change upon total internal reflection, which is revealed by modification of the polarization state. One can send a laser beam to a prism such that light is polarized at 45° with the horizontal. If we place and rotate a polarizer in the path of the beam right before the beam enters into the prism, we can reduce transmission to almost zero, which occurs when polarization axis of the polarizer makes 90° with the polarization direction of the beam. If we now take the polarizer—without modifying its polarization axis direction—and place it in the path of the beam after it exits the prism (Fig. 3), we notice that light is no longer totally blocked indicating modification of the polarization state. Rotating the polarizer axis will further reveal that the beam is not linearly polarized. Rather, it is now elliptically polarized.

Which event causes the polarization change? Entering the prism, exiting the prism, traveling in the prism, or total internal reflection? We will now discuss each of them and suggest simple experiments to investigate how each of these events can cause a polarization change.

As the beam enters and exits the prism it goes through glass-air interface, and it partially reflects. From Fig. 1, we know that reflectance and transmittance are both different functions of angle of incidence for s- and p-polarizations. Therefore, if we send a beam that has equal s- and p-polarization components, then we might have some polarization change depending on the angle of incidence. We should also consider phase shifts. Except for total internal reflection we see from Fig. 1 that phase shift for reflection is 0 or 180 degrees. For transmitted beam there is no phase shift. Therefore, variation of reflectance based on polarization and phase shifts might cause a polarization change, but cannot result in elliptically polarization, but they can change the polarization direction of the linearly polarized light. For close to normal incidence, however, both polarizations have equal reflectance and transmittance for external and internal reflection cases, and consequently no polarization change is expected upon entry to and exit out of the prism.

For an ideal non-crystalline material, such as glass, one expects no birefringence. Therefore, it is unlikely that the polarization be modified while the beam is traveling in the prism. For crystals, such as calcite, depending on the polarization axis relative to the crystal axis, we can expect polarization modification. If there is any stress frozen-in during fabrication of the prism, however, then we can expect some stress-induced birefringence. We can check whether the prism has any stress-induced birefringence by sending a beam so that it goes through the prism without any total internal reflection. If we know the angles of incidence at each interface, then we can estimate the outgoing polarization, which should still be in a linear polarization state. If the polarization is not linear, we can conclude that the prism might have some stress-induced birefringence.
If all the above tests show that there is no polarization modification that makes the outgoing polarization elliptically polarized, then the remaining option is that total internal reflection makes it happen, as expected from the Fresnel theory at interfaces. As displayed in Fig. 1, when light undergoes total internal reflection at glass-air interface, s- and p- polarization components will incur different phase shifts, which will result in elliptically polarized light.

3.2. Determining phase shift difference by a polarizer and a photodetector

Experimental setup is shown in Fig. 3. A single polarizer and a photodetector—without a quarter-wave plate—can be enough to determine the relative phase shift. We used a silicon PIN photodiode (Thorlabs FDS100) with a load resistor, and read its voltage output with a digital voltmeter.

The best way to determine \( \Delta \phi \) is to use nonlinear least squares fitting algorithm, which is readily available in commercial data analysis software, such as Igor Pro or Origin. After taking data for the transmitted intensity through the polarizer as a function of the angle \( \alpha \), a nonlinear least squares fit to Eq. 9 with \( \Delta \phi \) as a free parameter can be carried out. There is, however, a subtle point. First, \( I_{\text{max}} \) needs to be determined. Secondly, \( \alpha = 0 \) corresponding to transmission axis being perfectly horizontal needs to be identified.

A better way to perform this nonlinear fit is to use two more free parameters: \( I_{\text{max}} \) and \( \beta \), an angular offset for \( \alpha \). Therefore, a nonlinear fit to:

\[
I(\alpha) = \frac{I_{\text{max}}}{2} \left[ 1 + \sin(2\alpha + \beta) \cos(\Delta \phi) \right]
\]

where \( I_{\text{max}}, \beta \) and \( \Delta \phi \) are free parameters is more appropriate.

Note that this method is only possible since we already know that the relative phase shift upon total internal reflection in the prism is less than \( \pi/2 \). Otherwise, there will be some ambiguity in the measurement, as phase shift differences of \( \Delta \phi \) and of \( \Delta \phi + \pi \) result in the same transmitted intensity function. Fig. 4 shows data for \( \theta_i = 51.6^\circ \) fitted with this function revealing \( \Delta \phi = 45.7^\circ \pm 0.3^\circ \). We repeated the data collection and analysis for multiple angles of incidence thereby obtaining Fig. 5, which confirms excellent agreement between data and theoretical curve that was calculated using Fresnel theory.

3.3. Total internal reflection in a right angle prism vs. other prism types

No matter which method we use to determine the polarization state after the light beam comes out of the prism, we assume that the incoming polarization is always linear, and have equal components for each axis. In reality for the right angle prism shown in Fig. 1, this is strictly satisfied only when light enters and exits the prism along the normal—perpendicular to surface—, giving rise to an angle of incidence of 45° at the total-internal-reflection surface. If the angle of incidence at entry is nonzero, however, then each polarization (parallel and perpendicular to the plane of incidence) will reflect differently making the polarization state of the transmitted beam change slightly.

An experimental solution to this problem is to use a half-cylinder prism, for which the beam always enters and exits along the normal, as shown in Fig. 6. We know, however, that such special types of prisms are not readily available in most undergraduate laboratories, whereas 45°-45°-90° prism is usually very common.

For a right-angle prism, we can adjust the initial polarization so that after the reflection at the first air-glass interface the desired polarization with equal components parallel and perpendicular to the plane of incidence is ensured. For the exit surface, the reflection needs to be accounted for in the theoretical curve, as the elliptically polarized light is reflected at the glass-air interface. Fortunately, this effect is not strong. We suggest the instructor to ask students to take data for total internal reflection with angles of incidence larger than \( \approx 70^\circ \) at the glass-air interface, and ask them to explain the reason for slight discrepancy.
4. CONCLUSION

We showed that one can teach about optical phase measurement utilizing a simple setup that measures relative optical phase shift upon total internal reflection. Fresnel equations can be used to calculate the relative phase shift. Because light that undergoes total internal reflection, analysis of elliptically polarized light enables us to determine the phase shift upon total internal reflection. One needs only a linear polarizer and a photodetector to quantitatively measure optical phase shift. In addition, within the experiment there are opportunities to use Jones calculus and nonlinear least squares fitting.

ACKNOWLEDGEMENT

We are very thankful to Michael Pantell for assistance in data collection. We are also extremely grateful to Prof. Peter Siegel for his comments and suggestions.

REFERENCES

Fig. 1 Reflectance and phase shift upon reflection as a function of angle of incidence for s- and p-polarized beam at glass--air interface ($n_{\text{glass}}=1.5$ and $n_{\text{air}}=1.0$). $\theta$ is the polarization angle (Brewster angle), and $\theta_c$ is the critical angle. When phase shift is constant (0° or 180°) reflectance continuously varies for both external and internal reflection; when reflectance is constant at 100% (total internal reflection), then phase shift continuously varies.

Fig. 2 Relative phase shift upon total internal reflection, which is the difference between phase shifts of s- and p-polarized light. The plot is produced for typical glass-air interface, where we used 1.00 and 1.50 for refractive indices of air and glass, respectively.
Upon total internal reflection within the prism, light that is initially linearly polarized ($P_0$) becomes elliptically polarized ($P_1$). By rotating the prism while keeping the plane of incidence unchanged, we can take data at various angles of incidence. With a polarizer, and a photodetector it is possible to determine the difference in optical phase change upon total internal reflection for s- and p- polarizations.

Data for $\theta_i = 51.6^\circ$ fitted to function in Eq. [fit]. From this nonlinear fit: $\Delta\phi = 45.7^\circ \pm 0.3^\circ$. There are three free parameters for the fit: $I_{\text{max}}$, $\beta$ and $\Delta\phi$. 
Fig. 5 Relative phase shift data at various angles of incidence. Theoretical curve is obtained for $n_{ii} = 1.00/1.50$, that is, air-glass interface.

Fig. 6 Instead of using a right-angle prism, one can use a half-cylinder prism, for which the beam enters and exits along the normal if is directed towards the center. As a result, the polarization state will not be affected as the beam enters and exits the prism.
Optoelectronic Technology Profiles – Motivating & Developing Research Skills in Undergraduate Students

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ABSTRACT
A case study is described of the redesign of an assessment task – the writing of an Optoelectronic Technology profile – to achieve improved outcomes in student education and capability development, in particular, research skills. Attention is drawn to the value of a formally scheduled discussion between teacher and student around controlling the scope of the profile via an appropriately constructed “brief”, and the selection and evaluation of the reference resources to be used in completing the task. Student motivation is improved through “student publishing” and encouraging students to regard their technology profile as an example of their work that can be shown to potential employers, possibly as part of a portfolio. Students have the choice as to whether they will also use the technology profile task as a vehicle to develop teamwork experience and skills.

INTRODUCTION
Macquarie University introduced a three year Bachelor of Technology (Optoelectronics) degree as one of a program of BTech degrees in 1990. The first cohort of students completed the degree in 1992. The graduates of this degree were targeted to employment in the emerging photonics industries of Australia. Thus, components of the degree (and its successor phased in from 2007) have to address development of skills and capabilities in several key areas such as: knowledge and understanding of appropriate content; problem solving skills; comfort and confidence with sophisticated photonics and optics related instrumentation; communication skills; time management; and research skills. One key assessment task to develop the latter three skills requires the students to research and write a Technology Profile, on an area of optoelectronic/photonic technology of their choice, most often from a comprehensive list provided. This was one of the assessment tasks in the unit of study “Optoelectronic Systems and Devices II”, a third year, second semester unit. They also gave a seminar to the class and teaching staff, drawn from the content of their Technology Profile. After almost ten years of this offering, teaching staff noted that the engagement by students with this assessment task, was waning. Also, the quality of the technology profiles submitted was perceived as diminishing and there was an increase in use of “cut-and-paste”. These changes were not judged as being correlated with any identifiable change in the ability or background of the student cohort at that time. Instead it was concluded that a process of renewal of the task should be undertaken with the aim of increasing student motivation, increasing student engagement and learning, decreasing plagiarism, increasing the priority student’s gave to completing the task, and increasing the real and perceived benefits by the students. These learning dimensions are summarised in Table 1. To assist the students to develop the necessary research skills they are given an example of an Optoelectronic Technology Profile written by the author, along with a “how to/ where to” find the information that will be needed for different types of technology profile. Examples are reviews of a mature technology, or a state-of-play of an emerging technology. Students are assisted to use their “brief” as a tool to manage the reference set that needs to be assimilated and synthesised to adequately address their chosen topic. They learn about time and project management, as well as the technology, via this task design.
Learning Dimension

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<table>
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<tr>
<td>Student motivation</td>
<td>to be increased</td>
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<td>Student engagement and</td>
<td>learning - to be increased</td>
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<td>Research skills</td>
<td>to be developed</td>
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<td>Original authorship</td>
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<td>Quality Writing</td>
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<td>Creativity – the brief,</td>
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<td>creative communication</td>
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<td>Selection of references</td>
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<td>Presentation Skills</td>
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<td>Planning</td>
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<td>use of time</td>
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<td>Completing the task</td>
<td>within a planned timeline</td>
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<td>Plagiarism</td>
<td>to be decreased</td>
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<td>Increase the real and</td>
<td>perceived benefits gained by students</td>
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Table 1: Summary of planned learning outcomes and skill and capability development.

Student motivation is also addressed by “publishing” an annual volume of the technology profiles from the class as a whole and this has been a successful motivator for most students. Students are encouraged to produce an example of their work that they can show to potential employers. This student publishing was one of the features of teaching practice in the department that was selected for inclusion in the resource booklet from the project “learning outcomes and curriculum development in physics” produced as a national resource for tertiary physics teaching and learning in Australia. Plagiarism is still an issue for a small number of students and some technology profiles are not “published” for this and other reasons. The importance of the dialogue between the “teacher” and each student as an individual, around the task, emerges as a key driver of deeper learning. Motivating students to complete the planning stages of the task in good time, so they may avoid making poor decisions on topic, and reference resource selection, with inadequate time to complete the task to the best of their abilities, remains a challenge. Student engagement, and therefore benefits, remains variable across the student population. A major benefit of the explicit and detailed nature of the task design is that it facilitates the teacher to have an evidence based discussion with individual students on how they could readily improve by planning and increased engagement.

Fig. 1 Optoelectronics technology profile volumes as distributed to each student in the class. Profiles are copyright of the individual students and permission must be sought from the student for profiles to be distributed outside the class.
THE OPTOELECTRONIC TECHNOLOGY PROFILE TASK

The description of the Technology Profile (TP) task that is distributed to students is given in Appendix A. The task is divided into three main components – (i) the development of a "brief", and the selection and evaluation of an appropriate set of reference materials; (ii) the completion of the technology profile, informed by the discussion of, and appropriate modification of (i); and (iii) producing a twenty minute presentation from the technology profile. A range of educational resources are available to support student learning in the various parts of the task and these are referenced below. Advice on development of the "brief" and accessing reference resources is also illustrated to the students in the context of an example TP distributed to students. This advice is reproduced in Appendix B. A PERT diagram of the skills and capabilities to be developed, and the elements of the task that support them, is shown in Fig. 2. To support the prime focus on developing research skills, this figure should also be interpreted to students to note the link between good time management and good communication skills as necessary partners to good research skills. It is possible to present all these skills as research skills.

Fig. 2 PERT diagram of the components of the task, the skills to be educated and developed, and the links and relationships between them. Sub-tasks and the sub-skills appear chronologically down the time management and communication columns of the diagram and correlate across the diagram.
The students completing this task have had extensive experience with writing laboratory reports on experiments they have completed – for all of three hour, six hour, and nine hour experiments across optoelectronics, optics, and physics. Their laboratory report writing skills are well developed and the consensus guideline used by all students in the department is informed by research into processes for improving student writing\(^2\). They have also completed assessment tasks involving familiarisation with optoelectronic device and system specification sheets and application notes. In this task they are building on this experience and capability to write the technology profile. Accessing standard educational support materials on evaluation of reference resources\(^3\)–\(^8\) and report writing\(^9\)–\(^11\) does facilitate completing the task. However, it is also important to inform the students of the need to include reference resources such as product information and patents that are not highlighted in many of the standard guidelines for “How to do library-based research”.

It is the discussion of the task that occurs, between teacher and students, that is the vehicle by which students learn a number of important points:

(i) How the type and quality of the reference resources used will, in large part, determine the quality of the technology profile.
(ii) How the type of reference resources that are best suited changes with the nature of the “brief”.
(iii) The importance of time and content management when completing the task is to be matched to a finite time available.

They are encouraged to assign a specific time allocation to completing the technology profile – say 25 hours. They then learn there is limited benefit in spending a large amount of the available time accessing more reference material than they can subsequently assimilate, compare and contrast. Student awareness of how the quantity of material that needs to be accessed and assimilated scales with the breadth of the technology area to be addressed, is raised. If the topic is to be a review of a broad technology area the students learn it will be very difficult to produce a high quality technology profile that is an excellent synthesis of the field without high quality review resources to use as references. The students have their awareness raised of the causal links between the scale of the task, an appropriate set of high quality reference materials that will be needed to complete the task to an excellent standard, and the time it will take to follow this through the various research stages to completion. The students are empowered to plan for an excellent technology profile through their control of the brief. They can scale the task to achieve an excellent technology profile in the time they assign. The task supports the student to gain self knowledge of their own capability, and, work rate and ethic. The lecturer can also provide feedback to the student on these issues as part of the discussion.

**Uptake by Teams**

Few students elect the option of completing a larger scale TP by a team. Four is the largest number of students who have cooperated on the task and pairs are the most common multiple submission. Despite the identification of the additional skills, that are highly valued by potential employers (grey-font text boxes in figure 1), that come from teamwork, students mostly pursue the task individually, on workload grounds. The assignment of a single grade to all members of a team, and the loss of an opportunity to produce an individual portfolio work sample are also disincentives to some students. However, the design of the task raises student awareness of the additional communication requirements brought by working in a team and the necessity of deploying a team to achieve a major report in a prescribed time. Students do engage more frequently, as a team, on smaller scale assessment tasks such as group assignments. However, compulsory teamwork would ensure students do gain teamwork experience. Formal contact hours for team meetings would then need to be assigned to the task.

**DISCUSSION & CONCLUSIONS**

The technology profile learning task has been designed to address specific learning dimensions as listed in Table 1. Evaluation of the success of the TP in achieving the planned improvements is based on student feedback and the reflections of the teacher as ‘practitioner’. They are not research based. The small student numbers in the class prevent a statistically significant result of a controlled study from being achieved in the specific case described. However, the purposeful engagement by students in the discussion of their
technology profile brief and the selection and evaluation of appropriate reference materials to use, and their subsequent modified briefs and reference sets, have been clear indicators of improved learning outcomes. Given the clear learning advantages identified it would be difficult to justify carrying out a controlled study, where similar GPA distribution groups are compared, one group denied the discussion step in the process in order to measure quantitatively the difference it makes in final assessment. The learning opportunity would be significantly reduced for the control group. The research skills of the teacher-as-guide are also important for the successful implementation of such learning tasks. The teaching staff are required to have active and current high level research skills. The planned inclusion of such learning tasks in the curriculum is one argument for the need to maintain highly skilled teaching-and-research staff in university departments. At a time when research skills are being identified as needing to be included explicitly in undergraduate curricula, at an increased proportion, any trend towards increased specialisation and separation of research and teaching in staff demographics will reduce the positive learning outcomes that can be expected in developing research skills in the graduates.

**APPENDIX A – DESCRIPTION OF THE TASK (EDITED)**

**Technology Profiles**

A technology profile on an optoelectronics device or system is due on “Date”. A list of suggested topics is supplied. The technology profile by an individual should be about 3000 words in length with appropriate use of figures and diagrams. You have the option to complete the technology profile as a team task with proportional scaling of the length. This would enable a profile covering a small technology area in great detail, or discussion of a related series of technologies, or a broader technology to be covered in detail, in addition to gaining teamwork skills. Most workplaces are structured around teams of people rather than individuals. The profile will be preceded by handing in a brief and a list/file of reference material to be used for the profile by “Date – 1 month”.

We will provide all students in the class with a bound copy of the profiles, subject to an appropriate level of quality being achieved. A copy of the profiles will also be included in the Optoelectronics Laboratory library. We hope that these profiles will be useful for you in your future careers, and you may wish to show your profile to potential employers to indicate your abilities.

**What is required?**

You should begin by determining your **brief** and the **reference sources** to be used in producing the technology profile. For example, imagine that you are a technology consultant, asked to summarise the current state of a particular optoelectronic technology (system or device) for a company that is considering using the technology. Your brief would be to understand how the system or device works, to analyse the advantages and limitations of the technology either generally, and/or for the specific purpose envisaged, and possibly to compare and contrast the technology with the one currently being employed. Selection of reference resources is critical to completing a high quality technology profile.

You **must** submit your brief and list/file of references to be used, and the members of your team if applicable, on or before “Date - 1 month”.

The profile should first state the brief, and provide an executive summary of no more than 250 words of your conclusions with respect to your brief. The body of the text should explain the physical phenomena underlying the technology that you select, and discuss typical designs, specifications, parameters or operating conditions. You should aim to provide an up-to-date survey of the topic, and must cite the sources (books, journal articles, patents, web sites and product literature) used for the profile fully. Depending on your topic, you may discuss commercial or fabrication issues associated with the technology. You should aim for a clear, readable style in your profile text. Profiles written by teams should not be simply an assembly of individual efforts, but should have a coherent overall structure. You should only choose the teamwork option
if you can timetable meeting as a team to plan and coordinate the production of a single, larger-scale technology profile. Building teamwork skills is highly desirable.

Seminars
Each member of the class will present a 20 minute talk, either as part of a team presentation or as an individual presentation from their technology profile, after “Date + 1 week”. Additional notes will be given on seminar presentation later in the semester.
Your audience will be both academics and peers, and each member of the audience will provide written comments on the talks. You should aim for clear, persuasive and logical presentation of the concepts and ideas. Enthusiasm and careful preparation are important for good presentations, and we expect you should practice your talk in advance to improve your timing and fluency. Teams should ensure that each member presents a coherent section of the whole.

Topics
Each individual and team should choose a different topic. This will avoid doubling up on topics in the seminars and bound collection of profiles to be distributed at the end of semester. The topic should be different to your industrial project. Other topics of your own choosing may be acceptable. Please discuss your topic, and subsequently develop your brief in discussion with “The Lecturer” early in the semester.

| Laser applications in chemical or trace gas analysis | Laser material processing |
| Laser applications in diagnostic and therapeutic medicine | Wireless optical communication systems |
| Fibre optical communications systems - long haul or metropolitan area networks | Wavelength reference sources for optical communication systems |
| Laser-assisted mass deposition | Dense wavelength division multiplexing |
| Laser marking | Optical data storage |
| Laser welding systems | Optical computing |
| The lasers and optics of lithography systems | Optical switching and signal processing |
| Remote sensing / LIDAR | Point to point communications |
| Barcode readers | Optical fibre gratings |
| Optically Pumped Semiconductor Lasers | Passive fibre components |
| Industrial holography | Active fibre components |
| Optical coherence tomography | Quantum dot lasers |
| Identify an application that needs a laser source at a single, particular wavelength and then research all possible laser systems that might meet the need. | Optical measurement standards (e.g. time or frequency standards) |
| Laser TV | High speed modulated light sources |
| 3-D displays | Integrated optic modulators |
| LCD or laser displays | Fibre-compatible optical switches |
| Spatial light modulators | Blu-ray Disc |
| Laser scanners | Planar integrated optoelectronics |
| Fibre endoscopes | Photonic crystals |
| Image processing | Photonic band gap materials or holey fibres |
| Confocal microscopy | Polymers in optoelectronics |
| LEDs for Lighting | Optical superprisms |
| Thin film optical coating systems | Radiometry |
| Spectrometers | Thermal or IR viewers |
| Optical wave meters | Laser beam profilers |
| Optical spectrum analysers | Laser beam quality measurement systems |
| Micro opto-mechanical systems | Photometry |
| Streak cameras | Laser power meters |
Students are issued with a detailed breakdown of how the technology profile and seminar are assessed.

APPENDIX B – ADVICE ON DEVELOPMENT OF THE “BRIEF” AND ACCESSING REFERENCE RESOURCES USING AN EXAMPLE TECHNOLOGY PROFILE - “ORGANIC SEMICONDUCTOR LASERS”, WRITTEN IN 2001

The Brief
A company which uses standard 5-100 mW semiconductor lasers, at wavelengths in the range of 650 nm to 1.5 μm, as a light source in a range of spectroscopic analysis equipment, has heard that the first injection laser based on an organic semiconductor was demonstrated and reported in the year 2000. The company engages you as a consultant to prepare a technology profile on organic semiconductor lasers so they may evaluate on what timescale, if ever, organic semiconductor lasers will be a possible alternative laser source for incorporation in their instrumentation. They are also interested to know if there are any identifiable advantages of organic semiconductor lasers over standard semiconductor lasers for their instrumentation.

Finding Appropriate Reference Material
As the injection organic semiconductor laser has just been demonstrated you know they will not be commercially available and so a search for commercial suppliers on the world wide web is not appropriate. There may well be some patents, however. Also, a normal precursor to demonstrating injection laser operation of semiconductor gain media is to demonstrate LED operation, and possibly laser operation using optical or electron beam excitation. You expect there will be a wealth of research literature on these topics and possibly some commercial suppliers. However, there are likely to be far more research papers than you would care to study and the information in them is likely to be in more detail than you require for your profile. Hence, the best start points for you are to

(i) locate the report(s) of the first injection organic semiconductor laser,
(ii) search for review articles on organic semiconductor LEDs, and lasers excited by means other than injection
(iii) look at websites of the institutions of the authors of any reviews found in (ii),
(iv) identify other key research papers or trade magazine articles from (i), (ii) and (iii) and database searching,
(v) search patent office sites for relevant patents, and,
(vi) search the web for any companies which have, or are about to commercialise organic LEDs or lasers.

A search of the INSPEC database for articles on organic semiconductor lasers published in the year 2000 locates the Science article of Schon et al that has generated the interest *. Still using INSPEC, combining a search of the complete database on organic semiconductor lasers and a search on reviews unearths a review published in 1999. This is good luck as a recent review article is a perfect primary source from which to begin your study and from which to source additional secondary sources. Also, having identified the address of someone sufficiently expert in the field to be the author of a review article you can search the www to determine if they have a website which may contain useful information on your topic. This is found to be the case. The Cavendish Laboratory Optoelectronics Group homepage has a report of a research project on LEDFOS (light emitting devices from organic semiconductors) which lists key references and companies active in the research. Careful reading of the review article shows its not actually a high quality reference in terms of coverage and content so its usefulness is more in determining other reference sources. A search of the US Patent Office website (www.uspto.gov) lists 12 patents on organic semiconductor lasers. You browse

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*This research was subsequently shown to be fraudulent and key papers were withdrawn from Science. However, the example is still used, but, it is also used to discuss research and professional ethics using the Schon case as an example.
through these and select one that has information that is relevant to your brief. The LEDFOS project website identifies several companies involved in commercial development of polymer LEDs, predominantly for display applications. You find the Philips company website has some excellent print resources on making polymer LEDs. With this collection of resources you are well placed to complete your technology profile for the company.

In selecting references to prepare the technology profile it is important to select resources you can understand with a reasonable amount of mental effort on your part and to ensure that they are sufficient in number, range and quality to gain an overview of your topic. If a “blowout” in reference material occurs you have the control of the “brief” that can be modified to avoid this blowout.

A copy of the example Optoelectronics Technology Profile – “Organic Semiconductor Lasers” is available upon request by email from Deb Kane

ACKNOWLEDGEMENTS
It is a pleasure to acknowledge discussions with A/Prof Judith Dawes and A/Prof David Coutts, both staff of the Department of Physics, Macquarie University with whom I have shared lecturing the third year “Optoelectronics Devices and Systems II” unit in which the Optoelectronic Technology Profile is one of the assessment tasks. The list of suggested topics evolves over time with input from all teaching staff.

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University to night school, to graduate school, to training to short course

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ABSTRACT

Observations from teaching and learning over a 50 year span in various venues are made. The emphasis is on optics/photonics, but excursions are made into lower frequency electro-magnetic waves. Night-school students have priorities and necessities that are different from full-time students, visiting foreign students have another goal, graduate students (and their supervisors!) have a focus on research, contractual programs and short-course participants have specific interests in equipment and projects. The requirements place different demands on timing, assignments, emphasis, etc, for the lecture/teaching/laboratory aspects of the programs. Lessons that have been learned over the years are outlined.

KEYWORD LIST

military, radiometric equation, supply teaching, professional courses, cultural difference, certificates, virtual experiments, Satellite Earth Station, weather satellite, co-op students, political decision

INTRODUCTION

This discussion is a career outline as it applies to ETOP. Some detail is given of specific courses and concepts on how a given topic was presented, and provides ideas that have worked for motivation, some that have not, some omissions, and some guidance and hints that may be useful for others. It is a kind of confession with suggestions. The programs are disparate, had different requirements, entailed varying effort, had mixes of lectures, demonstrations, and laboratory work, varied as to assignments and examinations as well as in mathematics content, and enjoyed different results. The order is not chronological, but by topic. Now ending a career as an optical engineering consultant there have been many opportunities to take note of what works and what does not.

a) Most recently: Subject Matter Expert, Maritime Helicopter Project, CFB Ottawa(North), DND, Ottawa, ON (2002-06)

TECHNOLOGY

A few final-year science and engineering students as well as many graduate students find work in their career discipline as teaching assistants, TAs. Individuals desire to supplement their income; the department needs the TA to advance the programs. Few TAs receive instruction as to how to teach or organize. The TA is an on-the-job trainee who is to demonstrate technology and provide some instruction. TAs are under stress to mark weekly reports, maintain good order, set up new experiments, and show how to overcome difficulties. For most TAs this is the first introduction to the teaching/education process.

The TA is often the only person with whom the student has close contact; the professor is a face at the front of the lecture theatre who appears for 45 to 50 minutes, two or three times a week. A student may wish to be involved in discussion, but there is little time opportunity. Hiring a TA is a value judgment. It must not be the hiring of a body to fill the position. To work as a TA is also a value judgment; the TA has to balance work with personal study. Not enough care is taken in choosing the TA nor by the TA in applying for the job.
A mistake that some universities make in presenting any laboratory program is to use antiquated equipment. This may be financially driven, or perhaps is a mistaken belief that the student should have an indication of the difficulties of experimentation. The expectation is that the student will develop patience, appreciate the work, and gain understanding. The reality is that it foments frustration, because results can be unconvincing. The student not needing to proceed beyond the initial optics course gets an incorrect impression of the discipline. Virtual demonstrations provide a far more flexible, smart, and illustrative picture.

Military personnel require technical instruction in their various disciplines. Lessons in radio communications were offered to a group of reserve airmen one night per week over a two-year span. A degree in engineering, PG work in progress, and a commission as an aircrew officer, qualified me as having some knowledge greater than the students’. Since my knowledge of aircraft radios was minuscule, the lectures were limited to basics: resistance, capacitance, inductance, Ohm’s law, and some circuitry. Like many new instructors, my mistake was to try to cover a year’s material in the first few lectures! Like all neophytes, the class wanted to understand the complexities of radio without knowing anything about fundamentals. The class was tolerant in the hope that the next week would see the resolution of everything! The goal was clear, but the delivery was murky. Such programs must be given by an experienced instructor in order to have value. Training for technicians has to change as the technology advances.

Undergraduate Programs

Untried lecturers can be asked to do many things:

1) While working on PG programs, many of us have been asked to fill-in for a supervisor; that is to “supply” teach, or substitute, for one or two lectures. The raison d’être is to give the professor some relief or perhaps to maintain 'momentum' because the professor is away, or possibly because of illness; the PG student gets a little experience. Students do not like it, the new face presents a new attitude, the professor does not like it, there is uncertainty whether the material was covered properly; the PG substitute does not like it, he or she is often not paid, and there is uncertainty whether the 'pitch' is at the right level. Unless a significant number of classes would be missed, it is better to cancel the lectures.

2) In large urban centres, the population base allows for classes in the evenings. Courses that were given by me working as a part-time lecturer three nights per week over six years included: optics, heat, atomic physics, fluid dynamics, and thermodynamics to physics students and electricity and magnetism to engineering students. Laboratories operated without TAs. Students went to assigned work stations, an operator activated the station and the student had a fixed time to carry out the experiment. If not completed, a new time was scheduled for the lab, but marks were then lost from the report. This program was successful, but the stress level is high; one of my first students was arrested for murder during the term, and a group in a different program, mistaken in their inferences about racial discrimination, vandalized the computing facilities!
A one-week course detailing use of laser anemometry equipment was joined. There were about 20 participants from eight or nine countries. The course included many details on advanced systems than was needed; the company's desire to try to sell more equipment outweighed the specificity. This course seemed to be a clone of a university course that had developed into a book, but the book was hampered by its unusual course-slide description format. Both the book and course are examples of multi-purpose efforts that fail.

**GENERAL PROGRAMS**

An opportunity was uncovered to enhance the education of foreign students taking engineering courses at various Canadian universities. Because of Canadian law relating to visitors, such students were not allowed to work in Canada; their sponsor, the Canadian International Development Agency, was keen to provide such an opportunity; two programs were organized for 2nd and 3rd year students at different Canadian universities.
Each program was of eight weeks duration, eight hours per day.

The first was to construct a weather-satellite tracking station. The effort used commercial kits to construct the various sub-systems—receiver, amplifier, power supply, and test equipment; the antenna and its tracking system were built from 'scratch'. The students were from Uganda, Kenya, Jamaica, and Taiwan. What they lacked in background was made up by desire. They came together to work on a project with a goal. A side benefit was the development of leadership skills as the project advanced. My education into the 'real world' came about when four of them disappeared suddenly because of direct death threats to them from their home country because they were getting an education!

The second saw the presentation of lectures and labs on: laser theory, IR detectors, radiometry, basic optics, electronic equipment, and communication fundamentals. The students were from Viet Nam, and Singapore. The program included visits to nearby government and industrial laboratories as well as many demonstrations of state-of-the-art equipment, techniques, and measurements. This project was too similar to a university lecture and laboratory program; the desired object of work experience was not achieved.

It was natural later to hire Canadian co-op students from Canadian universities to work as research assistants. Because of the rules associated with such hirings, the match between student and job is not always exact. In addition, when there is not enough financial resources to entice permanent staff, a compromise is required. The short term employee is usually a compromise worker.

\[ P_{\text{req}} = N_h \cdot \tau \cdot A_s \cdot \left( A_c / R^2 \right) \cdot \tau_{\text{atmos}} \cdot \tau_o \]
Here: \( N_i \) is the radiance, \( r_i \) is the reflectivity of the source or target, \( A_i \) is the cross section of the source, \( (A_i/R^2) \) is the solid angle for the receiver, \( A_c \) is the area of the collector, \( R \) is the range or distance between source and collector, \( \tau_{\text{atmos}} \) is the atmospheric transmittance, and \( \tau_o \) is the transmittance of the optics.

[\[p\]] University of Waterloo, Kitchener, ON, (1980-83)
[\[q\]] University of Sherbrooke, Sherbrooke, QC, (1988-89)
[\[r\]] Mechanical Engineering Department, RMC, Kingston, ON, (1976-2003)

Hidden in the radiance term is the emissivity (or reflectivity if is is passive). Students could see the significance of reflectivity, of solid angle, of atmospheric transmittance, of collector aperture, etc, and became interested in learning the detail associated with each of these parameters. The lectures were supplemented by several references \( 2, 3, 4, 5 \).

As this PG program became more established, scholars from other countries wrote to ask for Post Doctoral attachments as Research Associates. Funds were available, but RMC was not comfortable when a request came from a researcher in a country that was on DND's short list of places to avoid. Politics took precedence.

**SHORT COURSES**

As the PG program became popular, it became obvious at National Defense Headquarters, NDHQ, that others should have more than a rudimentary knowledge in ETOP. The Electro-Optics Short Course, duration two weeks \( 5 \), was organized for DND personnel and provided once per year at no cost \( 6 \). This attracted 19 to 22 serving officers, Captain to Lt Colonel, including two or three civilians each year to come to RMC. Special lecturers—some from industry, some from government laboratories, some from overseas—were found through personal contacts to present specific parts of the course. All were pleased to come, also at no cost for this was an opportunity to contact individuals who would be playing a key role in different departments in NDHQ. The program was in place for nine years. Two editions of notes were written and issued to all participants \( 7 \).

The Electro-Optics Short Course ended in 1996 with NDHQ suggesting that the two weeks be compressed into three days (or less)—an impossible task: ‘A sherry glass cannot hold the contents of a bottle of scotch—single malt at that!’ It is my view that the Electro-Optics Short Course ‘died’ because of a lack of visibility; that is, being a part of an ME department was not seen as having value within NDHQ. Due diligence had not been done to publicize and emphasize the utility of the program.

During a sabbatical \( 4 \), a different short course in Electro-Optics, 1/2-day per week for three months, was developed for technologists, for people who had some knowledge, but little specific optics background. There were 12 participants, but their presence depended on their on-going work; average attendance was six—not always the same six. Such courses need to be mandatory, but there was a lack of focus for some and not enough for others on this one. The notes \( 7 \) were available in French, but were not specific enough.

[\[s\]] Electro-Optics Short Course, RMC, Kingston, ON, (1988-96)

The Applied Military Science Department, AMS, was started at RMC with the purpose to repatriate a program previously given at RMCS for land element officers to upgrade their skills in the use and appreciation of vehicles, artillery, ammunition, and the sub-systems for control, and the appreciation of safety aspects \( 6 \). Known at RMC as the Land Forces Technical Staff Program, it lacked lectures in optical systems that included laser systems, thermal imaging, low light level TV, sighting mechanisms, etc. The lectures were provided at no cost, an allotment of 27 periods was available \( 8 \). The participants needed notes; the only notes available were those of the Electro-Optics Short Course \( 7 \). It is my understanding they are still in use. Being a mix of participants—arts and business, with a few science and engineering graduates—mathematics had to be
downplayed, but could not always be avoided.

A one-half day professional course on diffractive elements, was presented at two ICAPT(SPIE, OSA, IEEE) meetings v, w. Participants at professional meetings, having paid for a course, are demanding, but the presenters can be reticent about giving away all 'their secrets'. There are mixed feelings on the part of the presenter, when such a 'professional course' is offered. To my knowledge, there are few professional courses in optics/photonics that have been expand into text books, with one notable exception 9.

FURTHER COMMENTARY

Some of the optics/photonics problems that have been noticed follow:

a) Because optics is an old study, fundamentals tend to be accepted without full understanding. The true nature of a concept may be a problem for years because the 'little knowledge has become dangerous'; the mis-understanding has continued to be accepted.

b) sign conventions for image orientation, right/left and up/down, are readily accepted, but are forgotten when multiple elements are involved. Further problems are created when polarization is considered.

c) the terms aberrations and diffraction are often interchanged—their proper meaning is lost.

d) the distinctions between time constant, time of response, and rise time, is not appreciated.

e) diffraction is a difficult topic without the use of Fourier Transforms. The mathematics is essential. Showing the 'pretty pictures' to neophytes without expressing scale is useless. Far field and near field diffraction needs more discussion.

f) spectroscopic displays are beautiful; they are still beautiful even though the spectrometer/spectrograph may be poorly aligned. The need for proper laboratory alignment technique can be lost—the beauty hides the difficulties.

g) amplitude and phase are studied abstractly; not enough time is spent to understand why detector output depends on power, and the information about amplitude and phase is lost.

CONCLUSIONS

i) New faculty, be they lecturers, readers, or professors, should be required to 'sign off' on a basic instruction package obtained from the Dean's office before to begin lecturers, TA's must receive a modicum of instruction—a day at the least. Leaving the individual to use his or her initiative is asking for 'trouble'.

ii) Burying one program inside another does no one a service.

iii) Consistency in the presentation of lectures is paramount—consistency in use of symbols, in the logic, in the schedule, in the marking, in following the outline, and consistency in the treatment of students.

iv) Organization cannot be emphasized enough.

v) Language skills are poor. Associated with this is that too many marginal students are accepted into programs. At least 1/5 of one's career time is spent writing reports, the report must convey information.

vi) To be topical or fashionable without effective presentation of the fundamentals is a waste of time.

vii) Teaching by committee is anathema. Furthermore, multi-purpose activities are not effective.

viii) Supply teaching for a couple of lectures is not helpful. Supply teaching is sensible when the substitute can set the pace over an extended period so that the student is comfortable.

ix) Specific topics want specific answers -- not generalizations, nor a development of fundamentals.

x) Certificates or 'diplomas' without proper examinations only indicate attendance. Institutions accredited by national or provincial bodies should be the only issuers of documents associated with learning.

xi) Not enough effort is spent trying to understand and appreciate student concerns.

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Training Physics degree students in a research optics laboratory

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ABSTRACT

The unification of the new European studies under the framework of the Bologna process creates a new adaptation within the field of Physics this academic year 08/09 and in the coming years until 2010. An adjustment to the programs is required in order to migrate to the new European Credit Transfer System (ECTS), changing the credit from 10 to 25 hours. This adaptation is mandatory for the new students. However, the current students under the previous program have the opportunity to avoid these changes and to finish the degree with the old curricula.

One of the characteristics of the Image Processing Laboratory (IPL) is the feedback between the laboratory researchers and the students. From this mutual collaboration several students have participated in various scientific research studies. In general, when a student is introduced into the research group routine, they found some differences between the degree laboratory courses and the research laboratory dynamics. This paper provides an overview of the experiences acquired and the results obtained by undergraduate students in recent works related to liquid crystal display (LCD) characterization and optimization, LCD uniformity analysis, polarimeter design, LCD temporal fluctuation effects or diffractive optics and surface metrology.

Keywords: research optics laboratory, European higher education area, physics degree, final project, liquid crystal display, surface metrology.

1. INTRODUCTION

The unification of the new European studies under the framework of the Bologna process is leading Spain to the creation of a new studies curricula fully adapted to the new educational process. In the particular case of the Universitat Autònoma de Barcelona (UAB) and within the field of Physics, the new studies adaptation is being conducted this academic year 08/09.

The aim of the Bologna process is the so-called European Higher Education Area (EHEA), which is planned to be completely introduced in the year 2010. This initiative resulted in the reform of university systems in 29 countries which decided to participate. The implementation of the EHEA is done with the purpose of creating a new European educational area with a transparent range of high quality courses, providing the students and
scholars from other countries a more competitive, compatible and attractive education. The Bologna declaration of June 1999 shows some objectives that are supposed to be present in this new educational process. One of them, obtaining a system which permits the mobility of the students in all the European area and the possibility of integration of these students in the European work markets needs a convergence of the education systems from different countries. Then, the adaptation of the curricula, regarding structure, contents and definition of the competencies in terms of learning results is demanded1.

Since the 90s, professors of the Image Processing Laboratory (IPL) of the UAB have been given some subjects on Optics within the old Physics degree. One of the characteristics of the IPL is the feedback between the laboratory researchers and the students. From this mutual collaboration several students have participated in various scientific research works. Moreover, as a consequence of the Bologna process, we have adapted the experience of the IPL staff into the new structure of the Physics syllabus.

To take advantage of the feedback previously stated, diverse students collaborating within our research lines have been asked for giving us their perspectives related to the new studies curriculum, working techniques, degree of satisfaction, knowledge acquired, among others. The opinions collected in this survey are presented in this work. In addition, a brief report of some of the achievements reached by students in their IPL collaboration is also given in this paper. In particular, we provide an overview of the experiences acquired and the results obtained by students in recent researches related to liquid crystal display (LCD) characterization and optimization, polarimeters design and implementation, LCD temporal fluctuation effects on diffractive optics and x-ray flat mirror testing, specially related with the Lateral Shearing technique using a Fizeau interferometer.

2. BOLOGNA PROCESS AND ITS IMPLEMENTATION

2.1. Spain

The Spanish University framework is run by the Ley Organica 6/2001, December 21st and the Real Decreto 1393/2007, October 29th. The first one, states that the University carries out the public function of the higher education, especially by means of the creation, development, transmission and criticism of the science, the technique and the culture. According to the Real Decreto, the syllabus to achieve a degree should have 240 credits, except for the cases in which there is an opposite European directive, as the case of Medicine or Architecture. Each undergraduate degree has to be integrated in one of the following disciplines: Arts and Humanities, Science, Health Science, Social and Legal Sciences and Engineering and Architecture.

Education authorities are responsible for completing the full integration of the Spanish Education to the European higher education area. The development of the European Credit Transfer System (ECTS) has been one of the measures leading to the construction of the European higher Education area. This system permits that the equivalences and the recognition among degrees around Europe become easier. One of the important tasks of the Spanish education authorities is, also, to make compatible the Spanish University structure (4 years of undergraduate courses plus 1 year of master’s courses) with the European model (in general 3 years of undergraduate courses plus 2 years of master’s courses).

The introduction of the Bologna process in Spain is being implemented with difficulties, discussion and controversy. Among other reasons, this fact can be attributed to the lack of information about this topic given by the corresponding Authorities.
2.2. Universitat Autònoma de Barcelona

The Universitat Autònoma de Barcelona (UAB) is one of the most important universities in Catalonia. It has around the 23% of the students of the Catalan university system and the Bologna process changes should maintain this percentage of students. In 2008/09, UAB offers the following EHEA degrees in Physics, Humanities and Mathematics. In 2009/10 the majority of the degrees will be under EHEA guidelines.

In accordance with “El Mapa de Títols de Grau a la UAB”³, to make compatible the Spanish structure (4+1) to the European model (3+2), degrees have the structure (3+1), where the first three years conducts to a university specific degree, equivalent to the bachelor given by the majority of the European universities, and the fourth year conducts to the official degree in Spain.

In accordance with the guidelines established for the implementation of new EHEA degrees, all studies will include work placements. These can be either a compulsory subject which forms part of the core of the studies (practicum), or an optional subject which can be taken in the fourth year (work experience).

The degree scheme at the UAB (see Figure 1), shows that the 180 ECTS which complete the first three years include compulsory subjects, basic training and core training, while the fourth year concentrates on optional subjects and a compulsory final project¹.

Figure 1: The structure scheme for all the degrees of the UAB.

In the first year, students will attend compulsory basic training modules. The second and third years correspond to the core modules of the degree and are made up of compulsory modules. The last year, the fourth one, consists in complementary training and optional modules, and a final project from 6 to 15 ECTS. This innovative and additional possibility enables the student to obtain a second specialization in an additional area. The minors are UAB qualifications that students can take at the same time as they attend the courses or when they have finished the degree.
2.3. Physics

The degree in Physics has been implemented in the course 2008-09. It is a face-to-face learning and it has two fundamental objectives. Firstly, to enable students to obtain a solid scientific basis of the main concepts in physics both at a theoretical and a practical level. Secondly, to acquire interdisciplinary and transversal scientific training adapted to the new frontiers. Once the students complete the degree, they have a general training in physics and advanced knowledge in today’s most important scientific disciplines.

The different subjects of the curriculum are structured according to the following scheme: basic formation (60 ECTS), obligatory (105 ECTS), optional (63 ECTS) and the final project (12 ECTS). The degree structure allows the student to follow different specializations (minors) in the fourth year. They are called Fundamental Physics and Applied Physics. Figure 2 describes all the subjects proposed for the fourth year of the degree in physics. In order to obtain the minor in Fundamental Physics, they must complete at least 30 credits: 12 credits are from the Principal unit, 12 credits from Theoretical Foundations unit, and 6 credits from one of both. In order to obtain the minor in Applied Physics, they must complete at least 30 credits: 12 credits are from the Principal unit, 18 credits from Applications of Physics unit or choosing the work experience course. The student can also combine these specializations with a degree in Mathematics. In this last year, the final project is always mandatory and it has 12 ECTS.

<table>
<thead>
<tr>
<th>Optional subjects</th>
<th>Principal unit</th>
<th>Theoretical Foundations unit</th>
<th>Applications of Physics unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantum Mechanics</td>
<td>6</td>
<td>Advanced Quantum Mechanics</td>
<td>6</td>
</tr>
<tr>
<td>Theoretical Mechanics and non linear Systems</td>
<td>6</td>
<td>Fluids and Superfluids</td>
<td>6</td>
</tr>
<tr>
<td>Electrodynamics and Synchrotron Radiation</td>
<td>6</td>
<td>Quantum Optics</td>
<td>6</td>
</tr>
<tr>
<td>Statistical Physics</td>
<td>6</td>
<td>General Relativity</td>
<td>6</td>
</tr>
<tr>
<td>Solid State Physics</td>
<td>6</td>
<td>Quantum Information</td>
<td>6</td>
</tr>
<tr>
<td>Nuclear and Particle Physics</td>
<td>6</td>
<td>Applied Optics</td>
<td>6</td>
</tr>
<tr>
<td>Advanced Laboratory</td>
<td>6</td>
<td></td>
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</tr>
</tbody>
</table>

Figure 2: Subjects of the additional training for the fourth year.

The first final projects of the physics degree have been developed following different approaches. Thus, they can broadly be subdivided in two main types of work: bibliographic or research work. We think that the final project is an excellent framework to provide last year undergraduate students a first contact with a specific research field and to introduce them in the dynamic of a research group. In the following section, the main results of these final projects and some details of the feedback between the personal involved are provided.

3. DEGREE WORKS

The Image Processing Laboratory (IPL) is a part of the Optics Group into the Physics Department of the Universitat Autònoma de Barcelona (UAB). Since the IPL formation, the IPL staff has been involved in the physics degree, by teaching different subjects related to Optics. In particular, the aims established by the IPL
team are leading to two different main achievements: the training of new students in Optics and the development of different research lines always within the optics framework. Nowadays, the IPL team is developing the following research lines: Image processing, optical systems quality modification by means of non uniform transmission filters, characterization and optimization of Liquid Crystal Displays response, diffractive optical elements design, polarimeters design and surface metrology.

As we have shown in section 2, in order to obtain the new Physics degree, it is mandatory for the students to present a final project of 12 credits. The first final projects, corresponding to students which are finishing the Physics degree, have been submitted this academic year 2008-2009. As previously stated, the IPL team is participating in developing diverse final projects by leading and supervising some students work. The specific approach of the IPL staff when leading the degree works is detailed in section 4. During the students’ collaboration, we have structured the student duties (required for the degree work achievement) in four different periods. First, an introductory period: introduction into a research laboratory, work rules into the laboratory, knowledge of optical elements, healthy cautions required in the lab, introduction to the theoretical background required for the development of the specific research. Second, a period where the experiment is designed and performed: design and implementation of the experimental set-up, simulations developing, deeper understanding of the conducted research, performance of the experimental measurements needed in the research, and analysis of the obtained results. Next, a third period in which the knowledge acquired by the student is consolidated by resolving the doubts that arise in the analysis of the results and writing work process. Finally, a supervision and training of an oral presentation, that is required for the final project achievement.

In this section, we present some experiments and results of several degree works conducted in the IPL during the academic year 2008-2009. In particular, we shown three different works developed in the following research lines: LCD characterization and optimization, polarimeter design and surface metrology. In addition, we have done a survey between the students performing the final projects with the IPL team, with the purpose of extract some feedback with students. Some of their opinions are also provided in section 4.

3.1. Liquid Crystal Displays research line.

Over the years, spatial light modulators have been playing a key role in several of the optical applications developed by the IPL team: optical correlators, diffractive elements generation, apodizers implementation, among others. In this sense, we have used twisted nematic LCDs with helicoidal structure working in transmission or in reflexion (LCoS). In order to increase the optical application efficiency where a LCD is used, it is desirable to perform an optimization of the LCD response. Then, the IPL team has thoroughly studied the polarimetric characteristics of some LCDs and different LCDs characterization and optimization methods have been developed. One of the degree works developed in the first semester of the academic year 2008-2009, which has last six months, has been done in the LCDs research line. In this section, the research conducted by the student corresponding to its final project is briefly explained and some of the results are also provided.

LCoS displays are LCDs that work in reflection. They are very attractive in optical applications because the light beams perform a double pass thorough the device, leading to a higher phase modulation than transmissive LCDs with the same LC thickness. However, some degree of unpolarized light has been detected at the reflected beam when working with these devices. It has been shown that this depolarization is originated by time-fluctuations of the LC molecules optical axis orientation, which as a consequence of the type of binary signal addressed to the LCoS display, are not able to be still in a frame period. The temporal average of the LC molecules orientation fluctuations produces the detected depolarization values. In addition, there is an other physical effect related to the time-fluctuations phenomena that can adversely affect the efficiency of diffractive elements (DE) addressed to the LCoS display: the time fluctuations of the phase.

The Physics undergraduate student has characterized a PLUTO Spatial Light Modulator PA LCoS display by following the characterization method given in Ref. 8 that is based on the Mueller-Stokes formalism. The
novelty of this work with respect to the performed in Ref. 8 is that this device has parallel aligned molecules. The device under analysis has an active reflective mode matrix phase only LCD with 1920x1080 resolution and 0.7” diagonal. The pixel pitch is of 8.0 μm and the display has a fill factor equal to 87%. The signal is addressed via a standard DVI (Digital Visual Interface) signal. By means of the RS-232 interface and its corresponding provided software, different sequences (electrical signals) can be addressed to the driver. Then, we have selected a configuration which leads to a magnification of the phase fluctuation phenomena. The final project developed by the undergraduate student with the IPL staff presents two main studies: On one hand, the characterization and polarimetric analysis of the PA LCoS display and on the other hand, a study related to the phase-fluctuation phenomena. The whole experiment is done by illuminating the PA LCoS with a He-Ne laser beam (632.8 nm) and under quasi-normal incidence (angle of incidence equal to 2°).

Figure 3 shows the PA LCoS display characterization developed by the student. In fact, all the PA LCoS display Mueller matrix coefficients as a function of different gray levels are plotted. The experimental results indicate that all the coefficients are null except the m11 coefficient that is constant (equal to one) as a function of the gray level and the m22, m23, m32 and m33 coefficients that show a sinusoidal behavior as a function of the gray level.

From these and other additional results, we have proved that the PA LCoS display performs as a waveplate with its corresponding neutral lines at 0 and 90 degrees of the laboratory vertical and whose retardance value depends on the gray level addressed to the device. In addition, the results show that the PA LCoS display under analysis is a non polarizing, non diattenuating and homogeneous display.

The second part of the project work done by the undergraduate student is related to the phase-fluctuation phenomena, whose experimental prove is provided in Ref. 7. In addition, in Ref. 7 there is a theoretical discussion related to the phase-fluctuation effect. In fact, the dependence of the visibility of the interference pattern corresponding to the interference of two light beams as a function of the amplitude of the phase-
fluctuation is studied. In particular, large amplitude of the phase-fluctuation involves a reduction of the interference pattern visibility.

In order to obtain an experimental prove of this theoretical analysis, the PA LCoS device has been placed between two polarizers and the student has selected two different configurations of the external polarizers. In one case, the PA LCoS display shows a short phase-response (config. (a)), and in the other case, a large phase-response (config. (b)). As a consequence, the first configuration (config. (a)) leads to a small amplitude of the phase-fluctuations and the second configuration (config. (b)) leads to a large amplitude of the phase-fluctuations. Then, the undergraduate student has measured the phase-fluctuations as a function of the time corresponding to these two configurations. It has been done by using the diffractive method detailed in Ref. 7 and using the gray levels 0 and 160. The results are plotted in Fig. 4 (a), where it can be seen that the amplitude of the phase fluctuations corresponding to the config. (b) is clearly higher.

Next, by using an interferometric set-up\textsuperscript{7}, the student has detected the interference pattern for these two configurations, and by addressing the same gray levels used with the diffractive method. The results are given in Fig. 4 (b), where we see that in presence of large phase-fluctuations an evident visibility diminution of the interference pattern is detected, i.e., when using config. (b).

![Figure 4. a) Time fluctuations of the phase for two configurations config.(a) and config.(b); b) Interference pattern detected when using two light beams with the gray levels 0 and 160 and the two different configurations.](image)

3.2. Surface Metrology research line. Instrumentation for the flat mirrors testing.

In recent years, IPL staff have developed research projects dealing with surface metrology: aspheres deflectometry, wavefront sensors, etc. These projects use similar techniques to those applied in synchrotron mirrors testing. Given the characteristics of the light source, high intensity and brightness, the performance of the line of light is limited by the quality of the optical surfaces. This makes it necessary to characterize mirrors, crystals and reticles of diffraction with high accuracy, during manufacture, installation and alignment.

The Group of Optics in ALBA synchrotron light source facility, in collaboration with the UAB, will characterize all the mirrors used in the synchrotron. For this task there is a laboratory in ALBA, where the environment conditions are controlled to optimize the stability of the measurements, and a Fizeau interferometer. Its accuracy is limited by the quality of the optical reference used by the instrument, sometimes worse than the optical surface to characterize.

Then, if it is used a reference surface of $\lambda/20$, which means that the peak to valley (ptv) is 30 nm, the reconstruction $s^R(x, y)$ of the profile of the tested mirror $s(x, y)$ is

$$s^R(x, y) = s(x, y) \pm 15\text{nm}$$
X-ray mirrors have profile lower than 30 nm ptv. Consequently, the reconstruction using a Fizeau is not acceptable because the error of the tested mirror and the reference surface are of the same order.

One of the final projects, developed along the second semester of the academic year 2008-2009, is related with the use of a set-up based on Lateral Shearing technique to eliminate the reference surface error. It consists on installing the sample mirror on top of a linear stage, in front of the Fizeau interferometer. The sample mirror is measured at two different positions of the linear stage one after the other. At each position, the Fizeau provides an accurate measure of the optical path difference between the sample and the reference surfaces. They are related as follows

\[ t(x, y) = s(x, y) - r(x, y) \quad \text{and} \quad t_1(x, y) = s(x - d, y) - r(x, y) \]

where \( t_i(x, y) \) is the measurement at a displaced position. The difference function \( w(x, y) \) between both measurements is given by

\[ w(x, y) = t(x, y) - t_1(x, y) = s(x, y) - s(x - d, y) \]

It can be seen that it does not depend on the reference surface. According to the Shift Theorem, the translation in the space domain between \( s(x, y) \) and \( s(x-d,y) \) introduces a linear phase shift in the frequency domain. Then,

\[ W(u,v) = FT[w(x,y)] = S(u,v)(1 - \exp(-2i\pi ud)) \]

Finally, applying the inverse Fourier transform, the measurement surface \( s(x,y) \) is recovered without the influence of the reference surface.

\[ s^R(x, y) = TF^{-1}[W(u,v)/(1 - \exp(-2i\pi ud))] \]

The application of the technique requires that the method is discretized, i.e. sampled and finite domain functions have to be used. In a finite domain, the Shift Theorem is true only for periodic functions with the period equal to the domain. If it is not, boundary errors are introduced. Natural Extension (NE) extends the function of differences to fulfill the periodic conditions of the Shift Theorem for discrete Fourier transform.

Once solved the periodic requirements for finite domain, the influence on the accuracy of the translation stage errors should be studied. The sampled mirror is shifted with a linear stage. This device has both guidance (pitch, roll and yaw) and positioning errors. These movement imprecisions limit the accuracy of the reconstruction for the proposed technique.

When the sampled surface is displaced to obtain the second measurement, it is actually displaced by \( d + \delta \) instead of \( d \), where \( \delta \) is the positioning error. In the proposed reconstruction technique, the positioning error affects mainly the parts of the process where the displacement \( d \) appears directly: mainly the equation of the STF but also the Natural Extension.

Then, to check the extra error introduced in the NE, we analyze the influence of the positioning error in two cases: when the function is periodic and when it is not. In the first case, the NE is not needed and in the second case, we need to use the NE to make the extended function periodic. To do that, we perform two statistical studies generating in each case 10000 random surfaces with the same characteristics.

In the first study, we consider that the functions are periodic, then, the Natural Extension is not needed and the errors will only come from the error in STF. In the second study, the functions are not periodic, then, the Natural Extension is needed before applying the STF. In this case, NE introduces an extra error. The results in both studies are compared to analyze the error in the STF and the error in the NE. We consider an addition of a random positioning error, normal distributed with 0 mm mean and standard deviation of 0.025 mm. Then, the Q quality factor of the reconstruction is calculated and the 500 best reconstructions are eliminated because they are not representative of the reconstruction errors.

Figures 5 (a) and (b) show the histogram of Q quality factor, defined as the quotient of \( \lambda_{\text{HeNe}} \) and ptv of reconstruction error, when using periodic functions and non-periodic functions, respectively. Since they are very similar, the influence of the positioning error affects mainly the STF. Nevertheless, the histogram
corresponding to non-periodic functions increases faster than the other. To better show these small differences, the cumulative histogram is shown in figure 5 (c). The black line corresponds to non-periodic functions and the grey one to periodic functions. One can see that the cumulative histogram for non-periodic functions grows faster than the other. This means that there are a higher number of experiments with a lower Q quality factor due to the effect of the positioning error in the NE. The difference between the grey line and the black line corresponds to the extra error introduced in the NE by the positioning error.

Figure 5. (a) and (b) Histograms of Q adding a random positioning error with standard deviation of 0.025 mm. not using and using NE, respectively. (c) Cumulative sum of the number of experiments with Q factor minor than the value of Q in x axis, using NE (black line) and not using NE (grey line).

In all cases, when no other error is present, the Q quality factor of the reconstruction using the proposed technique is better than 360. This implies that the reconstruction error using the described technique is 18 times lower than that obtained with a λ/20 reference surface. Therefore, regarding the positioning error, the technique guarantees a reconstruction surface in the range of

\[ s^E(x, y) = s(x, y) \pm 0.87 \text{ nm} \]

3.3. Polarimeter design research line. Variable waveplate-based polarimeter.

Polarimetry is an optical technique currently used in many research fields as biomedicine, polarimetric metrology or material characterization, where the knowledge of the state of polarization of light beams and the polarizing properties of polarizing samples are required. As a consequence, in such as applications it is necessary to use polarimeters which by means of radiometric measurements, lead to the obtaining of some important polarimetric information. Recently, the IPL team has started a research line related to the design and implementation of different polarimeters.

One of the final projects presented in the second semester of the academic year 2008-2009, is related with the implementation of polarimeters by using LCD conducting the function of variable retarder. In fact, the degree work contains an optimization procedure for the design of a polarimeter based on a polarizer and two lineal variable waveplates.

By means of diverse intensity measurements corresponding to the projection of a light beam upon different configurations of a polarimeter (polarization analyzers), we are able to calculate the state of polarization (SoP) of the studied light beam. This relation can be expressed as follows:

\[ S = A^{-1}I, \]
where $A^{-1}$ is a matrix $nx4$, with $n$ corresponding to the number of polarization analyzers, $I$ is a column vector containing the intensity measurements and $S$ the Stokes vector of the analyzed light beam. Depending to the specific matrix $A$, the transmission of the associated instrumental error of the intensity measurements is different. Some parameters give useful indicator of this noise amplification, as for instance the conditional number10 ($CN$) and the Equally Weighted Variance10 ($EWV$).

$$CN(A) = \frac{\sigma_{\text{max}}}{\sigma_{\text{min}}} \quad \text{and} \quad EWV(A) = \sum_i \frac{1}{\sigma_i^2},$$

where $\sigma$ are the $A$ matrix singular values different of zero.

The undergraduate student, by means of the Matlab tool has developed computer simulations that minimize the $CN$ and the $EWV$ parameters, leading to optimized polarimeters for different numbers $n$ of polarization analyzers.

On one hand, the matrix $A$ according to $CN$ minimization for 4 polarization analyzers results on a regular tetrahedron, whose vertexes are upon the Poincare sphere. Then, we have repeated the optimization process for rotated tetrahedrons and we have realized that they have the same $CN$. Therefore, for a polarimeter with four polarization analyzers, any of the infinite regular tetrahedrons inscribed into the Poincare sphere give the best solution. An example of an obtained regular tetrahedron is plotted at Fig. 6(a).

On the other hand, the undergraduate student has performed different optimizations of polarimeters corresponding to different numbers $n$ of polarization analyzers. In particular, the values of $n$ used are the number of the vertexes of the so-called Platonic Solids ($n = 4, 6, 8, 12, 20$). When using $n=6$ and $n=8$ polarization analyzers, the optimized polarimeters obtained correspond respectively to the vertexes of an octahedron and of a cube, when represented upon the Poincare sphere (Fig. 6(a) and 6(b)). These results show that the optimum configuration for $n$ polarization analyzers corresponds to the vertexes of a regular polyhedron, in the case that the polyhedron exists for the specific number $n$. Then, this configuration has vertexes at the same equidistance. The corresponding set of polarization analyzers leads to unitary matrices, and so, to the minimum possible $CN$. In other words, the regular polyhedrons lead to polarimeters whose noise propagation of the intensity measurements is minimized.

![Figure 6. CN minimization for: (a) four, (b) six and (c) eight polarization analyzers. The vertexes of the regular polyhedrons are located upon the surface of the Poincare sphere.](image)

The second part of the study developed by the undergraduate student is an analysis of the $CN$ and $EWV$ variation as function of the number of polarization analyzers. In order to perform a rigorous comparison, the configuration minimizing the $CN$ has been chosen in every case.

A graphic of the $CN$ as a function of number $n$ of polarization analyzers is plotted in Fig. 7(a). We see a $CN$ with a constant value (1.732) for $n<20$, because the optimization process reach one of the possibles rotations...
of the corresponding regular polyhedron. The CN does not take into account data redundancy. It can be seen when decreasing or increasing the experimental error $\Delta I$ by a factor $\alpha$. When this occurs, the numerator and the denominator of the CN appear multiplied by the same factor $\alpha$, and the quotient is not affected. However, for $n>20$ the CN values slightly increase, presenting the data curve a positive slope. It can be understood by taking into account the random profile of the optimization procedure used. In this sense, increasing the number of available polarization analyzers the probability to reach the optimum configuration by means of the random computing process decrease. Nevertheless, the variation of the CN as a function of the number of polarizing analyzers is very small and it can be considered constant. Thus, Fig. 7(a) proves the invariance of the condition of the matrices $A$ corresponding to the different optimized polarimeters with the number of polarization analyzers used. Note that in experiments, data redundancy leads to better results as a consequence of the experimental error minimization.

In order to detect this improvement in the optimized configurations, we have used the $EWV$ criteria. Then, we have analyzed the behavior of the $EWV$ indicator when increasing the number of polarization analyzers. The results are shown in Fig. 7(b). We see as the $EWV$ values decrease by following an asymptotic behavior, when increasing the $A$ matrix dimensions. Then, it is clear that in the $EWV$ indicator, the influence of the factor $\alpha$ is present.

![Fig. 7. Analysis of the CN (a) and EWV (b) as a function of the polarization analyzers number](image)

### 4. FINAL COMMENTS

In this section, an overview of some competences acquired by the students are presented. In addition, diverse comments and observations made by the students during their collaboration with the IPL staff are given. The specific student training corresponding to the stated research lines lead to a common achievement of skills: the scientific, communicative and the information processing competences. In the scientific competences, the students increase their knowledge of theories, concepts and methods related to the problems that they have to solve. As a consequence of the final project requirements, the students have to present their work in two different ways: written presentation and oral presentation. The IPL staff steer, advice and correct the student in the work performing process, leading to an increasing of the communicative competences.

Regarding the information processing competences, all the students have done an analysis and processed the data obtained in the research by means of different computing tools as Matlab, LabView, Office, among others. We consider that it has led them to a higher insight of the experiment and to an increase of their skills associated to the new technologies. In addition, this type of final projects can train the students for a work in a team, well appreciated by the industrial companies.

However, in every case, some particular aptitudes are acquired as a consequence of the specific developed research line. In section 3.1 an important part of the work related with the Liquid Crystal Displays research line
has an experimental profile, so the student had to learn the use of laboratory instrumentation and the software
necessary to manipulate it. The work in relation to surface metrology in section 3.2, is mainly a computer
simulation based on real situations, therefore, it is essential to have some knowledge of numerical analysis and
the student has to develop algorithms. Finally, in section 3.3 the work on the Polarimeter design research line
has experimental and simulating parts and the student receives a useful training in both issues.

Besides from the student training explained above, diverse comments and observations of the three students
follow similar thoughts. These inputs give some ideas for a major understanding of their outlooks. They agree
with the positive experience for their formation as a physicist. The integration in a research group is very
useful for them: the team work, duties planning, acquire experience in the laboratory and simulating skills,
drawing conclusions, among others. With this final project the students assess a real experience in a research
laboratory, being an important help when deciding their future professional aims. Since they combine theory,
which is more specific than in the degree courses, and experiments, the learning process becomes faster and
deeper. They also improve the implementation of computer simulations during their IPL collaboration, being
very useful to analyze the corresponding data.

The undergraduate students are guided at the same time by different members of the IPL staff. Mainly a
professor, who is the work tutor, and with the collaboration of different PhD students. This mutual interaction
is very enriching for all parts: the undergraduate students can be supported more constantly in time with the
Ph.D. student and, on the other hand, the Ph.D. student can increase their teaching skills.

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Problem-based learning in photonics technology education: Assessing student learning

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ABSTRACT
Problem-based learning (PBL) is an instructional approach whereby students learn course content by collaboratively solving complex real-world problems and reflecting on their experience. Research shows that PBL improves student knowledge and retention, motivation, problem-solving skills, and the ability to skillfully apply knowledge in new situations. One of the challenges with PBL, however, is that real-world problems are typically open-ended with more than one possible solution, which poses a challenge to educators with regard to assessing student performance. In this paper, we describe an approach to assessing student performance in PBL developed by the Photon PBL Project, a three-year National Science Foundation Advanced Technological Education (NSF-ATE) project in which eight interdisciplinary multimedia PBL “Challenges” were created in collaboration with photonics industry and university partners for use in high school and college math, science and technology courses. Assessment included measures of content knowledge, conceptual knowledge, problem-solving skills, motivation, self-efficacy, and metacognitive ability. Results from pilot testing at four community college photonics technology programs are presented.

Keywords: Photonics, problem-based learning, problem solving, self-regulation, metacognition, assessment, motivation, self-efficacy, critical thinking, multimedia.

1. INTRODUCTION
The new global innovation economy demands creative, teamwork-oriented problem solvers capable of adapting to the ever-changing needs of business and industry. This is especially true in the field of photonics, in which rapid advances in technology require engineers and technicians to apply their knowledge and skills in solving problems in new and emerging situations. But what does it mean to be a good problem solver? Problem solving has been described as “knowing what to do when you don’t know what to do.” 1 Researchers generally agree that a good problem solver is someone who can approach a problem, any problem, and systematically dissect, analyze, and formulate a coherent and viable strategy for solving the problem. Good problem solvers are patient and methodical, carefully considering all options before moving forward toward a solution. Good problem solvers break complex problems down into smaller, more manageable steps, making reasoned decisions on how to approach each step. Good problem solvers use metacognitive strategies to
manage the problem solving process by planning, monitoring, and evaluating their progress and strategies during problem solving, adjusting their approach when necessary. Good problem solvers persist in the face of difficulty and have the confidence and motivation to seek alternative solutions. Unfortunately, traditional instructor-centered approaches to education do not provide adequate opportunities for students to develop the knowledge, skills, and attitudes necessary to be good problem solvers. One instructional method that has been shown to be effective in helping students develop these skills is PBL.

PBL is a learner-centered instructional method in which students learn by solving authentic real-world problems, actively and collaboratively. In PBL, the instructor serves as a facilitator or consultant, guiding the students through the problem solving process and providing instruction on an “as needed” basis. Research shows that PBL results in “deep” learning rather than “surface” learning, improves critical thinking and problem-solving skills, motivation for learning, and students’ ability to skillfully apply knowledge in new and novel situations – skills deemed critical for lifelong learning. In PBL, students actively participate in their own learning by solving real-world problems in which the parameters are ill-defined and ambiguous. Unlike traditional instruction in which students attend lectures, solve well-defined end-of-chapter homework problems, and engage in highly structured “cookbook” type laboratory activities, PBL is open-ended and contextualized, and student learning is driven by the problem itself. With PBL, students’ learn the process of learning in addition to course content by engaging in a systematic and recursive process that begins problem analysis, carefully and methodically dissecting and framing a problem by reflecting on prior knowledge to identify knowledge gaps, situational constraints, and other pertinent problem features required to formulate a solution. Once the problem has been properly framed, students engage in self-directed learning to acquire the knowledge and skills needed to solve the problem, followed by brainstorming possible solutions with peers, and finally solution testing, developing viable strategies to test and validate their solutions.

One of the challenges of implementing PBL in photonics technology education, however, has been the lack of resources and training available to educators to help them transition to PBL. To address this challenge, the New England Board of Higher Education received funding for project PHOTON PBL from the National Science Foundation Advanced Technology Education (NSF-ATE) program to (1) create eight multimedia PBL “Challenges” in partnership with photonics industry and university research labs, and (2) provide professional development to high school teachers and college faculty in the principles and applications of PBL using the PBL Challenges, (3) conduct research into the efficacy of PBL in photonics technology education.

2. THE PHOTON PBL CHALLENGES

The PHOTON PBL Challenges are self-contained multimedia instructional modules designed to develop students’ problem solving ability and understanding of photonics concepts and applications. The Challenges provide students with authentic real-world photonics technology problems presented in a multimedia format designed to emulate the real-world context in which the problems were encountered and solved. Each PBL Challenge contains five main sections: (1) Introduction - An overview of the particular photonics topic to be explored; (2) Company/University Overview - An overview of the organization that solved the problem to set the context of the problem; (3) Problem Statement - A re-enactment of an authentic real-world photonics problem as originally presented to the organization’s technical team; (4) Problem-Discussion - A re-enactment of the brainstorming session engaged in by organization’s technical team; and (5) Problem Solution - A detailed description of the organization’s solution to the problem. The Problem Discussion and Problem Solution sections are password protected allowing instructors to control the flow of information and pace of instruction. Each of the five main sections contains additional information and resources (i.e., scripts, websites, spec sheets, etc.) designed to guide the student through the problem solving process. Designed to be implemented using three levels of structure ranging from highly structured (instructor led) to guided (instructor guided) to open-ended (instructor as consultant), the PHOTON PBL Challenges provide the necessary scaffolds to assist students in the development of their problem solving skills through a developmental continuum.

One unique feature of the PHOTON PBL Challenges is the “Problem Solvers Toolbox.” The Problem Solvers Toolbox helps students develop a systematic approach to problem solving through a feature called “The Whiteboards.” Four Whiteboards guide students through a four-phase problem solving process:
- **Problem Analysis** – Identifying what is known, what needs to be learned, and any problem constraints to properly frame the problem.
- **Self-Directed Learning** – Setting specific learning goals, identifying necessary resources, and developing a timeline for achieving those goals.
- **Brainstorming** – Collaboratively generating and evaluating ideas and alternative solutions best suited for addressing the task at hand.
- **Solution Testing** – Developing a plan to validate the solution based on specific performance criteria.

The Whiteboards help students systematically capture and document their thoughts, ideas, and learning strategies during each stage of the problem solving process. Eight PBL Challenges have been developed to date in partnership with photonics industry and university partners and are available online at [http://vilenski.org/pub](http://vilenski.org/pub). An Implementation Guide for Teachers, and several related conference publications and resources providing a complete description of the PBL Challenges are available online at [www.photonprojects.org](http://www.photonprojects.org).

### 3. ASSESSING STUDENT LEARNING

Educational assessment usually involves measuring students’ knowledge, skills, and attitudes. Assessing student learning in PBL, however, presents a unique challenge for educators accustomed to traditional assessment methods. Researchers agree that while traditional assessment methods such as multiple choice questions, true/false tests, and well-defined “end-of-chapter” problems are a convenient and effective way to measure students’ factual knowledge and recall, they do not adequately capture higher-order thinking skills. To accurately assess student performance in PBL, measures must capture not only factual and conceptual knowledge within a specific content area, but more importantly problem solving ability, the ability to skillfully apply factual and conceptual knowledge to solve problems in new situations. Whereas factual and conceptual knowledge can be assessed using traditional methods such as quizzes, tests and concept maps, problem solving ability is more difficult because it involves capturing the process by which students solve problems.

#### 3.1 PHOTON PBL Assessment Model

The PHOTON PBL approach for assessing student learning in PBL was informed by research conducted by the Vanderbilt-Northwestern-Texas-Harvard-MIT (VaNTH) Research Center for Bioengineering Educational Technologies on assessing adaptive expertise. Research on the development of expertise shows that in contrast to novices, experts rely on a readily accessible foundation of factual knowledge organized into a conceptual schema centered on core principles or concepts. Adaptive experts are able to apply this knowledge in solving problems in a variety of situations and contexts by recognizing similar features and underlying principles. Based on this research, the VaNTH model for assessing adaptive expertise consists of three weighted measures: content knowledge, conceptual knowledge, and transfer (the ability to apply factual and conceptual knowledge in new and novel situations). Similarly, the PHOTON PBL assessment model shown in Figure 1 includes three measures: content knowledge, conceptual knowledge, and problem-solving ability in which specific weights are assigned by the instructor depending on the course format.

![Figure 1 – Student Assessment in PBL](image)
3.1.1 Content Knowledge
Content knowledge refers to a student’s understanding of key facts and principles within a specific domain of knowledge. Each PBL Challenge includes a test bank consisting of multiple-choice questions, closed-ended problems, and higher-level thought provoking questions centered on specific technical content associated with the Challenge. To enhance adaptability, the PBL Challenges were designed to be implemented as either a supplemental activity in a traditional course or as a stand alone instructional method allowing instructors the flexibility to assess content knowledge in several different ways including traditional textbook assignments, lab reports, quizzes and tests, and assign an appropriate weight to the measure. We recommend pre-post testing for each PBL challenge introduced to provide a measure of improvement in content knowledge associated with each challenge.

3.1.2 Conceptual Knowledge
Conceptual knowledge refers to a student’s understanding of the relationship between key concepts within a particular domain of knowledge. Research on expertise shows that compared to novices, experts have a deep foundation of factual knowledge, understand facts and ideas in the context of a conceptual framework centered on core concepts and principles, and organize knowledge in ways that facilitate retrieval and application. Experts’ rich interrelated framework of concepts and principles allows them to understand and give meaning to new information by seeing patterns and relationships that are not apparent to novices, allowing them to access relevant information more efficiently. As expertise in a particular domain of knowledge increases through experience and practice, however, an individual’s conceptual framework becomes more complex and interrelated, improving their ability to transfer learning to new situations and domains. One method for assessing conceptual knowledge is through concept mapping. Originally developed in 1972 by Joseph Novak at Cornell University, concept maps typically consist of groupings of circles labeled with key concepts, connected with lines and arrows, and labeled with words in a way that describes the relationship between concepts. Each pair of concepts and linking lines produces a proposition whose validity represents a measure of a student’s understanding of the relationship between the two concepts. The overall number of connections between concepts and the respective proposition validity formed represents a measure of a student’s conceptual knowledge in a particular domain. While a number of different methods for scoring concept maps exist in the literature, scoring is usually based on the number of connections formed and the quality and validity of the propositions generated.

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Each PBL Challenge contains a list of main concepts related to the topic being explored, a reference or “expert” concept map for instructors, detailed instructions for students on how to construct a concept map, and a concept map scoring rubric. Instructors are encouraged to introduce the concept mapping using a simple topic to ensure students understand the concept mapping process and how they will be scored prior to assigning a concept mapping exercise for the PBL Challenge.

3.1.3 Problem Solving Ability
In the VaNTH model for assessing adaptive expertise, researchers defined transfer as “the extent to which students recognized the relationship between what had been taught and the new situation presented in the problem.” In the PHOTON PBL Challenges, we depart somewhat from the VaNTH model in how we define the transfer variable. We believe that problem solving ability is the cornerstone of transfer, and is a measure of metacognitive ability, which includes reflecting on prior knowledge, identifying key problem parameters and features, developing and planning a coherent strategy for solving a problem, setting specific learning goals to acquire the knowledge and skills needed to solve the problem, monitoring progress while problem solving, and evaluating the effectiveness of problem solving strategies after a solution has been developed. Research has shown that metacognitive ability is a key factor linked to students’ ability to transfer knowledge and skills to new situations.

Measuring problem solving ability involves both formative and summative assessments. Formative or in-process assessment is accomplished via the Whiteboards. As students collaboratively engage a problem by completing the four Whiteboards, they reflect upon and elucidate their current state of understanding, their
thought process, and problem solving strategies. Research shows that verbalizing the thought process while engaging in problem solving improves metacognition, which is essential for effective problem solving\(^8\). Summative or post-process assessment is accomplished using the Final Challenge Report, a reflective journal. Upon completion of a PBL Challenge, students reflect upon and provide a detailed summary of each stage of the problem-solving process in which they have engaged. The Final Challenge Report represents a synthesis of the knowledge, skills, and strategies employed in solving the PBL challenge. Researchers maintain that this final reflective exercise is essential in the development of effective problem-solving skills\(^4\). A scoring rubric is used to grade the Final Challenge Report.

### 3.2 Motivation and Self-Efficacy

The attitudes that students bring to learning situations is an important factor related to their overall performance in problem-solving situations. Motivation affects the amount of effort a student is willing to commit to a particular activity and can vary depending on the value that a student places on the activity. Students who engage in a learning activity out of personal interest in the topic, or learning for learning sake, are said to be intrinsically motivated or mastery oriented. In contrast, students who engage in a learning activity for external rewards such as a good grade or promotion are said to be externally motivated or goal oriented. Research shows that while both motivational orientations are important for achieving learning objectives, students who are intrinsically motivated are more likely to engage in “deep learning” and persist in the face of difficulty\(^19\). Self-efficacy refers to a student’s confidence that he/she will be successful in a particular learning endeavor. Research shows that self-efficacy is an important factor related to positive learning outcomes and can moderate the amount of effort learners put forth in achieving a specific learning objectives\(^20\). In this study, intrinsic motivation, extrinsic motivation, and self-efficacy were measured using selected subscales from the Motivated Strategies for Learning Questionnaire (MSLQ)\(^21\). The MSLQ is a widely used and validated 81-question Likert-scaled instrument designed to assess motivation and use of learning strategies by college students.

### 4. METHODS

This pilot study was conducted during the 2008-2009 academic year as an observational case study. Based on the literature\(^22,23,24\), this approach was chosen to gain a deep description of how engagement with the PHOTON PBL Challenges influences student learning, self-efficacy, motivation, and metacognitive ability. Quantitative and qualitative measures were applied to answer the following research questions:

1. How and to what extent does PBL affect student learning outcomes?
2. How and to what extent does PBL affect student motivation?
3. How and to what extent does PBL affect student self-efficacy?
4. How and to what extent does PBL affect student metacognitive ability?

In this study, student learning outcomes are defined in terms of content knowledge, conceptual knowledge, and problem solving ability as described previously. Motivation is defined using two constructs: (1) intrinsic goal orientation – the extent to which students are intrinsically motivated to engage in the particular problem-solving task; and (2) extrinsic goal orientation – the extent to which students are motivated to engage in the particular problem-solving task for external rewards (i.e., grade). Self-efficacy is defined as a student’s confidence in his or her ability to solve real-world open-ended problems. Metacognitive ability is defined as a continuous and integrated process utilizing reflection skills and metacognitive knowledge to plan, monitor, and evaluating ones learning.

### 4.1 Data Collection

Participants in the study were students and instructors from four community college photonics technology classes. Prior to the study, instructors participated in one of two weeklong professional development workshops conducted in summer 2007 and summer 2008 in which they learned the principles and applications of PBL through engagement with the PHOTON PBL Challenges. Instructors participating in the study were required to (1) complete at least two PBL Challenges over the course of the fall 2008 and/or spring 2009 semesters with their students, and (2) provide samples of student concept maps, Whiteboard data, and Final Challenge Reports for each PBL Challenge completed. Students were invited to participate in
the study by volunteering to complete a pre-post online survey (MSLQ) at the beginning and end of the fall 2008 and/or spring 2009 semesters, and participate in a personal interview at the end of the spring 2009 semester. To encourage student participation, a cash-prize raffle was held for those students who completed both pre- and post online surveys. Researchers were available to respond to any questions or concerns via e-mail, BlackBoard®, and telephone.

Four instructors (3 male; 1 female) and 21 students (15 male; 6 female) from four community colleges participated in the pilot study. Six of the 21 students (3 male; 3 female) who completed the pre-post online survey (MSLQ) participated in personal interviews.

4.2 Data Analysis and Results
4.2.1 Content knowledge
Content knowledge was to be assessed using student performance on pre-post content knowledge tests included with the PBL Challenges. Unfortunately, due to variations in curricula and instructor implementation methods, there was insufficient data available for analysis of this measure. However, given that the PBL Challenges were implemented as supplemental activities in traditional lecture-based courses, a comparison of student grade averages between PBL students and historical grade averages of non-PBL students in past classes using traditional measures as reported by instructors revealed that grade performance for PBL students was “comparable to better” than historical student grade performance.

Additional information regarding the effect on students’ content knowledge was acquired through thematic analysis of student interviews. When asked, “Did your experience with the PBL Challenges improve your understanding of the technical content (optics and photonics) in your course?” all six students interviewed replied positively. Sample student responses included:

- “Yes, absolutely. You had to think outside the box…think for yourself, instead of having the teacher tell you what to do or think…”
- “I do believe so, because its easier to learn something if you have to do it yourself as opposed to just lecturing because…someone can lecture to you for 10 minutes and you won’t retain as much as if you had to do it yourself.”
- “Yes, it helps to have an actual problem to know where to research, so it kind of creates a focus point…you get set areas to focus on to do research on, so that focus does help…and the practicality, knowing what your working on has applications in the real world make you want to learn more.”

While individual pre-post scores for content knowledge were not available for this pilot study, results from student and instructor interviews suggest that student content knowledge in classes supplemented with PBL was, at minimum, comparable with student content knowledge resulting from traditional lecture-based instruction. Results from student interviews also revealed that the problems presented in the PBL Challenges helped link course content to real-world applications, resulting in a more contextualized and meaningful learning experience, which has been linked to improved student learning outcomes16.

4.2.2 Conceptual Knowledge
Conceptual knowledge was assessed through scoring of students’ concept maps. For each PBL Challenge completed, students were provided with a list of 10-20 main concepts and specific instructions for creating a concept map. Instructors were given detailed instructions on how to guide students in developing their concept maps as well as a reference concept map developed by the Photon PBL principle investigators. Students completed their concept maps as a group activity after completing each challenge. A scoring rubric was used to evaluate the quality and validity of the concept maps. Scoring rubric criteria consisted of two main components, proposition validity and presentation, in which student performance was scored on a scale from 1 to 4 (1=poor, 2=fair, 3=good, and 4=excellent). The proposition validity criterion included attributes relating to accuracy, depth of knowledge reflected, and number of propositions generated. The presentation criterion included attributes relating to strength of organization, legibility, and clarity. Development of the rubric and scoring of the concept maps was performed by two experts to ensure face validity and interrater
reliability. Additional information regarding students’ conceptual knowledge was acquired through thematic analysis of student interview transcripts.

Comparisons were made between initial and subsequent concept maps to investigate if and to what degree students’ conceptual knowledge had changed after completing two or more PBL Challenges. Samples of 10 initial and 10 subsequent concept maps were evaluated. Because students worked in small teams to develop their concept maps, individual student scores were not available. Two experts scored each concept map individually and mean scores were calculated for each. The mean score for the 10 initial concept maps was 2.86/4.0. The mean score for the 10 subsequent concept maps was 3.42/4.0, representing an improvement of approximately 20%.

To gain further insight into whether results were due to an increase in conceptual understanding, an improved ability to construct concepts, or both, student interviews were conducted in which interviewees were asked the question, “Did you find the concept mapping exercise valuable in helping you to understand the relationships between the concepts presented?” Sample student responses included:

- “Yes, in the end…at first it was complicated to grasp them all together (concepts)…but when it’s finally completed, being able to see the sentence go together with the two concepts and the relationships with all the others…all those focus points… it brings it all together.”
- “I found them valuable… you can interconnect ideas that you never think would be connected in any way. I found it valuable also because it lets you hear other people’s ideas which could be better than yours…and it just allows you to put them all together.”
- “I like the concept maps… I now use them in writing my English papers a lot. It helps you to organize your thoughts…how like ever idea connects with something else.”

These results suggest that as students progressed with the PBL Challenges, their conceptual knowledge as measured by their concept maps as well as their skill in creating concept maps improved, reflecting a deeper understanding of the interrelationships between concepts presented. In addition, student interview results revealed that students viewed the concept maps a valuable tool for visualizing and understanding the relationships between concepts of which they otherwise may not have been aware. Moreover, while some viewed concept maps as somewhat tedious to construct, they also found them to be a valuable tool for engaging in collaborative learning that provided a unique opportunity for gauging their understanding through feedback from and exchange of ideas with others.

4.2.3 Problem Solving Ability

Problem solving ability was assessed through analysis and scoring of students’ Final Challenge Reports, which provided a reflective summary of the problem solving process engaged in by the students. In the Final Challenge Report, students responded to five probing questions that required them to reflect on their problem solving experience as captured in the Whiteboards. Responses to the five questions provided a measure of students’ knowledge, skills, and strategies employed in solving the PBL Challenge, and the reflective judgment used in the assessment of their problem solution as compared to the PBL Challenge solution. The scoring rubric used to evaluate students’ Final Challenge Report consisted of performance criteria relating to the five questions, in which student performance was scored on a scale from 1 to 4 (1=poor, 2=fair, 3=good, and 4=excellent). Performance criteria included: clearly and precisely defining problem parameters and constraints, identifying required knowledge and skills needed to solve the problem, setting specific and appropriate learning goals, collaborative brainstorming of solutions, development of viable a test plan, solution quality and effectiveness, and comparing and contrasting with the PBL challenge solution. Development of the scoring rubric and independent scoring of the Final Challenge Reports was performed by two experts to ensure face validity and interrater reliability. Additional information regarding students’ problem-solving ability was acquired through thematic analysis of student interview transcripts.

A sample of 10 Final Challenge Reports were evaluated to explore how and to what extent their experience with the PBL Challenges affected students’ problem solving ability. Individual student scores were not available because of the team-based approach used by instructors. Two experts scored each Final Challenge
Report independently and a mean score of 3.34/4.0 was calculated for the 10 reports. Analysis of the Final Challenge Reports revealed that students used the Problem-Solver’s Toolbox effectively to guide them in developing their problem solutions. The majority of students provided clear and detailed information regarding prior knowledge, setting learning goals, generating alternative solutions, and developing methods for testing their solutions. While instructors did report some angst amongst certain students with regard to their willingness to carefully document their problem-solving process using the Whiteboards (e.g., “Some students just want to jump right to the solution without taking the time to carefully examine all aspects of the problem.”), the majority of students did appear to work through the problems in a systematic fashion, and were able to converge on solutions that in most cases were very similar to the organization’s solution.

To gain further insight into the problem solving ability developed in students through engagement with the PBL Challenges, semi-structured interviews were conducted with six volunteer students at the end of the spring 2009 semester. Of the six students, three had completed two challenges and three had completed four or more challenges. Student selection was based on convenience and availability. Each of the six students interviewed were presented with a hypothetical problem to which they were asked to comment on: (1) the process by which they would solve the problem; (2) if their experience with the PBL Challenges has helped them in their ability to solve the problem; and (3) how they would have solved the problem prior to their experience with the PBL Challenges. Responses were recorded, transcribed, and analyzed for evidence of problem-solving ability consistent the methods prescribed in the Problem-Solver’s Toolbox.

**Problem Statement:** A telecommunications company would like to build a free-space optical communications system to transmit data from the roof of a 40 story high-rise building in lower Manhattan to the roof another 40-story high-rise building in upper Manhattan 2-miles away. They want the system to be eye-safe to avoid any possible hazards to low-flying aircraft or birds that may cross the beam’s path.

**Interview Question 1: How would you solve this problem? Explain your steps.**

Analysis of students’ responses revealed variations in problem-solving ability dependent upon the number of PBL Challenges completed. Students who had completed four or more PBL Challenges were much more clear in articulating the problem-solving process they engaged in, and specifically identified each of the four phases prescribed in the Problem-Solver’s Toolbox. One sample response was:

“Well…the first thing you would have to do is list all the things you know and then list all the things you need to know…and then go research. From there you can take what you’ve learned and brainstorm with your team…come up with different ideas…and rate them on a scale from 1 to 10 or 1 to 5 or how ever many steps you have…. Uhhmm…from there you would decide on which ones would work out the best…. and then test out each one of your solutions to see which one works the best for your particular situation.”

In contrast, students who had completed just two challenges appeared to be more concerned with surface features of the problem and finding an immediate solution, rather than taking the time to fully understand and properly frame the problem as prescribed in the Problem-Solver’s Toolbox. While students did describe certain elements of the problem-solving process, they applied more of a “shot gun” approach, characteristic of novice problem-solvers. A sample response is provided below:

“I’d have to do some research because I don’t know how high planes fly over Manhattan …uhhmm…We’d have to make sure it’s safe, …pause…birds….I’d have to check what birds are in the area, where they are…uhhmm… and…would this be possible? It could be…I can’t really answer that question because I don’t know enough about certain things in that situation…but… uhhmm…You’d have to check what the dangers are with the…uhhmm…. I’d definitely have to figure out what are we transmitting… How far away? Two Miles? Would that be cost effective? I was thinking if you enclosed it but that would block air space… You’d have to figure out some way of testing it out before you put it in place.”
Interview Question 2: Did your experience with the Photon PBL Challenges help you in your ability to solve this problem? If so, how?

Students’ responses were unanimously positive regardless of the amount of experience with the PBL Challenges. Overall, students felt that the PBL Challenges provided them with a systematic method for solving real-world problems that taught them how to break the task down into smaller, more manageable steps. In addition, three of the six students commented on the value of being able to work collaboratively in a way that provided critical feedback against which to gauge their own understanding and capitalized on the collective knowledge of the team in developing a problem solution. Sample responses included:

- “Yes – It definitely helps you to stay on target with what you need to do and… I would have looked at that and said “where do I go with this?” instead of saying “OK – research problem issues – safety, all those things you need to think about and how to tie them together”
- “Yes…because I filled out enough whiteboards to know…ha-ha…The way you have to break the problem down into such basic steps…uhhhmm…Lets you break down any problem into basic steps…Really lets you look at a real-world scenario…and just break it down into its most basic form so that you know what you need to know and how it can be done…”
- “Yes- definitely. It helped us organize what we did know and didn’t know and kept us on track…and then…uhhmm…It allows you to collect ideas together which normally you might have one or two…..but this lets you put many together…and decide which one is the best…I mean…you might be able to sit there and hear somebody else’s ideas and make it better.”

Interview Question 3: How would you have solved this problem prior to your experience with the Photon PBL Challenges? Explain.

Each of the six students reported that prior to their experience with the PBL Challenges, they would have had a much more difficult time solving the problem, in particular, not knowing where to begin. Students indicated that they would have immediately attempted a solution without first analyzing the problem to identify and understand important features and parameters, and developing a plan or strategy for attacking the problem. Student responses were consistent with the research identified in literature with regard to how “poor problem solvers” approach problems situations. Sample responses include:

- “I would have looked at it and went (Throw hands up)…I have no idea.”
- “I have no idea…but after we did the challenges it helped a lot…helped a great deal. Before that I wouldn’t really know where to begin…I’d probably start with like, this is my idea and then go check it…instead of actually going through your knowledge and going through the steps…I would have probably wasted a lot of time.”
- “No…I probably would have run in circles for quite some time…Asking myself a lot of questions but not really writing them down…Uhhmm…taking those questions as they popped into my head and then research, …but then more questions would come in as I’m researching…And then they’d get thrown out as I’m doing he research…so…uhhmm…there’d be a lot more confusion I’d have to say”

4.2.4 Motivation

Motivation, self-efficacy and metacognitive ability were assessed using selected subscales of the MSLQ. Cronbach’s alpha for each variable are reported as intrinsic motivation (4 items; $\alpha=.74$), extrinsic motivation (6 items; $\alpha=.62$), self-efficacy (8 items; $\alpha=.93$), and metacognitive self-regulation (12 items; $\alpha=.79$). Mean values were computed for each variable and data were screened for outliers and normality. Paired t-tests were conducted to measure changes in mean scores for each variable. Additional information regarding students’ self-efficacy, motivation, and metacognitive ability were acquired through thematic analysis of student interview transcripts.

Results of paired t-tests performed on the MSLQ motivation subscale data (n = 16) showed a statistically significant increase ($t = 4.09$, $p = .001$; Cohen’s $d = 2.11$) for intrinsic motivation representing a medium to large effect size. Results for extrinsic motivation and task value were not significant. Additional analyses were conducted to examine whether the number of PBL Challenges completed by students had an effect on motivation. Of the 21 students who completed the pre-post to the MSLQ survey, 12 students had completed
two PBL Challenges and 9 students had completed four or more PBL Challenges. Data were screened for normality and two outliers removed. Results of paired t-tests for students completing two PBL Challenges (n=10) showed a statistically significant increase for intrinsic motivation (t = 3.58, p=.006; Cohen’s d = 2.39) representing a medium to large effect size. While not statistically significant, a medium effect size (Cohen’s d = 1.28) was also found for extrinsic motivation. Results showed a slight increase for task value, but no statistically significant difference, and a small effect size (Cohen’s d = .21). Results of paired t-tests for students who had completed four or more PBL Challenges (n=9) showed a statistically significant increase for intrinsic motivation (t = 2.866, p=.021; Cohen’s d = 2.03) representing a medium to large effect size, but a statistically significant decrease in extrinsic motivation (t = 2.344, p=.047; Cohen’s d = 1.66) representing a medium effect size. Results for task value showed no significant difference and a small positive effect size.

Paired t-test results were corroborated through analysis of student interview data, which showed that overall, students were intrinsically motivated to learn by the real world problems posed by the PBL Challenges, and through the opportunity for collaborative learning. Supporting comments included:

- “Yes, I found them (PBL Challenges) really interesting…once we were doing the challenges it was pretty cool because you got to see how it works out…it really is interesting to see what processes it really takes to solve a problem in the real world…it helps you to think more accurately.”
- “Yes….whenever the whole group gets together… to share what they have learned in their research…. when you get together to concept map it you learn an extra large amount and you all get excited about it…you’re all excited to share what you’ve all researched…the motivation for working together…definitely.”

These results show that overall, engagement with the PBL Challenges improved students’ intrinsic motivation, which has been shown by research to promote deep, high-quality learning. Moreover, the results showed that increased experience with the PBL Challenges resulted in not only an increase in intrinsic motivation, but also a decrease in extrinsic motivation. This result suggests an internalization of external motivation, a shift from a more goal oriented approach to learning to a mastery orientation. Research has shown that compared to goal-oriented learners, learners with a mastery orientation are more flexible in their learning approach, are more likely to uses metacognitive strategies, and are likely to persist in the face of difficulty, which are all positive attributes of good problem solvers.19

4.2.5 Self-Efficacy
Results of paired t-tests on the self-efficacy subscale (n=16) of the MSLQ showed a statistically significant increase (t = 2.81, p=.013; Cohen’s d = 1.45) with a medium effect size. Additional analyses were conducted to examine whether the number of PBL Challenges completed by students had an effect on students’ self-efficacy. Results of paired t-test for students completing two PBL Challenges (n=10) were not statistically significant, but did show in a moderate increase for self-efficacy (Cohen’s d = 0.65) representing a medium effect size. For students completing four or more PBL challenges (n=9), however, results were significant (t= 3.04, p=.016; Cohen’s d = 2.15) representing a medium to large effect size.

Paired t-test results were corroborated through analysis of student interview data in which students were asked, “Do you believe your experience with the PBL Challenges has made you more confident in your ability to solve real-world problems?” Sample responses include:

- “At first I was a little nervous about it because it was like…. the first time, and I didn’t know how to explain or what I thought, but then afterwards, slowly, as we continued more challenges, I had more confidence to say, OK, I think this or this would work…”
- “Yes, because there were real-world issues there…the whole breaking down of the problem…what needs to be done…there’s this I need to do…it definitely help because I know how to problem solve now.”

These results showed that overall, students were more confident in their ability to solve real-world problems as a result of completing the PBL Challenges because of the specific skills developed in learning how to
approach a problem. Moreover, student self-efficacy improved significantly with more experience with the PBL Challenges.

4.2.6 Metacognitive Ability
Results of paired t-tests using the metacognitive self-regulation subscale (n=16) of the MSLQ showed a statistically significant increase (t = 3.45, p=.004; Cohen’s d = 1.77) representing a medium effect size. Additional analyses were conducted to examine whether the number of PBL Challenges completed by students had an effect on students’ metacognitive self-regulation. Results of paired t-test for students completing two PBL Challenges (n=10) were not statistically significant, but did show a modest increase in metacognitive self-regulation (Cohen’s d = 0.55) representing a small to medium effect size. For students completing four or more PBL challenges (n=9), however, results were significant (t = 4.95, p=.001; Cohen’s d = 3.50) representing a large effect size. These results were corroborated through analysis of student interview data, which showed that students who had completed four or more PBL challenges were more articulate in describing the process by which they would solve a problem. This included reflecting on their current understanding of the problem and its parameters, identifying knowledge gaps, and articulating the need for planning a strategy for implementing and testing their solution – all key attributes of metacognitive ability.

These results suggest that overall, students’ metacognitive ability improved as a result of completing the PBL Challenges. As in the case of self-efficacy, metacognitive ability improved significantly with more experience with the PBL Challenges, suggesting an internalization of the problem solving process.

5. CONCLUSION
In this paper, we presented the results of a pilot test conducted to evaluate the efficacy of the PHOTON PBL Challenges and associated assessment strategies in photonics technology education. The study included 21 photonics technology students and four photonics technology instructors from four community colleges. In the study, we examined how and to what extent engagement with the PHOTON PBL Challenges affected student problem solving skills, motivation, self-efficacy, and metacognitive ability. Students in the pilot study completed at least two PBL Challenges over the course of the fall 2008 and/or spring 2009 semesters, and a pre- and post online survey (MSLQ) at the beginning and end of each semester. Samples of student work (concept maps, Whiteboards, and Final Challenge Reports) completed for each PBL Challenge were obtained from the instructors and analyzed. Six student volunteers participated in semi-structured interviews to provide additional information regarding their experience with the PBL challenges.

Results of the pilot test revealed that with increased experience with the PBL Challenges, students’ conceptual knowledge and problem-solving ability improved markedly. While pre-post measures of student content knowledge was not available for the study, instructor observations and comparisons of student performance in aggregate using traditional measures (homework, quizzes, and exams) data for PBL students with performance of non-PBL students in the past showed that PBL students performed at least as well as non-PBL students. Results also revealed statistically significant increases in intrinsic motivation, self-efficacy, and metacognitive self-regulation. Of particular interest was a decrease in extrinsic motivation with increased experience with the PBL Challenges, suggesting an internalization of external motivation, a shift from a more goal oriented approach to learning to a mastery orientation. Finally, results showed a statistically significant increase in metacognitive self-regulation – a key factor linked to students’ ability to transfer knowledge and skills to new situations. While the results are encouraging, given the small sample size, self-report instrument, lack of control group, possible bias, and other threats to internal and external validity, generalizability of results is limited to the sample within the study. Future studies should include a larger sample size and an experimental or quasi-experimental design to improve internal validity and generalizability.

6. ACKNOWLEDGEMENTS
Funded in-part by the Advanced Technological Education program of the National Science Foundation (ATE #ATE 0603143) Principal Investigator, Fenna Hanes (Project Manager), New England Board of Higher Education; Co-Principal Investigators Judith Donnelly, Three Rivers Community College; Nicholas Massa Springfield Technical Community College; Richard Audet, Roger Williams University. Website: http://www.photonprojects.org.
7. REFERENCES


Practical Framework for Bloom’s Based Teaching and Assessment of Engineering Outcomes

Patricia F. Mead and Mary M. Bennett
Optical Engineering, Norfolk State University, Norfolk, VA

ABSTRACT
ABET’s outcomes-based assessment and evaluation requirements for engineering school accreditation has been a catalyst for curricular reform for engineering programs across the U.S. and around the world. Norfolk State University launched programs in Electronics and Optical Engineering in 2003. In 2007, Norfolk State became one of only six accredited Optical Engineering programs in the United States. In preparation for their first ABET evaluation in fall 2007, the faculty initiated an embedded-assessment program to insure continuous improvement toward the desired learning outcomes. The initial program design includes embedded assessments that have been generated using a practical framework for the creation of course activities based on Bloom’s Learning Taxonomy. The framework includes specific performance criteria for each ABET-defined learning outcome. The embedded assessments are generated by individual faculty for courses that they are assigned to teach, and the performance criteria provide sufficient information to guide the faculty as they generate the embedded assignments. The assignments are typically administered through course exams, projects, electronic portfolio assignments, and other structured educational activities. The effectiveness of the assessment design is being evaluated through faculty surveys, faculty group discussions, and student performance. This paper outlines the assessment and evaluation plan, and the integrated processes that have been used to support the evaluation of learning outcomes using embedded assessment instruments.

Keywords
Assessment, embedded-assessment, accreditation, Bloom’s Taxonomy, continuous improvement, teaching community

1. INTRODUCTION

In 1999, ABET introduced significant reform to its accreditation process with the introduction of Engineering Criteria 2000 (EC2000). In 2005, ten years after the release of the American Society for Engineering Education’s (ASEE) Green Report calling for changes in engineering education leading to the attainment of critical skills and knowledge in engineering graduates, ABET commissioned its own early evaluation of EC2000’s impact on engineering graduates[7]. As with many immature efforts in educational settings, more time and more information are needed to fully understand the impact of EC2000, and the subsequent EC2XXX1 criteria. A few basic themes have however emerged, as evidenced by annual professional meetings sponsored by ABET, the American Society for Engineering Education (ASEE), and virtually all of the engineering professional societies. First, the EC2XXX criteria on assessment and evaluation of program outcomes and program objectives remain problematic areas for programs seeking accreditation[1]. Specifically, programs have difficulty understanding how to demonstrate a well-documented process for assessment and evaluation, with a clear path for revision based on the evaluation results found. Indeed, some now assert that the accreditation focus has evolved into one that is attentive to the assessment and evaluation process, rather than a focus on demonstrated outcomes[7]. Second, clear distinctions between program objectives and program outcomes continue to exist. Third, non-uniformity among ABET program evaluators pose significant uncertainties for programs as they prepare for the accreditation evaluation experience.

1 ABET increments the official title of its criteria document annually. For example, the current version is EC2009. The designation EC2XXX is used as an indication of this annual change.
Norfolk State University (NSU) launched programs in Electronics (EEN) and Optical (OEN) Engineering in 2003. The two programs reside within a Department of Engineering, which staffs eleven full-time faculty members. The department averages about 50 incoming freshmen students each year, and in Spring 2009, a total of 165 undergraduate students were enrolled in the two engineering programs. The department also offers Master of Science degrees in Electronics and Optical Engineering, and selected faculty within the department also support a doctoral degree program in Materials Science and Engineering. The doctoral program is a multidisciplinary program that is administered in cooperation with faculty that have been appointed to the Physics and Chemistry Departments.

The preparation for NSU’s first ABET evaluation presented several exciting challenges, including the challenge of establishing program missions, objectives, and outcomes for the two undergraduate degree programs. To facilitate these actions, the engineering faculty launched a Faculty Advance process. The Faculty Advance is a retreat-like activity that brings the faculty group together for one to two days in a remote (preferably off-campus) setting. The Advance typically includes invited presentations, small-group sessions where details of proposed ideas and activities can be refined, and full-group sessions where final actions can be debated and agreed upon.

The Advance sessions began in fall 2004 and the faculty decided in spring 2005 to launch a year-long planning effort to research best practices in outcomes assessment, and to identify a favorable plan to implement within the department. The faculty agreed to immediately adopt the existing ABET program outcomes in their entirety. It was agreed that adjustments to this decision could be explored in the future. As a first step, self-reportable student and faculty surveys would be used to measure attainment of the ABET defined outcomes. This was not seen as a long-term activity, but it would be done so that the data collection process could begin. At the conclusion of the research and preliminary assessment activities, a formal assessment and evaluation process was reviewed and ratified by the engineering faculty.

2. METHODOLOGY: THE NSU ASSESSMENT AND EVALUATION PLAN

The NSU Assessment and Evaluation Plan (AEP) is based on the principles and best practices that have been promoted through ABET’s regular suite of assessment workshops, and in the teaching and learning literature. Specifically, the NSU AEP is intended to enhance student learning with respect to the intended learning outcomes, it is conducted in unison with other evaluative processes within the department, and assessment results provide meaningful feedback to faculty as they continuously improve and refine the program offerings.

The current NSU AEP is summarized in the Table 1, below. Over time, the plan is expected to evolve as the faculty better understand critical time cycles for meaningful evaluation based upon collected data and practical experience. A more detailed examination of the plan for program outcomes assessment follows:

Beyond the general actions that are outlined in Table 1, the faculty must decide on a detailed plan for data collection that informs the task of evaluating the program objectives and the program outcomes. The focus of this paper is on the assessment and evaluation of program outcomes. As discussed above, our initial choice has been to adopt the ABET defined program outcomes, commonly referred to as the a through k criteria. The balance of this paper outlines our current activities related to this task.

More importantly, the detailed performance criteria associated with each of the learning outcomes will evolve based on student academic level (e.g. freshman, sophomore, junior, or senior standing), course content, and the resources available to the faculty. Hence, there is a critical need to fully engage the faculty as the AEP becomes fully operationalized into the standard practices for the department faculty.
### Table 1. Overview of Assessment and Evaluation Plan

<table>
<thead>
<tr>
<th>Category</th>
<th>Function</th>
<th>Constituency</th>
<th>Evaluation Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Academic Functions</strong></td>
<td>Engineering Courses</td>
<td>Students, faculty</td>
<td>annually</td>
</tr>
<tr>
<td></td>
<td>Engineering Program Outcomes (a-k)</td>
<td>Students, faculty, employers</td>
<td>two years</td>
</tr>
<tr>
<td></td>
<td>Engineering Program Mission and Objectives</td>
<td>Employers, faculty, advisory board, alumni</td>
<td>three years</td>
</tr>
<tr>
<td></td>
<td>NSU Core Competencies²</td>
<td>Students, faculty</td>
<td>annually</td>
</tr>
<tr>
<td><strong>Physical Infrastructure</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Administration / Organizational Structures</strong></td>
<td>faculty, advisory board</td>
<td></td>
<td>three years</td>
</tr>
</tbody>
</table>

#### 2.1 Assessment of Engineering Program (Learning) Outcomes³

The NSU plan for assessment of program outcomes is inspired by work completed at the University Pittsburgh, and by the knowledge and experiences gained from ABET sponsored workshops on program and outcomes assessment. Specifically, the NSU engineering department has adopted an embedded assessment strategy that reflects a cognitive developmental approach to teaching and learning. Each semester, embedded assignments are generated in selected courses within the lower- and upper-division engineering curriculum. The assignments focus on specific skills needed to achieve the learning outcomes associated with ABET accreditation. The embedded assignments are intended to be transparent to students in that they are administered within the normal context of a course assignment and they require students to demonstrate knowledge and skills related to the course content. That is, a course in fiber optics understandably may ask students demonstrate their knowledge of step-index and graded-index waveguides. However, when faculty also ask students to design a system that guides uses step- or graded-index fibers for an outlined purpose, and to discuss the performance differences between the two designed systems, that assignment addresses domain specific learning outcomes, as well as professional outcomes. The professional outcomes might include: the ability to apply knowledge of math, science, and engineering; the ability to design a system or process; the ability to identify, formulate, and solve engineering problems; etc… This dual-perspective on the use of problem- and project-based assignments that typically comprise the engineering curriculum underscore an important principle in the NSU assessment strategy. Problem- and project-based assignments present an opportunity to combine standard educational activities with our assessment objectives. Moreover, we may refine the ways that we construct our problem- and project-based assignments to better support our commitment to help students achieve domain-specific knowledge and skills, as well as skills necessary for modern engineering practice as established by ABET.

#### 2.1.1 The Curriculum-Instruction-Assessment Paradigm

Pellegrino²⁰ has argued that three key elements exist in the education of the American workforce: curriculum, instruction, and assessment (CIA). These elements should be explicitly linked and any investigation of interdependencies between curriculum-instruction-assessment should begin with the exploration of students’ conceptions (including their misconceptions) of the subject matter. Programs that generate materials and approaches that integrate each of these aspects of the teaching and learning experience, build an implicit coherence into their educational approach. Analogous to the case of comparing total available energy from coherent versus incoherent optical signals, coherent links between curriculum (content), instruction

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² NSU core competencies are university defined learning outcomes for all NSU degree programs
³ The terms program outcome, educational outcome, and learning outcome are used interchangeably throughout this document
(pedagogy), and assessment may provide wonderful opportunities for deep learning experiences for students. Figure 1 presents an overview of the three interdependent components of NSU design.

Figure 1. Overview of the Curriculum – Instruction – Assessment Paradigm

As suggested above, the NSU assessment plan also incorporates a developmental cognitive model into its design. The ground-breaking work highlighted in How People Learn\[10\], reveals that the process of moving from novice to expert skills and abilities takes place over a number of authentic learning experiences that build new knowledge from an existing context. The pre-existing context (beliefs) that students bring to any new experience significantly influences their interpretation of the new information. Moreover, even if pre-existing beliefs are in fact false (wrong), students may be able to provide apparently correct interpretations of the new information without correcting the pre-existing beliefs. The new information will be based on a faulty foundation that becomes increasingly entrenched over time.

This model of developing new skills and knowledge based on an existing context is combined with a semi-quantitative framework that characterizes the degree of complexity that students demonstrate as they apply their knowledge. The Bloom’s Learning Taxonomy defines complexity in learning that begins with factual knowledge and increases in comprehension, application, analysis, synthesis, and evaluation\[3\]. Today, the Bloom’s Taxonomy has become increasingly popular among engineering educators as a framework that characterizes complexity and higher-order thinking. Moreover, Besterfield et al developed a comprehensive framework for application of Bloom’s Taxonomy in the assessment of ABET-defined program outcomes\[4\],[5].

Table 2. Bloom’s Taxonomy

<table>
<thead>
<tr>
<th>Bloom’s Level</th>
<th>Descriptive Verb</th>
<th>Key Words (descriptive tasks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>Remembering</td>
<td>define, duplicate, list, memorize, recall, repeat, reproduce state</td>
</tr>
<tr>
<td>Comprehension</td>
<td>Understanding</td>
<td>classify, describe, discuss, explain, identify, locate, recognize, report, select, translate, paraphrase</td>
</tr>
<tr>
<td>Application</td>
<td>Applying</td>
<td>choose, demonstrate, dramatize, employ, illustrate, interpret, operate, schedule, sketch, solve, use, write</td>
</tr>
<tr>
<td>Analysis</td>
<td>Analyzing</td>
<td>appraise, compare, contrast, criticize, differentiate, discriminate, distinguish, examine, experiment, question, test</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Evaluating</td>
<td>appraise, argue, defend, judge, select, support, value, evaluate</td>
</tr>
<tr>
<td>Synthesis</td>
<td>Creating</td>
<td>assemble, construct, create, design, develop, formulate, write</td>
</tr>
</tbody>
</table>
2.1.2 Practical Guidelines for Application of Bloom’s Taxonomy in an Embedded Assessment Program

Building the CIA paradigm into the teaching and learning experience was more effectively achieved by an examination of the current curricular design using the CIA filter. In our examination, it was found that a number of practical guidelines could help in simplifying the actions needed to meet our assessment and evaluation objectives.

First, practically speaking, the ABET defined program outcomes can be divided into two categories: (1) skills and abilities associated with technical proficiency, and (2) skills and abilities that complement technical skills, termed professional skills. The technical outcomes are summarized in Table 3a and the professional outcomes are summarized in Table 3b.

Given that this program was being developed from the ground up, the courses involved in our assessment plan only includes courses that are taught by engineering faculty. A curriculum mapping exercise was therefore conducted with two primary goals in mind. An initial review of courses was conducted during which faculty were asked to determine which ABET outcomes would likely be addressed through the normal activities of the course. It should be noted that at the time of this exercise, the Optical Engineering program was only in its second academic year of existence. Several courses from the junior and senior year had not yet been taught. Nevertheless, the curriculum mapping exercise would provide a snapshot of where we stand in light of the program outcomes required for accreditation. Not surprisingly, it was found that the technical outcomes, and outcomes \( a, b, \) and \( e \) in particular, were well emphasized in the curriculum. It was also found that the professional outcomes were underemphasized. While it was assumed that most of the professional skills would be addressed through general education courses that are taught outside of the Engineering Department, the faculty also agreed that opportunities to demonstrate the professional skills within the context of an engineering course would be favorable. In particular, assessment would be simplified if our data on professional outcomes could be collected from engineering course materials.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a )</td>
<td>an ability to apply knowledge of mathematics, science, and engineering</td>
</tr>
<tr>
<td>( b )</td>
<td>an ability to design and conduct experiments, as well as to analyze and interpret data</td>
</tr>
<tr>
<td>( c )</td>
<td>an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability</td>
</tr>
<tr>
<td>( e )</td>
<td>an ability to identify, formulate, and solve engineering problems</td>
</tr>
<tr>
<td>( k )</td>
<td>an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( d )</td>
<td>an ability to function in multidisciplinary teams</td>
</tr>
<tr>
<td>( f )</td>
<td>an understanding of ethical and professional responsibilities</td>
</tr>
<tr>
<td>( g )</td>
<td>an ability to effectively communicate</td>
</tr>
<tr>
<td>( h )</td>
<td>broad education necessary to understand the impact of engineering solutions in a global/societal context</td>
</tr>
<tr>
<td>( i )</td>
<td>recognition of the need for and an ability to engage in lifelong learning</td>
</tr>
<tr>
<td>( j )</td>
<td>A knowledge of contemporary issues</td>
</tr>
</tbody>
</table>
Second, once the inherent imbalance in the coverage of program outcomes had been summarized, the faculty assigned outcomes to courses to achieve balanced coverage of the outcomes across the full engineering curriculum. It was decided that our assigned distribution of outcomes should achieve balanced coverage of all technical and professional outcomes within the lower-division and upper-division curriculum. Hence, students would have opportunities to learn about and demonstrate their skills at an introductory and advanced stage of their academic experience.

It is expectation that students will achieve increasing ability to demonstrate higher-order cognition as they progress through the curriculum. It was therefore further decided that at the introductory level (lower-division), students should at a minimum demonstrate skills at the Bloom’s Taxonomy level of application, or higher. Accordingly, embedded assignments should challenge students to demonstrate application skills, as well as additional assignments for which analysis and evaluation may be demonstrated. For outcomes assessment purposes, application abilities are acceptable levels of demonstrated skills. Once students are into the upper-division, the minimum requirement for program outcomes is the Bloom’s Taxonomy level of analysis or higher (analysis being the minimum acceptable skill level). Effectively, faculty would be expected to help students achieve domain-specific content mastery and accreditation related skill mastery in their courses (see figure 2). The conventional grading structure would continue to be applied to the domain-specific content. However, the program outcomes would be evaluated using a different scale, and results of these evaluations of program outcomes would be used to support the case for accreditation.

2.1.3 Generating Embedded Assignments
Several critical tasks are needed to achieve an effective assessment program based on embedded assignments. These include development of specific criteria that clarify what specific abilities are expected, and developing rubrics that identify the differences between poor, average, and very good abilities. The criteria state what students must do, the rubrics help faculty recognize the difference between average and good skills and abilities.

The approach taken for generating the criteria mimics the models described by Felder[1] and Besterfield et al[5]. Each outcome is independently reviewed, and where appropriate, the steps needed to achieve the stated outcome are identified. Once these necessary steps are agreed upon, the faculty must decide what specifically is the distinction between acceptable and unacceptable demonstration of the skill. A well developed criteria and rubrics should also be helpful to faculty instructors as they develop assignments based on the criteria and rubrics.
The rubric may be highly definitive, prescriptive with little ambiguity. Or It may be general enough to leave space for interpretation. In our case, the fact that a given outcome could be assigned to several varied course types, has led us to opt for a loose definition of the rubric. Hence, we have taken the approach of looking first at whether or not students provide evidence that each task for a given outcome has been completed, then the quality of performance for each task is considered.

As an example, the ABET outcomes \(b\) and \(e\) are reviewed. Table 4 lists the example outcomes \((b\) and \(e\)) and a set of tasks (referred to as criteria) needed to successfully achieve the selected outcomes. Faculty may review the criteria to recognize the intermediate skills they must help students demonstrate, and the faculty may also use the criteria as a guideline for generating appropriate assignments. The instructor might then review the criteria for outcome \(b\) and develop an assignment that requires generation of a design to measure a parameter, presentation of evidence that the prescribed plan was completed, presentation of the data gathered while executing the plan, and results that indicate the collected data has been useful in drawing the conclusions. In practice, we have observed that student may choose to leave out one or more procedures in their presentation materials. Students may also attempt to carry out each task, but may have difficulty completing each task – for example, not knowing how to generate a logarithmic graph, or not realizing that a logarithmic presentation would help the reader interpret the data.

Table 4. Outcome Criteria

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Description</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>(b)</td>
<td>an ability to design and conduct experiments, as well as to analyze and interpret data(^4)</td>
<td>Generate appropriate design/plan to obtain a required measurement  &lt;br&gt; Carry out the design/plan  &lt;br&gt; Display and/or present measured data in clear and meaningful manner  &lt;br&gt; Draw justifiable conclusions based on an analysis and interpretation of the data</td>
</tr>
<tr>
<td>(e)</td>
<td>an ability to identify, formulate, and solve engineering problems</td>
<td>Formulate clear, concise problem statement  &lt;br&gt; Generate rational plan leading to problem resolution, including workplan, timeline, etc….  &lt;br&gt; Achieve solution with appropriate recognition of constraints</td>
</tr>
</tbody>
</table>

The final step needed to complete the assignment is the development of rubrics that may be used to score the assignment. This may or may not be a separate activity from grading an assignment for content mastery. In our experience however, grading for content is rarely done simultaneously with the scoring for outcomes assessment. A simplistic rubric for outcomes \(b\) and \(e\) would be to establish a category for each task, then describe characteristics that reflect poor, acceptable, and good performance for each case. The fact that these outcomes include analysis, design, and evaluation components mean that these outcomes are compatible with efforts to determine higher-order cognitive skills in students. Finally, a requirement that students achieve acceptable or better scores in selected categories is considered reasonable evidence that their Bloom’s-based rating is sufficient.

Table 5 outlines the scoring rubric for outcome \(b\). Note however, that there is a final level of detail that is dependent on the actual problem chosen. In a course on fiber-optics, a design plan would differ depending on the specifications given. Is the student designing with emphasis on size? Is the design emphasis on performance? Is the design emphasis on reliability? These factors make the scoring rubric domain specific and problem specific. Our approach has been to ask the faculty instructor to complete a detailed scoring rubric for their embedded assignment, but the rubric should be guided by the framework presented in Table 5. The table pairs shown for outcome \(b\) must be developed for all outcomes being evaluated. We have

\(^4\) Criteria listed for outcome \(b\) have been taken from model developed by Felder[7]
developed table pairs for outcomes that are evaluated to the level of Analysis and higher. These include outcomes b, c (design with realistic constraints), e (engineering problem solving), and f (ethics and professional responsibility). We specify below that selected outcomes are only evaluated to the Bloom’s level of Application.

Table 5a. Outcome b Scoring Rubric

<table>
<thead>
<tr>
<th>Task</th>
<th>Poor</th>
<th>Acceptable</th>
<th>Good</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generate appropriate design/plan to obtain a required measurement</td>
<td>Described plan omits critical steps and/or procedures</td>
<td>Described plan outlines all necessary steps, including appropriate presentation of foundational principles to support the approach chosen, but plan does not account for factors that impact integrity such as: likely sources of error; appropriate resolution to gain sufficient evidence needed to draw adequate conclusions; sufficient focus on parameters that should be emphasized in the conclusions</td>
<td>Described plan includes all necessary steps needed to collect and analyze evidence needed to make reasonable conclusions and judgments</td>
</tr>
<tr>
<td>Carry out the design/plan</td>
<td>Insufficient evidence that each step of the prescribed plan has been conducted, or if modified, no justification for modification has been presented</td>
<td>Sufficient evidence that each step of the prescribed plan has been conducted, but no indication that modifications or other adjustments have been considered</td>
<td>Sufficient evidence that each step of the prescribed plan has been conducted, including modifications that have been justified based on evidence collected</td>
</tr>
<tr>
<td>Display and/or present measured data in clear and meaningful manner</td>
<td>Incomplete presentation of data and/or incorrect presentation of data</td>
<td>Complete presentation of data collected, but not necessarily presented in a manner that emphasizes critical effects related to conclusions, mitigating factors, recommendations, etc…</td>
<td>Complete presentation of data collected, including appropriate emphasis on critical effects related to conclusions, mitigating factors, recommendations, etc…</td>
</tr>
<tr>
<td>Draw justifiable conclusions based on an analysis and interpretation of the data</td>
<td>Conclusions, recommendations, or other final comments are not clearly related to the evidence collected</td>
<td>Appropriate level of analysis based on science and engineering principles; Rational arguments given to support conclusions, recommendations, etc…</td>
<td>Strong level of analysis based on science and engineering principles, including demonstrated ability to acknowledge and incorporate impact of error, uncertainty, or other ambiguities;</td>
</tr>
</tbody>
</table>

Table 5b. Outcome b Scoring Rubric

<table>
<thead>
<tr>
<th>Task 1</th>
<th>Task 2</th>
<th>Task 3</th>
<th>Task 4</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor or higher</td>
<td>Acceptable or good</td>
<td>Acceptable or good</td>
<td>Acceptable or good</td>
<td>Acceptable/Application</td>
</tr>
<tr>
<td>Acceptable or good</td>
<td>Acceptable or good</td>
<td>Acceptable or good</td>
<td>Acceptable or good</td>
<td>Acceptable/Analysis</td>
</tr>
<tr>
<td>good</td>
<td>Acceptable or good</td>
<td>good</td>
<td>Acceptable or good</td>
<td>Acceptable/Evaluation</td>
</tr>
<tr>
<td>A score of poor in two or more categories</td>
<td></td>
<td></td>
<td></td>
<td>Unacceptable</td>
</tr>
</tbody>
</table>
2.1.4 Application Notes

After two iterations of our assessment activity, the faculty decided upon several application guidelines to help the process achieve greater efficiency and relevance.

It was decided that a few of the outcomes are particularly suited for specialized courses. For example, outcome \( b \), an ability to design and conduct experiments, and to analyze and interpret data, is well-suited for laboratory courses. Similarly, outcome \( k \), an ability to use techniques and tools necessary for modern engineering practice, is readily assessed in laboratory courses. The faculty therefore decided that laboratory courses would be used to support outcomes \( b \) and \( k \). These outcomes are not assigned to lecture or other courses that are taught within the engineering department.

For selected outcomes, demonstration of the skill beyond Bloom's Level of comprehension is not indicated. In some cases, the faculty have determined that students need only establish a knowledge-base to draw upon, and the appropriate standard for learning is the level of comprehension. The outcomes that fall into this category include outcomes \( a \) (application of math, science, and engineering), \( h \) (engineering solutions in a global/societal context), \( i \) (lifelong learning), \( j \) (contemporary issues), and \( k \) (tools for modern engineering practice).

It was quickly observed that embedded assignments that challenge students to the Bloom's level of Application or higher require a minimum knowledge base. It is considered helpful to delay the administration of embedded assignments to the second half (or latter portion) of a school term so that adjustments to teaching styles, and an appropriate knowledge-base may be established. Other design or other assignments may be given early in the school term, but those used for program assessment will be delayed.

Inherent in the embedded assessment strategy is the need to have a fully engaged faculty. Developing embedded assignments for our program requires familiarity with the Bloom’s Taxonomy, a well developed criteria for each program outcome, and a well developed rubric to score the embedded assignments. The overall requirement therefore includes professional development, and a corporate approach to development and evaluation of the criteria and rubrics on the part of the faculty. Faculty are also asked to submit their embedded assignment to an assessment committee at an early point in the school term. The assignments are not screened, but the requirement does help facilitate a thoughtfully constructed assignment.

3. CONCLUSIONS

The Norfolk State University Engineering Department has implemented an ambitious program of outcomes assessment based on embedded assignments informed by the Bloom’s Learning Taxonomy and the How People Learn philosophy of cognitive development. The program design effectively combines the curriculum, instructional emphases, and the assessment strategy to achieve a coherent package for effective teaching and learning. The program also provides mechanisms for the development of a faculty community around the goal of outcomes assessment. Although a space of time is recommended before wide-spread proficiency can be expected, we have observed that faculty gain in confidence and efficiency as they implement the embedded assignments. Given the appropriate time and resource, the embedded approach may readily become a systematically supported feature of the curriculum, and the faculty expertise also becomes integrated – perhaps to the point of transparency.

Acknowledgements

This work has been supported in part by the National Science Foundation HBCU-UP Program through NSF0625105. The authors would like to thank the full engineering faculty for their contributions and support. The authors particularly thank Drs. Rasha Morsi, Frances, Williams, and Arlene Maclin, and Mr. Kennon Outlaw.

References


Laboratory Report Writing on Optical Physics Undergraduate Labs – Draft and Feedback Processes to Facilitate Student Learning & Skill Development

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ABSTRACT
Writing high quality, formal laboratory reports about optical physics experiments is a key learning outcome for physics and optical technology graduates. Improved learning outcomes are achieved by a process of draft reports which receive feedback. Student engagement is discussed.

INTRODUCTION
There is a strong emphasis on developing high level experimental-physics skills and capabilities, including report writing, in bachelor degrees majoring in Physics, Optoelectronics or Optical Technology at Macquarie University. The Department has a tradition of establishing, maintaining and improving sophisticated experiments, using state-of-the-art equipment, for student experience. The length and sophistication of the experiments increases as students progress through the physics units of the degree. By third year students complete three 3 hour sessions in the laboratory for each experiment. They conduct their own background research on the physics of the experiment, away from the laboratory, guided by key reference resources that are provided. This contrasts with a continuation of three hour lab sessions followed by a shorter, results focussed report in optoelectronics or optical technology laboratories, where the emphasis is on providing students with time constrained "experiment and report" experience.

Third year students of Optical Physics undertake experiments selected from Optical Data Processing (Diffraction and Image Formation); Fourier Transform Spectroscopy; Fabry Perot Interferometry; Polarisation & Berry Phase; Holography; Correlation Interferometry & Spatial Coherence; Single Photon Counting and Interferometry; and Photonics Simulation Software for Teaching [1]. Pictures of some of the bench layouts for these experiments are shown in figures 1 and 2. Students write major reports on two of the experiments they complete, following the guideline for report writing developed as a consensus document within the department [2]. These reports and the lab book record of four completed experiments are major assessments that are included in a learning portfolio for the unit which the students have to complete.

Fig. 1 Experimental setup for the Fabry Perot (left) and optical data processing (right) experiments in the undergraduate optical physics laboratory, Department of Physics, Macquarie University. Photos: Dr Gina Dunford.
Assessing one of these optical physics laboratory reports typically takes 40 minutes to one hour to provide comprehensive feedback and correction of any remaining misconceptions or mistakes. It was noted some years ago that, even with quick turnaround of assessment, by the time such feedback is received by the student they have moved on to another experiment and tend to be interested only in the mark for their report. (Focus on assessment rather than learning is a mindset in many of our students that we are constantly challenging.) Thus, most students do not gain much benefit from the thoughtful and comprehensive feedback given – staff time and a learning opportunity are largely wasted. In order to assist the students to learn from the feedback provided, we introduced a process whereby students get feedback before assessment by submitting a draft of their laboratory report. They receive comprehensive feedback on this, and they can act on this feedback for their final laboratory report submission. This mirrors the interaction between research student and supervisor that is the standard approach to writing research papers. Early student responses to this process were largely negative. Students perceived this would increase their workload. Student response to this submission process is now primarily positive, but not always for reasons that are educationally positive. We report and discuss the process and the evolution of student response to this process. As teachers, we have learned that this process gives us useful insight into student learning style, and motivation, on an individual basis. We will discuss the “types and styles” that have been loosely “classified”, and our efforts to engage with each of these for the purposes of assisting students to improve their learning of experimental optical physics and laboratory report writing skills. Primarily, the process supports increased conversation with students about their learning, and, work effort and ethic, in a natural and relaxed way. We identify designing learning tasks to include exchange of feedback and response to feedback; and a “conversation” between the teacher and students, both individually and as a student group; as a preferred model for deep learning.

Fig. 2 Experimental setups for the Correlation interferometry (top), Polarisation and Berry phase (bottom left), and photon counting and interferometry (bottom right) experiments in the undergraduate optical physics laboratory, Department of Physics, Macquarie University. Photos: Dr Gina Dunford.
THE PROCESS & OUTCOMES

A flow diagram for the staged submission process is shown in figure 3. To mitigate student perception that the requirement of a draft report was an inappropriate increase in workload, it is optional for students to submit a draft report. Students are advised the draft submission process represents an important opportunity to improve their laboratory report writing, and their understanding of the optical physics, by gaining feedback as part of the writing process. This feedback may also address the writing difficulties of English second language students as developed from previous research within the department [3]. The draft reports are not formally assessed. They are returned annotated with suggestions for improvement and a completed evaluation sheet of the form shown in Appendix A. Every year some students ask to receive a grade on the draft report. It is their intention to make a decision on whether or not they will act on the suggestions for improvement on the basis of whether they are satisfied with the grade the draft would gain. The draft submission process is in place solely to facilitate learning and improvement and we explain to the students why no grade is issued at the drafting stage. Recent experience has seen about 90% of students submitting a draft report, with 60-70% of reports submitted being reasonably complete, 20% are incomplete by missing one or two major sections, and 10-20% are less than half complete. For the latter category the students derive minimal benefit from the draft submission. Drafts are guaranteed to be returned to students within one week of being received. The students have a further week to finalise their report for assessment after receiving the annotated draft.

Fig. 3 Flow diagram of the laboratory report writing process.

As the process is currently implemented, there is no formal discussion between student and reviewer on the draft. However, more than 50% of students approach the reviewer to gain further insight into the areas for improvement identified, including discussions of the optical physics. These discussions are highly valued by the students and have the advantage that they are driven by the individual student to support their individual learning. The intensity of engagement by these students at this point in the process is high and is educationally positive. (Experience of students completing a final report for assessment without a draft submission (primarily pre-dating this scheme) would have less than 20% of such students approaching teaching staff to ask questions to facilitate submitting a higher quality laboratory report). The highly motivated and engaged students are to be contrasted with the students in the group with lower levels of self motivation. These latter students span all ability levels and they have identified the draft submission process as a means of reducing their own workload. They see value in the reviewer identifying the shortcomings of a complete or incomplete draft. They then go through their report, implement and tick off a response to every piece of
feedback provided. They do little or no additional thinking about the optical physics and the report as a whole. These were the students who initially responded negatively to a change in process that they perceived would be more work. But, they learned that the additional support of the process could be used to reduce work on their part in favour of work done by the reviewer. This is a strategy which is familiar to anyone with experience of team work dynamics. Some members of the team will use the support of others to reduce their workload in an inequitable manner. Finding the balance between reasonable support from others and reasonable self effort will always be a subject of discussion in teams. The process, as implemented, sees some students reconceptualising the reviewer as part of their “team”. This is not a positive educational outcome. However, it is a predictable outcome when considering the analogous joint writing between research students and their supervisors that generated the idea for the process in the first place. Here, the teacher needs to be mindful that their role is not to become a joint writer.

The educational challenge of designing a learning and assessment process that causes a modification in learning behaviour of students pre-disposed to study-and-work avoidance remains. It is hypothesised that a sequential withdrawal of the feedback process over the course of a year in the laboratories (2 units of study in the Macquarie University context), while raising the expectation of the laboratory report quality that will be required to achieve a specific grade, as experience grows, would be worthy of testing. A judgement of whether a net improvement in learning outcomes could be achieved for a larger percentage of the students by this means could then be made. Other proposals are to incorporate critical evaluation of example laboratory reports by the students against a set of well defined guidelines, and/or to set the task of improving a partially completed report to a well defined guideline and standard. On balance, the positive learning outcomes for those students who fully engage with the learning opportunity involving submission of a draft report, outweigh the negatives of partial learning avoidance by some students. The process involves an increase in time commitment by the teacher/reviewer, and is thus, only suitable for implementation in small class teaching situations. The improvement in learning outcomes that the teacher/reviewer sees directly through the conversations with students makes the time commitment worthwhile.

APPENDIX A

Laboratory Report - Draft - Feedback

The key for the descriptors used against the evaluation criteria follows.

Key: Ex – Excellent, VG - Very Good, G – Good, A – Acceptable, U – Unacceptable, NA – Not Applicable

<table>
<thead>
<tr>
<th>Content</th>
<th>Presentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract/Introduction</td>
<td>General Structure</td>
</tr>
<tr>
<td>Background Theory</td>
<td>Style/Grammar/Spelling</td>
</tr>
<tr>
<td>Description of Experiment</td>
<td>Correct use of Units/ Presentation of numerical</td>
</tr>
<tr>
<td></td>
<td>values with Uncertainties</td>
</tr>
<tr>
<td>Comments on Important Observations</td>
<td>Drawing of Graphs</td>
</tr>
<tr>
<td>Results, Calculations and Data Analysis</td>
<td>References/ Bibliography</td>
</tr>
<tr>
<td>(Including Comparison with Theory and Available Reference Data)</td>
<td></td>
</tr>
<tr>
<td>Logical Conclusions Supported by Experimental Evidence</td>
<td>Layout (Pages, Sections, Figures &amp; Tables</td>
</tr>
<tr>
<td>Extra Effort</td>
<td></td>
</tr>
</tbody>
</table>

General Comments (specific comments are on the report):

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1. Photonics Simulation Software for Teaching, Malcolm Dunn, Bruce Sinclair, Peter Lindsay and Aly Gillies, School of Physics and Astronomy, St Andrews University, [http://www.st-andrews.ac.uk/~psst/index.htm](http://www.st-andrews.ac.uk/~psst/index.htm)

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Acknowledgements
It is a pleasure to acknowledge collegial exchange and discussion with Drs Terry Freeman, Tony Farrow and Ian Guy – past staff of the Department of Physics, Macquarie University who led other physics undergraduate teaching laboratories at the time this process was first introduced. The optical physics laboratory has been supported by highly committed professional staff, in particular Mrs Ann Hazard, and currently Dr Gina Dunford. Dr Dunford has kindly provided images of several experiments in the optical physics laboratory.

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Optics and radiometric magnitudes: are their connections clear?

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ABSTRACT

The relations between radiometric magnitudes and quantities associated to optical properties of materials (processes of reflection, transmission and emission of radiant flux by or through material media) have been analyzed. By studying some particular examples, we illustrate the dependence of optical properties of materials on the radiometric magnitude chosen and it is shown that quantities obtained from a radiometric point of view differ mathematically and physically from the corresponding Optics expressions.

1. INTRODUCTION

Radiometry is a system of language, mathematics and instrumentation used to describe and measure the propagation of electromagnetic (EM) radiation, including the effects on reflection, absorption, transmission and scattering by material substances. Many textbooks on electromagnetism¹⁻⁷ and optical physics⁸⁻¹⁷ analyze these physical phenomena. In most of them the flux of energy associated to electromagnetic radiation is described in terms of the time average of the Poynting vector. This average is related to the square of the amplitude of the electric field and it is called “intensity” or “power density”. Likewise, the reflectance and transmittance at an interface separating two different media or the reflectance and transmittance of a plane parallel plate are expressed as a function of the incident, reflected and transmitted amplitudes of the electric field. The basic concepts of radiometry are introduced in most undergraduate optics textbooks⁹,¹⁴,¹⁷. However, these texts do not explain in adequate detail the relation between the “intensity” and the radiometric magnitude called irradiance neither express the reflectance and transmittance (either at an interface or of a plate) as a function of the radiometric magnitudes. Other example where the link between both views (optical and radiometric) is far from clear is the propagation of radiation through a lossy medium. The empirical law which describes this behavior is the well-known exponential decay of the radiation with the distance. EM textbooks describe this decrease of radiation studying the decay of the amplitude of electric field with the traveled distance. However, in Optics books, there is a great dispersion in the magnitudes used to describe the exponential law and it seems that exponential decay takes always the same form regardless of the radiometric magnitude.

The purpose of this article is to contribute to a better understanding in the relation between the optical properties of materials and radiometric magnitudes, paying special attention to the physical concepts underlying the equations and trying to clarify what is somewhat messed. With that purpose in mind, in the next section radiometric magnitudes are briefly introduced. In section 3, the definitions of reflectance and transmittance at an interface and the propagation of an elemental beam of radiation immersed in a lossy medium are analyzed as a function of radiometric magnitudes. In section 4 we develop an example which is found in most textbooks: the optical properties of plane parallel plates. The reflectance and transmittance by calculating the power fluxes at each interface of the plate have been obtained and compared with the corresponding optical expressions found in optics textbooks. Finally, we end with the conclusions.
2. REMARKS ON RADIOMETRIC MAGNITUDES

Let us begin regarding the principal magnitudes used in radiometry. They are displayed in Table I. The meanings of most of the quantities are shown by their defining equations.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Defining equation</th>
<th>Radiometric magnitudes</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Φ</td>
<td>( \Phi = \int d\Phi )</td>
<td>Radiant power or flux</td>
<td>W</td>
</tr>
<tr>
<td>I</td>
<td>( I = \frac{d\Phi}{d\omega} )</td>
<td>Radiant intensity</td>
<td>W/sr</td>
</tr>
<tr>
<td>M</td>
<td>( M = \frac{d\Phi}{ds} )</td>
<td>Radiant exitance</td>
<td>W/m²</td>
</tr>
<tr>
<td>E</td>
<td>( E = \frac{d\Phi}{ds} )</td>
<td>Irradiance</td>
<td>W/m²</td>
</tr>
<tr>
<td>L</td>
<td>( L = \frac{d^2\Phi}{ds\omega \cos \theta} )</td>
<td>Radiance</td>
<td>W/sr²</td>
</tr>
</tbody>
</table>

Usually, the definition of the intensity \( I \) as flux per unit of solid angle, is related to point sources. However, the definition can be applied to extended surfaces using the concept of radiance \( L \). The intensity of an infinitesimal surface \( ds \) at \( \theta \) direction respect to its normal is defined as:

\[
dl_{\theta} = L \cos \theta \, ds \tag{1}\]

where \( L \) is the radiance at \( ds \). The definition of \( L \), stated here for a source, is extended trivially for a detector and even for a ray, at any point along its path. For a source, radiance may vary from point to point, and for a fixed point, it may vary as a function of the direction. Radiance is the most general quantity for describing the propagation of radiation through space. Its importance stems mainly from the invariance theorem that states that, in any optical system, the radiance along the path of a ray is invariant.

Irradiance \( E \) is the most important quantity for describing radiation incident on or leaving a surface when it is not essential to describe the directional distribution of that radiation in detail. It does not discriminate, for example, between very collimated radiation and radiation that is impinging from all angles. In order to take into account the orientation of the elemental surfaces in which the radiation impinges with respect to the
direction of propagation of the beam, we propose the use of what we have called perpendicular irradiance, \( S \), which is the radiant flux which crosses a unit area perpendicular to the direction of the flow. The definition of this perpendicular irradiance would be:

\[
S = \frac{d\Phi}{dS \cos \theta}
\]  

which matches the definition of the time average of the Poynting vector \( S = \frac{1}{2} \frac{\varepsilon}{\mu} E_0^2 \) where \( E_0 \) is the amplitude of the electric field.

The perpendicular irradiance is equal to the irradiance when the surface element is perpendicular to the direction of propagation of the radiation. The propagation of the radiation is frequently studied for wave planes, that is, it would correspond to a parallel beam of radiation. In this case the surface is usually placed perpendicular to the direction of propagation (\( \theta = 0 \)), so there is no distinction between irradiance and perpendicular irradiance and both magnitudes are identical to the radiation "intensity". In this case, some Optics textbooks call correctly the "intensity" irradiance.

The necessity of the perpendicular irradiance will be fully revealed when, in the next sections, we proceed to develop the reflectance and transmittance coefficients as functions of radiometric magnitudes as well as in the study of the propagation of radiation in a lossy medium.

3. PROPAGATION THROUGH AN INTERFACE SEPARATING TWO MEDIA AND A LOSSY MEDIUM

We examine the situation where a beam of radiation passes through a smooth surface separating two media with different refractive indices (\( n_1 \) and \( n_2 \)). The geometric situation is shown in figure 1. We consider the extremely thin surface region of a perfectly smooth homogeneous and isotropic dielectric material. This interface is too thin to absorb significant quantities of the radiation incident on it. The radiation incident upon the interface is split into two parts: some is reflected and the rest is transmitted. The angles of incidence and reflection (\( \theta_i \) and \( \theta_r \)) are identical due to considering a specular reflection. The conservation of energy at the interface implies:

\[
d^2\Phi_i = d^2\Phi_r + d^2\Phi_t
\]  

where \( d^2\Phi_i \) is the element of the incident flux on the area \( ds \), \( d^2\Phi_r \) is the element of the reflected flux and \( d^2\Phi_t \) is the element of the transmitted flux. The definitions of reflectance and transmittance for incident radiation of a given spectral composition, polarization and geometrical distribution are the ratios of the reflected or transmitted flux to incident radiant flux:

\[
\rho = \frac{d^2\Phi_r}{d^2\Phi_i} \quad \text{and} \quad \tau = \frac{d^2\Phi_t}{d^2\Phi_i}
\]  

Let's write them as function of the different radiometric magnitudes. By applying the definition of the corresponding radiometric magnitude and performing simple geometrical and mathematical operations, we obtain the expressions of reflectance and transmittance at an interface as a function of radiometric
The obtained expressions have been depicted in Table II. Note that reflectance is always the ratio of the reflected quantity to the incident one. On the contrary, transmittance expression changes with the radiometric magnitude. Similar relations to the expressions obtained for perpendicular irradiance have been found in some texts but they simply call $S$ irradiance instead of perpendicular irradiance, what is a bit misleading. This is not the case of the text by Born, where reflectance and transmittance are correctly defined as the ratio of irradiances $\rho = \frac{E_r}{E_i}$, $\tau = \frac{E_t}{E_i}$, then written in terms of $S$, and finally, in terms of the electric fields amplitudes. Although in the end, in all cases $\rho$ and $\tau$ are expressed in terms of the amplitudes, authors define them as ratios of different magnitudes. Therefore, it becomes absolutely necessary to use correctly the corresponding magnitude in order to describe accurately the optical properties of the material.

Table II. Reflectance and transmittance at an interface as a function of radiometric magnitudes. Dependence with these quantities of the exponential decay of radiation in a lossy medium.

<table>
<thead>
<tr>
<th></th>
<th>ENERGY CONSERVATION</th>
<th>REFLECTANCE</th>
<th>TRANSMITTANCE</th>
<th>EXPONENTIAL LAW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flux</strong></td>
<td>$d^2\Phi_i = d^2\Phi_r + d^2\Phi_t$</td>
<td>$\rho = \frac{d^2\Phi_r}{d^2\Phi_i}$</td>
<td>$\tau = \frac{d^2\Phi_t}{d^2\Phi_i}$</td>
<td>$d^2\Phi_2 = d^2\Phi_1 e^{-cx}$</td>
</tr>
<tr>
<td><strong>$L$</strong></td>
<td>$L_i = L_t + L_t \frac{n_i^2}{n_2^2}$</td>
<td>$\rho = \frac{L_r}{L_i}$</td>
<td>$\tau = \frac{L_t n_i^2}{L_i n_2^2}$</td>
<td>$L_2 = L_1 e^{-cx}$</td>
</tr>
<tr>
<td><strong>$I$</strong></td>
<td>$dI_{\theta_i} = dI_{\theta_r} + dI_{\theta_t} \frac{n_i^2 \cos \theta_i}{n_2^2 \cos \theta_t}$</td>
<td>$\rho = \frac{dI_{\theta_r}}{dI_{\theta_i}}$</td>
<td>$\tau = \frac{dI_{\theta_t} n_i^2 \cos \theta_i}{dI_{\theta_i} n_2^2 \cos \theta_t}$</td>
<td>$dI_{\theta_2} = dI_{\theta_1} \frac{(ds_2)<em>\perp}{(ds_1)</em>\perp} e^{-cx}$</td>
</tr>
<tr>
<td><strong>$E$</strong></td>
<td>$E_i = E_r + E_t$</td>
<td>$\rho = \frac{E_r}{E_i}$</td>
<td>$\tau = \frac{E_t}{E_i}$</td>
<td>$E_2 = E_1 \frac{(ds_1)<em>\perp}{(ds_2)</em>\perp} e^{-cx}$</td>
</tr>
<tr>
<td><strong>$(E)_\perp$</strong></td>
<td>$S_i = S_r + S_t \frac{\cos \theta_t}{\cos \theta_i}$</td>
<td>$\rho = \frac{S_r}{S_i}$</td>
<td>$\tau = \frac{S_t \cos \theta_t}{S_i \cos \theta_i}$</td>
<td>$S_2 = S_1 \frac{(ds_1)<em>\perp}{(ds_2)</em>\perp} e^{-cx}$</td>
</tr>
</tbody>
</table>

Suppose now we have some radiation leaving the surface element $ds_1$ in the direction $\theta_1$ and another surface $ds_2$ at $x$ distance receiving this radiation flux from direction $\theta_2$. This is illustrated on Figure 2 (a). The flux entering the solid angle $d\omega_1$ and leaving $ds_1$ is $d^2\Phi_1$. The flux received by $ds_2$ is $d^2\Phi_2$. If the two surfaces are immersed in lossy medium whose absorption of light results from linear response, the flux falls off exponentially with increasing the distance travelled in the medium:

$$d^2\Phi_2 = d^2\Phi_1 e^{-cx}$$ (5)
here \( c \) is the attenuation coefficient which we suppose constant. This coefficient is the absorption coefficient when only absorbing effects are considered. If the surfaces were within a lossless medium, the flux would remain constant. By performing the appropriate calculations we can express this equation as a function of the radiometric magnitudes. The obtained equations have been included in Table II.

\[
\text{(a)} \quad \text{(b)} \quad \text{(c)}
\]

Figure 2. (a) A narrow beam of radiation that pass through the elemental areas \( ds_1 \) and \( ds_2 \). (b) Collimated beam propagating along the direction indicated by the arrows. (c) Point source: Radiation flux contained in the solid angle \( d\omega \).

If one has a collimated beam of radiation, that is, a bundle of approximately parallel rays propagating in the same direction with the associated flux contained in a small but measurable solid angle (Figure 2(b)), the irradiance is usually considered on a plane perpendicular to the ray. In this case, \( (ds_1)_{\perp} = ds_1 = (ds_2)_{\perp} = ds_2 \), the irradiance and the perpendicular irradiance, are identical and the simple exponential law is satisfied with all radiometric magnitudes. For the case of a point source immersed in a lossy medium (Figure 3(c)), it can be demonstrated that simple exponential law is satisfied if the magnitude chosen is the intensity of point source. If the magnitude used is the irradiance or the perpendicular irradiance the obtained equation is the familiar inverse-square law of radiation from a point source with the exception that the radiation is being attenuating by the medium. These results are summarized in Table III.

**Table III.** Exponential law of the radiation propagating within an absorbing medium applied to the case of a collimated beam of radiation and a point source. \( R \) is the radius of the point source \((x>>R)\), \( I_0 \) is the intensity of the point source and \( E_0 \) is the irradiance on the surface of the point source.

<table>
<thead>
<tr>
<th></th>
<th>Collimated beam</th>
<th>Point source</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I )</td>
<td>( dl_0 = dl_0 e^{-cx} )</td>
<td>( I(x) = I_0 e^{-cx} )</td>
</tr>
<tr>
<td>( E, S )</td>
<td>( E_2 = E_1 e^{-cx} )</td>
<td>( E(x) = E_0 e^{-cx} \left( \frac{R^2}{x^2} \right) )</td>
</tr>
</tbody>
</table>

To end with this section, we would like to emphasize the importance of the different cases we have studied here in order to relate properly the physical situation with the appropriate radiometric magnitude. The next section illustrates an application of the equations we have just worked out (and displayed in Table II).

**4. CASES STUDIES: PLANE PARALLEL PLATE**

A material bounded by two parallel interfaces defines an object that can reflect, transmit and absorb radiation incident on it. (Scattering processes are considered negligible). Let’s now obtain the optical properties of the plate by separating the power flux at each interface into an outgoing component and an incoming component. The reflectance, transmittance and absorptance of this object are defined respectively.
as the fraction of flux incident upon the object that is reflected, transmitted and absorbed by the object for defined directions of incidence and emergence, polarization state and wavelength.

Let's consider an unpolarized collimated beam of radiation of wavelength $\lambda$ at the direction $\theta_1$ impinging on a plane parallel plate of a homogeneous and isotropic material of known thickness $d$ and refractive index $n$ which is surrounded by two media of index $n_1$ and $n_2$. The multiple reflections and transmissions of the incident beam are shown in Figure 3.

![Figure 3. Multiply reflected and transmitted beams in a parallel plate. The value of $x$ is given by $x=d/\cos\theta$. The values of $S$ in different positions of the beam have been plotted for incident $S_i=1$. The expressions in parenthesis are the values of radiance ($L$) for incident $L_i=1$.](image)

The reflectance and transmittance of the left interface are $\rho_{12}$, $\tau_{12}$, and $\rho_{21}$, $\tau_{21}$ depending on the direction of the radiation (from $n_1$ medium to $n$ material or from the material to the $n_1$ medium). In the same way, the reflectance and transmittance of the right interface are denoted by $\rho_{23}$, $\tau_{23}$, $\rho_{32}$ and $\tau_{32}$. The definitions of
these interface magnitudes as a function of different radiometric magnitudes have been displayed in Table II. They can be determined by using Fresnel equations, which give the ratio of reflected (or transmitted) electric field amplitude to the incident one. Absorption is considered by taking into account that the flux of the ray propagating across the material will decrease according to the exponential law.

4.1 Radiation view

Supposing that the incident flux is \( \Phi_1 \), the total reflectance \( R \) of the plate for this situation will be the ratio of the sum of all the fluxes emerging to the left of the incident flux:

\[
R = \frac{\sum_k (\Phi_r)_k}{\Phi_1}
\]

(6)

where the summatory is extended to the total number of interreflections in the material. Taking into account that the direction of reflected radiation is the same for all the emergent beams and that the angles of reflection and incidence are equal, the next relations are satisfied: \( \cos \theta_k = \cos \theta_1 \quad \forall \ k \Rightarrow \ \omega \Phi_k = \omega \Phi_1 \quad \forall \ k \Rightarrow \ \omega \Phi_k \cos \theta_k = \omega \Phi_1 \cos \theta_1 \quad \forall \ k \) (collimated beam \( ds_k = ds \quad \forall \ k \)). Applying these relations the reflectance can be expressed as a function of different radiometric magnitudes as follows:

\[
R = \frac{\sum_k (\Phi_r)_k}{\Phi_1} = \frac{\sum_k (L_r)_k d\omega_k ds_k \cos \theta_k}{L_1 d\omega_1 ds \cos \theta_1} = \frac{\sum_k (L_r)_k}{L_1}
\]

(7)

\[
R = \frac{\sum_k (\Phi_r)_k}{\Phi_1} = \frac{\sum_k (E_r)_k ds_k}{E_1 ds} = \frac{\sum_k (E_r)_k}{E_1}
\]

(8)

\[
R = \frac{\sum_k (\Phi_r)_k}{\Phi_1} = \frac{\sum_k (S_r)_k ds_k \cos \theta_k}{S_1 ds \cos \theta_1} = \frac{\sum_k (S_r)_k}{S_1}
\]

(9)

Therefore, the reflectance of the plate can be defined as the ratio of reflected to incident radiance or irradiance or perpendicular irradiance. Let's perform the same calculations in order to obtain the transmittance of the plate. The total transmittance \( T \) of the plate will be the ratio of the sum of all the fluxes emerging to the right of the plane parallel plate:

\[
T = \frac{\sum_k (\Phi_t)_k}{\Phi_1}
\]

(10)

Now, the directions of the transmitted radiation are identical but they are different to the incident direction. The transmittance expressed as a function of different radiometric magnitudes will be:

\[
T = \frac{\sum_k (\Phi_t)_k}{\Phi_1} = \frac{\sum_k (L_t)_k d\omega_k ds_k \cos \theta_k}{L_1 d\omega_1 ds \cos \theta_1}
\]

(11)

In this case \( d\omega_k ds_k \cos \theta_k = d\omega_2 ds \cos \theta_2 \quad \forall \ k \) and we can write:

\[
T = \frac{\sum_k (L_t)_k}{L_1 d\omega_1 \cos \theta_1}
\]

(12)

Applying the Snell laws \( n_1 \sin \theta_1 = n \sin \theta \), \( n \sin \theta = n_2 \sin \theta_2 \) and their differential equations the expression for the transmittance is reduced to:
The equations for the transmittance as a function of irradiance and perpendicular irradiance will be:

\[
T = \left( \frac{n_1^2}{n_2^2} \right) \sum_k \frac{(L_{t,k})}{L_i} \tag{13}
\]

The equations for the transmittance as a function of irradiance will be:

\[
T = \sum_k \frac{(\Phi_{t,k})}{E_{i}} = \sum_k \frac{(E_{t,k}) ds}{E_{i}} = \sum_k \frac{(E_{t,k})}{S_{i} ds \cos \theta_i} \tag{14}
\]

\[
T = \sum_k \frac{(\Phi_{t,k})}{E_{i}} = \sum_k \frac{(S_{t,k}) ds \cos \theta_k}{S_{i} \cos \theta_i} \tag{15}
\]

It can be observed that the expressions do not depend on the material refractive index \((n)\) and the direction of the interreflections \((\theta)\) and that they are quite similar to the expressions for an interface. If the plate is surrounded by the same medium (i.e., \(n_1=n_2\)), the angles of incidence, reflection and transmission are equal and the reflectance (transmittance) can be defined as the ratio of reflected (transmitted) to incident radiometric magnitude, no matter which one is chosen.

Let's write the reflectance and transmittance of the plate \((R\) and \(T)\) as a function of the reflectance, transmittance of the interfaces, \(\rho_{12}, \tau_{12}, \rho_{21}, \tau_{21}, \rho_{23}, \tau_{23}, \rho_{32} \) and \(\tau_{32}\). For that purpose, after choosing one radiometric magnitude we must apply its corresponding equations from Table II. Figure 3 shows the values obtained when using perpendicular irradiance \((S)\) for the multiple reflections and transmissions between the two interfaces. If, for instance, radiance \(L\) were chosen, the values inside the material and at the right would be different from the \(S\) values displayed on figure 3, while the \(L\) values at the left of the figure would not change.

The exponential law for the decreasing of radiation has been applied in the propagation of the beam inside the material. In this case this law does not change with the radiometric magnitude and takes its simplified expression (for instance, \(S_2 = S_1 \exp(-cx)\)) due to \((ds_1)_\perp = (ds_2)_\perp\). By performing mathematical operations the following expressions for \(R\) and \(T\) are obtained:

\[
R = \rho_{12} + \frac{\rho_{23} \tau_{12} \tau_{21} e^{-2cx}}{1 - \rho_{21} \rho_{23} e^{-2cx}} \quad \text{and} \quad T = \frac{\tau_{12} \tau_{23} e^{-cx} \cos \theta_2}{1 - \rho_{12} \rho_{23} e^{-2cx} \cos \theta_1} \tag{16}
\]

and the law of energy conservation implies that the absorptance \(A\) of the plate is given by \(A = 1 - R - T\).

In the case that the external medium be the same (\(n_1=n_2\) and \(\cos \theta_1=\cos \theta_2\)), using Fresnel equations we get \(\rho_{23} = \rho_{21} = \rho_{12} = \rho\) \(, \tau_{12} \tau_{21} = (1-\rho)^2\) \(\), so that equations (16) are simplified to:

\[
R = \rho + \frac{\rho(1-\rho)^2 e^{-2cx}}{1 - \rho^2 e^{-2cx}} \quad \text{and} \quad T = \frac{(1-\rho)^2 e^{-2cx} \cos \theta_2}{1 - \rho^2 e^{-2cx}} \tag{17}
\]

If absorption processes are neglected \((e^{-cx} \approx 1)\), the result is:

\[
R_{rad} = \frac{2\rho}{1+\rho} \quad \text{and} \quad T_{rad} = \frac{1-\rho}{1+\rho} \tag{18}
\]
These magnitudes, that we call radiation reflectance and transmittance, only depend on $\rho$, that is, on the incident angle and the refraction indexes.

4.2 Optical view

Let’s pay attention to the corresponding expressions that appear in many Optics textbooks for the last case (i.e., same external medium $n_1=n_2$); these books usually provide the total reflected and transmitted “intensity”, from which the reflectance and transmittance of the plate are easily calculated by performing the corresponding ratios. The reflection and transmission expressions of a plate when absorption processes are negligible are given by:

$$ R = \frac{(2 - 2\cos \delta) r_{12}^2}{1 + r_{12}^4 - 2 r_{12}^2 \cos \delta} \quad \text{with} \quad |f_{12}| = |f_{21}| $$

$$ T = \frac{(t_{12} t_{21})^2}{1 + r_{12}^4 - 2 r_{12}^2 \cos \delta} \quad \text{with} \quad t_{12} t_{21} = 1 - r_{12}^2 $$

where $\delta$ is the phase difference of two consecutive waves $\left( \delta = \frac{4\pi}{\lambda} nd \cos \theta \right)$, and $r$ and $t$ are reflection and transmission coefficients; the latter are defined as the ratio of reflected/transmitted electric field amplitudes to the incident electric field amplitude, $r = \frac{\langle E_0 \rangle_r}{\langle E_0 \rangle_i}$, $t = \frac{\langle E_0 \rangle_t}{\langle E_0 \rangle_i}$, and they are determined by applying the Fresnel equations. Taking into account the definition of $S$ as a function of the electric field amplitude, considering nonmagnetic materials and using properly the definitions displayed in Table II, the correct values for $\rho$, $\tau_{12}$, $\tau_{21}$ are obtained in this case as $\rho = r_{12}^2 = r_{21}^2$, $\tau_{12} = \frac{n \cos \theta_1}{n \cos \theta_i} t_{12}^2$, $\tau_{21} = \frac{n \cos \theta_1}{n \cos \theta_i} t_{21}^2$. We can then transform equations (19)-(20) into:

$$ R_{\text{opt}} = \frac{2(1-\cos \delta) \rho}{1 + \rho^2 - 2 \rho \cos \delta} \quad \text{and} \quad T_{\text{opt}} = \frac{(1-\rho)^2}{1 + \rho^2 - 2 \rho \cos \delta} $$

4.3 Comparison

Let’s compare now equations (18) and (21). Obviously, they are not the same. It can be noticed in equations (21) the dependence on the phase difference of two consecutive waves which implies that these expressions depend on the thickness of the plate. On the contrary, equations (18) do not depend on the thickness. As an example, we plot in Figure 4 both transmittances as a function of thickness for an uncoated calcium fluoride window at 486nm at two angles of incidence. Calcium fluoride has very low absorption at this wavelength, so the equations (18) and (21) are appropriate for this case. The curved lines are values obtained from eq. (21) and the straight line from eq. (18). As it can be seen, the optical values oscillate around those calculated from the radiation method and the oscillations change with the value of angle of incidence. The maximum dispersion of the $R_{\text{opt}}$ and $T_{\text{opt}}$ values is $\Delta R_{\text{opt}}=\Delta T_{\text{opt}}=4\rho/(1+\rho)^2$, which only depends on $\rho$. In Figure 5, it can be seen the dependence of both transmittances ($T_{\text{rad}}$ and $T_{\text{opt}}$) and the dispersion $\Delta T_{\text{opt}}$ with the angle of incidence. The dispersion is constant and small at low angles and increases strongly at higher angles of incidence. As we have noticed in the previous figure, the $T_{\text{opt}}$ values oscillate around the $T_{\text{rad}}$ values. How can we explain from a physical point of view these results?
At first sight, and due to the fact that the optical equations (21) have been obtained taking into account interference processes, it may seem that performing some kind of averaging to the phase difference $\delta$ ($\delta = \frac{4\pi}{\lambda} nd\cos\theta$) in the optical equations can lead us to the equations (18). But, what type of average? By supposing a homogeneous and isotropic material, the net variation of $\delta$ can be expressed as the following expression:

$$\Delta\delta = 4\pi \left( n \frac{\Delta d}{\lambda} |\cos\theta| + n \frac{\Delta \lambda}{\lambda^2} d|\cos\theta| + n \frac{d}{\lambda} |\sin\theta| \Delta\theta \right)$$  \hspace{1cm} (22)$$

Hence, we conclude that the phase differences produced by the waves inside the plate can adopt any value, if:
i) The plate surfaces are rough, meaning that the thickness ($\Delta d$) and the surface normal ($\Delta \theta$) vary randomly.

ii) The incident light is a non-monochromatic radiation with a spectral bandwidth ($\Delta \lambda$).

By assuming that any of these effects take place, the $R_{\text{opt}}$ and $T_{\text{opt}}$ could be averaged over all possible values of $\delta$. If the following averages are performed:

$$<R> = \frac{1}{2\pi} \int_{0}^{2\pi} R_{\text{opt}} \, d\delta = \frac{1}{2\pi} \int_{0}^{2\pi} \frac{2(1-\cos\delta)\rho}{1+\rho^2-2\rho\cos\delta} \, d\delta$$

$$<T> = \frac{1}{2\pi} \int_{0}^{2\pi} T_{\text{opt}} \, d\delta = \frac{1}{2\pi} \int_{0}^{2\pi} \frac{(1-\rho)^2}{1+\rho^2-2\rho\cos\delta} \, d\delta$$

we obtain $<R> = R_{\text{rad}}$ and $<T> = T_{\text{rad}}$, that is, the optical equations averaged over $\delta$ become into the radiation expressions for reflectance and transmittance. So, clearly distinguishing these two types of magnitudes is very important not only from a basic physical point of view but from a practical viewpoint. Accurate reflectance and transmittance measurements are necessary for calibration spectrometers or for determination of the optical properties of materials. It is also important to distinguish both magnitudes in optics catalogues, where the transmittances of the colored glass filters, the neutral density filters, the interference filters, the uncoated windows, etc., are shown. Evidently, the expressions for transmittance which describe the corresponding behaviours are different for each type of filter; therefore we must take into account the above considerations, such as, the roughness of the plate or the spectral bandwidth of the radiation in order to correctly interpret the given information.

5. CONCLUSIONS

1) The definition given in Electromagnetic and Optics textbooks of the “intensity” as the time average of the amount of energy which crosses per second a unit area perpendicular to the direction of the flow is the radiometric magnitude *irradiance* only if the direction of the propagation is perpendicular to the surface.

2) The reflectance $\rho$ at an interface can always be expressed as the ratio of the reflected radiometric magnitude to the incident one. In contrast, the transmittance $\tau$ expression changes with the radiometric magnitude. Furthermore, the decreasing exponential law of the radiation propagating within an absorbing medium depends on the radiometric magnitude used. The more conventional version of this law corresponds to the case of a collimated beam of radiation, expressed as a function of *irradiance*. In this situation, the simple exponential law is satisfied with every radiometric magnitude. For other cases, the expression of the law may change. So one has to be very careful while interpreting this very well known equation.

3) Equations for reflectance $R$ and transmittance $T$ have been obtained for the case of a plane parallel plate by computing the total power flux (reflected and transmitted) at each interface. These expressions show a dependence on radiometric magnitudes similar to the one displayed by the reflectance $\rho$ and the transmittance $\tau$ at an interface. Only if the plate is surrounded by the same medium, $R$ and $T$ can be defined as the ratio of the reflected (transmitted) to the incident radiometric magnitude, no matter which one is chosen. The expressions obtained for this simple case have been compared with the corresponding ones found in Optics textbooks. Not only the mathematical expressions differ, but also the inner physical meaning, since the effect of interferences is only considered in the optical view. Both expressions (the radiation ones and the optical ones) coincide if the plate does not have smooth and parallel surfaces and/or the radiation presents a broad spectral bandwidth.
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A new technique to teach basic concepts of refraction and reflection of light

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ABSTRACT

Nature of light is a fascinating subject of education and training for children. However, it is not easy to demonstrate and explain fundamental properties of the light to the primary & secondary school students. In this paper, we will present a new technique to teach concept of refraction, reflection, and total internal reflection of light in glasses by utilizing deviation angles of a prism for various surrounding index-matching oils.

Keyword list: reflection, refraction, total internal reflection, deviation angle, prism, index matching oil

1. INTRODUCTION

Glass, developed in Mesopotamia around B.C. 1700, provides us daily necessaries, arts, and the beauty. In addition, basic behavior of the light in glasses such as refraction and reflection allow us to observe a distant star or to detect the virus in micro scale. Therefore, it is quite important for children to understand basic concept of refraction and reflection of the light to the primary & secondary students since it helps them to understand nature of light as well as modern optical instruments.

There have been some difficulties to explain basic concept of reflection and refraction to the primary & secondary school students. If students understand the concept of a trigonometry, it may be easy for us to give them a clear idea of the law of reflection and refraction. However, unfortunately, most of primary & secondary school students are not exposed on these concepts. Even though various materials and experiments have been developed to help students to get basic behaviors of the light, therefore, most of them are not easy for the primary & secondary school students to understand them easily and clearly. In particular, some of these materials even require calculating the trigonometric problem and/or following the complicated experimental processes [1,2].

In order to teach basic concept of reflection and refraction for primary & secondary school students, it is necessary to introduce a relatively simple technique and to develop experimental set-up, which can provide intuitive pictures for the reflection and refraction of light [3,4]. In this paper, we will demonstrate a new technique to teach refraction, reflection, and total internal reflection of light by using a prism and index-
matching oils simultaneously. In particular, we have utilized that the deviation-angle changes as the refractive index of the index-matching oil increases.

2. UNDERSTANDING OF OPTICAL PROPERTIES

When a light traveling through a transparent medium encounters a boundary leading into another transparent medium, a part of the light is reflected and the other part enters the second medium. Since the incident light and reflected light are symmetrical with respect to the line which is perpendicular to the boundary, in general, the angle of incidence equals the angle of reflection. On the other hand, the light that enters the second medium is bent (or refracted) at the boundary. The aspect of refraction depends on the differences in dielectric constants between air and acrylic, between glass and water, etc., and on the angle of incidence, as shown in fig. 1(a), (b) [3,4].

![Fig. 1 Reflection and refraction of the light for (a) $n_a < n_b$ and (b) $n_a > n_b$](image)

In order to instruct the concept of reflection and refraction to the students intuitively, it is useful to introduce the velocity of the light and its relation with refractive index. In fact, the optical properties of dielectric media are quite closely related to the refractive index. The velocity of the light in the medium is determined by refractive index by the equation (1) [2,3,4].

$$\nu = \frac{c}{n} \quad \text{where} \quad c : \text{speed of light in vacuum} \quad \nu : \text{speed of light in material of refractive index } n$$ (1)

When the light travels in the air, its speed is approximately $3.00 \times 10^8$ m/s, but this speed is reduced down to approximately $2.00 \times 10^8$ m/s when the light transmits inside a glass. The difference in the light speeds between two transparent media can be utilized to explain the refraction of the light at the interface between two media. A well-known example to explain the law of refraction for the primary & secondary school...
students is as follows. What if students holding hands with each other jumped in at an angle from paved road to muddy land? As students hold hands tight with each other, their running speed is same and forms a straight line of students. When the right end of the running students reaches the muddy land as shown in Fig. 2., he slows down, while the left end remains on the paved road and moves at their original speed. This difference in speeds causes the line of students to pivot, and changes the direction of travel. Therefore, the relationship between the refractive index and the speed of light can be effectively utilized to provide an important physical property of the light to the students. Of course, we can explain also that the refraction angle increases as the difference of the refractive index in two media increases.

In addition, the behavior of light re-emerging into air, after passing through the substance, can be understood easily. When the light re-emerges into air, its speed instantaneously increases to its original value of 3.00×10^8 m/s. This phenomenon often makes the students quite confused since it is far different from what happens in daily life, for example, such as the reduced speed of a bullet firing through a block of wood. In this case, the speed of the bullet is reduced as it moves through the wood because part of its original energy is transferred to the wood in the form of heat due to the frictional force. When the bullet enters the air once again, therefore, it emerges at a speed just before leaving the block of wood. However, in case that the light travels in vacuum or the some transparent medium, it interacts with surrounding media by repeating absorption and radiation. In the glass, light travels from one glass atom to another at 3.00×10^8 m/s, the absorption and radiation that take place cause the average light speed through the material to fall to about 2.00×10^8 m/s. When the light re-emerges into the vacuum, the absorption and radiation of the light cease and the speed of the light returns to the original value. It is a similar situation that slow student in muddy land can run at their original speed in paved road.

An interesting effect called total internal reflection can occur when light is directed from a medium having a given index of refraction toward one having a lower index of refraction. Consider a light beam traveling in material $a$ and meeting the boundary between material $a$ and material $b$, where $n_a$ is greater than $n_b$. Various possible directions of the light are indicated as shown in Fig. 3(a). The refracted lights are bent away from the normal because $n_a$ is greater than $n_b$. At some particular angle of incidence $\theta_i$, called the critical angle, the refracted light moves parallel to the boundary. The critical angle to produce total internal reflection is small when $n_a$ is considerably greater than $n_b$. For example, the critical angle for a diamond in air which has refractive index of 2.4 is 24.5°. Any light inside the diamond that approaches the surface at an angle greater than this is completely reflected back into the crystal. This property, combined with proper faceting, causes
diamonds to sparkle and colorful. The angles of the cutting facets are accurately adjusted so that light is “caught” inside the crystal through multiple internal reflections.

![Fig. 3 Total internal reflection](image)

3. DESIGN OF EXPERIMENT

Various experimental equipments for training basic concepts of reflection and refraction of the light have been developed. A typical experimental setup to provide better understanding of the law of reflection and refraction is shown in Fig. 4 [6]. In this experiment, the deviation angle of the refracted light by semi-cylinder block is measured. By tracing rays of light through a transparent semi-cylinder block and measuring the angles at the interfaces, the refractive index of material in the semi-cylinder vessel is calculated using Snell’s law.

![Fig. 4 Experiment for refraction and reflection of light](image)

However such method may not be easy for the primary & secondary school students to understand who have just encountered the phenomenon of refraction. They may feel frustrated by the associated mathematical problems, which act as unnecessary barriers at the level of their knowledge. Therefore, in this paper, we propose an effective experimental set-up in order to overcome these disadvantages. Our experimental set-up consists of glass prism, oils with various refractive indexes, and a water tank.
Conventional glass prism is utilized and it has refractive index of 1.517. The prism is placed into water tank, and index-matching oil is filled in water tank. When the light from the laser pointer is illuminated directly through the water tank and the prism, we can observe the two aspects of light propagation: reflection and refraction. The light is partly reflected in the interface separating two transparent materials, that is, oil and glass prism. Fig. 5(a) shows a schematic diagram of our experimental set-up.

In order to observe the light propagation more clearly, some of milk drop can be mixed with oil as a scattering source. If the index-matching oil is not available, other substance, which can be obtained in our daily life, is very useful such as honey, water, and cooking oil. These substances can be filled up water tank in layers because of the difference of their densities. As the result of layered substances with different refractive index, various refracted lights can be observed in condition of fixed incident angle at the same time.

The incident light propagated through the prism from the left emerges refracted from its original direction of travel by an angle, called the deviation angle. The deviation-angle changes as the refractive index of the index-matching oil increases. With changing the incident angle, total internal reflection happens at the critical angle which varies according to the refractive index of the ambient medium. Fig. 3(b) shows a deviation angle of a prism for a given incident angle at 60° as a function of refractive index of surrounding medium.

This proposed experiment is intuitive for children who are unfamiliar with physical concepts such as reflection and refraction. Moreover, showing the process of emerging new scientific phenomena, total internal reflection, during experiment can make children feel attracted more to scientific experiments.

4. CONCLUSION

In this paper, we have demonstrated a simple technique to teach refraction, reflection, and total internal reflection of light by using a prism and index-matching oils simultaneously. This experimental mechanism helps us to observe the refraction of light between two media which have different refractive indices as well as the phenomena of total internal reflection. In particular, we have utilized that the deviation-angle changes as
the refractive index of the index-matching oil increases. This experimental technique can be utilized as an effective teaching tool since it can offer students in various age groups an integrated and entertaining way of learning basic concepts of light, such as refraction and reflection as well as total internal reflection simultaneously, by employing a simple and easily available equipment.

References

Numerical modeling of thin film optical filters

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ABSTRACT
Thin films are an important and sometimes essential component in many optical and electrical devices. As part of their studies in optics, students receive a basic grounding in the propagation of light through thin films of various configurations. Knowing how to calculate the transmission and reflection of light of various wavelengths through thin film layers is essential training that students should have. We present exercises where students use Mathcad to numerically model the transmission and reflection of light from various thin film configurations. By varying the number of layers and their optical parameters, students learn how to adjust the transmission curves in order to tune particular filters to suit needed applications.

Keyword list: thin films, numerical modeling, optical filters

1. INTRODUCTION
In the Introduction to Optics class students learn about the thin film concept through interference, (constructive and destructive interference), antireflecting coating, Michelson and Fabry-Perot interferometers. The course is taken by students in the spring semester of their second year after they have finished their introductory physics classes. The course is a three credit hour course with an accompanying lab that is one credit hour. In the same year the students are required to take the Programming and data analysis course in which, among other techniques, they learn how to use Mathcad. Since thin films are such an integral part of our daily lives, the purpose of these exercises is to give students a better understanding about the design and applications of thin films as related to optical filters. Other exercises related to thin films can be developed on the same structure.

This paper highlights the concepts that students are introduced to as related to thin films and Mathcad exercises. While more sophisticated thin film analysis software packages exist, the purpose of these exercises is to encourage students to practice and combine their newly acquired knowledge of thin film concepts with the Mathcad skills to understand the importance of “theory and practice”. This will also make them more comfortable and fast in their Mathcad programming and hopefully appreciate the ease with which Mathcad can simplify the tedious multiplication of matrices.

2. TRANSFER MATRIX
The transfer matrix is used to represent the film and characterize its performance. Its explanation and the subsequent theory presented below follows that which students are typically introduced to in undergraduate textbooks and follows that presented by Pedrotti. Mathcad will allow for calculations of net fields at one boundary of the film knowing the net fields at the other boundary. A one layer film is presented in the diagram.
below along with the components of the electric and magnetic fields of the incident, reflected, and transmitted wave.

![Diagram](image)

Figure 1. One layer film of thickness $t$ and index of refraction $n_1$ on a substrate of index $n_s$.

We assume a homogenous, isotropic film with index of refraction $n_1$ deposited on a substrate with index of refraction $n_s$ and placed in a medium with $n_0$. The incident beam undergoes an external reflection at the first interface (a) and the transmitted beam undergoes an internal reflection and transmission at the second interface (b). According to the boundary conditions, the tangential components of the resultant electric and magnetic fields are continuous across the interface,

\[
E_a = E_0 + E_{r1} = E_{t1} + E_{r1}
\]
\[
E_b = E_{t2} + E_{r2} = E_{r2}
\]

(1)

and

\[
B_x = B_0 \cos \theta_0 - B_{r1} \cos \theta_0 = B_{t1} \cos \theta_{t1} - B_{r1} \cos \theta_{t1}
\]
\[
B_y = B_{t2} \cos \theta_{t1} - B_{r2} \cos \theta_{r1} = B_{r2} \cos \theta_{r2}
\]

(2)

where the magnetic field has tangential and perpendicular components. Using the relation $B = n\sqrt{\varepsilon_0 \mu_0} E$, the boundary conditions (2) for the magnetic field can be written as a function of the electric field:
where \( \gamma_0 \equiv n_0 \sqrt{\varepsilon_0 \mu_0} \cos \theta_0 \), \( \gamma_1 \equiv n_1 \sqrt{\varepsilon_0 \mu_0} \cos \theta_1 \), and \( \gamma_s \equiv n_s \sqrt{\varepsilon_0 \mu_0} \cos \theta_2 \). Additionally, there is a phase difference, \( \delta \) between \( E_{12} \) and \( E_{11} \), where \( \delta = k \Delta = \left( \frac{2 \pi}{\lambda_0} \right) n_1 t \cos \theta_1 \). The electric fields then become:

\[
E_{12} = E_{11} e^{-i \delta} \quad \text{and} \quad E_{11} = E_{12} e^{i \delta}
\]

and, when included in the boundary conditions above, yields

\[
\begin{align*}
E_b &= E_{11} e^{-i \delta} + E_{12} e^{i \delta} = E_{12} \\
B_b &= \gamma_1 (E_{11} e^{-i \delta} - E_{12} e^{i \delta}) = \gamma_s E_{12}.
\end{align*}
\]

\( E_{11} \) and \( E_{12} \) can be solved in terms of \( E_b \) and \( B_b \):

\[
\begin{align*}
E_{11} &= \left( \frac{\gamma_s E_b + B_b}{2 \gamma_1} \right) e^{i \delta} \\
E_{12} &= \left( \frac{\gamma_s E_b - B_b}{2 \gamma_1} \right) e^{-i \delta}
\end{align*}
\]

and finally, substituting the above expressions in the initial field components, obtain

\[
\begin{align*}
E_a &= E_b \cos \delta + B_b \left( \frac{i \sin \delta}{\gamma_1} \right) \\
B_a &= E_b \left( i \gamma_1 \sin \delta \right) + B_b \cos \delta.
\end{align*}
\]

These expressions relate the field components at the first boundary to those at the next one and can be written in matrix form, where the numerical indices now indicate the boundary encountered by the wave as it passes through the system:

\[
\begin{pmatrix}
E_a \\
B_a
\end{pmatrix} =
\begin{pmatrix}
\cos \delta & \frac{i \sin \delta}{\gamma_1} \\
\frac{i \gamma_1 \sin \delta}{\cos \delta}
\end{pmatrix}
\begin{pmatrix}
E_1 \\
B_1
\end{pmatrix} = M_1 \begin{pmatrix}
E_1 \\
B_1
\end{pmatrix}.
\]

Each layer of a multilayer coating has its own transfer matrix and the overall transfer matrix of the system is the product of individual transfer matrices, taken in the order in which the light propagates through the multilayer stack,

\[
M = \prod_{i=1}^{N} M_i.
\]

Using the boundary conditions the transfer matrix could be rewritten in the form:
The coefficients of reflection and transmission are defined as: 
\[ r = \frac{E_1}{E_0} \quad \text{and} \quad t = \frac{E_2}{E_0} \]
and, when rewritten in terms of the transfer matrix components are as:

\[
t = \frac{2\gamma_0}{\gamma_0 m_{11} + \gamma_0 \gamma_1 m_{12} + m_{21} + \gamma_1 m_{22}}
\]
\[
r = \frac{\gamma_0 m_{11} + \gamma_0 \gamma_1 m_{12} - m_{21} - \gamma_1 m_{22}}{\gamma_0 m_{11} + \gamma_0 \gamma_1 m_{12} + m_{21} + \gamma_1 m_{22}}.
\]

These expressions can be used for any number of layers in a coating to determine the coefficients of reflection and transmission that can then be used to determine transmittance \( T = |t|^2 \) and reflectance \( R = |r|^2 \).

3. MATHCAD MODELING FOR REFLECTION AND TRANSMISSION CASES

Students will consider the most common case for thin films, that being normal incidence \( (\theta_0 = 0 \text{ rad}) \). The phase difference becomes \( \delta = \left( \frac{2\pi}{\lambda_0} \right) n_1 t \) and the film has an index of refraction larger than that of the substrate. At normal incidence they can recalculate the expression for reflectance \( R \)

\[
R = |r|^2 = \frac{n_1^2 \left( n_0 - n_r \right)^2 \sin^2 \delta + \left( n_r n_0 - n_0^2 \right) \sin^2 \delta}{n_1^2 \left( n_0 + n_r \right)^2 \sin^2 \delta + \left( n_r n_0 + n_r^2 \right) \sin^2 \delta}.
\]

3.1 One layer reflecting coating

A simple problem for students is to calculate the reflectance for a single layer.

**Example #1**: A 50 nm thick film of TiO2 \( (n=2.40) \) is deposited on glass \( (n=1.50) \). What is the normal reflectance at a wavelength of 550 nm?

The students easily compute the reflectance using the above equation to be 33.6%. However, a more meaningful calculation for them would be to determine reflectance over a range of wavelengths, using a Mathcad program. The program gives them flexibility to vary the index of refraction through choice of materials and analyze the effect of layer thickness on reflectance or transmittance.

Figure 2 shows the Mathcad program for a single layer. The student begins by defining the necessary constants and conditions, such as the wavelength range, indices of refraction for the medium, film and substrate, and the layer thickness. Next follow the equations including the transfer matrix necessary for the calculations of the reflectance and transmittance, which can be computed and graphed simultaneously.

Students can now see the behavior of the reflectance and transmittance over a wavelength range in the optical spectrum including the case analyzed in Example #1.
For quarter-wave thick films \( t = \frac{\lambda}{4} = \frac{\lambda_0}{4n_i} \) the reflectance is given by the expression \( R = \left( \frac{n_0n_s - n_i^2}{n_0n_s + n_i^2} \right)^2 \).

The index of refraction, \( n_i \), for an antireflecting coating would then be \( n_i = \sqrt{n_0n_s} \). Again, students could analyze the film for a wavelength range using Mathcad and by selecting the appropriate material for the film and substrate. This type of coating will be included next in two-layer antireflection films.

### 3.2 Two-layer antireflecting coating

Given the limited selection of materials for various indices of refraction, a double layer coating of quarter-wave films yields near zero reflectance at one wavelength. For normal incidence the transfer matrix is given by the product of the two transfer matrices that characterize each individual layer:

\[
M = M_1M_2 = \begin{pmatrix}
0 & i & 0 & i \\
\gamma_1 & 0 & \gamma_2 & 0 \\
i\gamma_1 & 0 & i\gamma_2 & 0 \\
0 & \gamma_1 & 0 & -\gamma_2
\end{pmatrix} = \begin{pmatrix}
-\gamma_2 & 0 \\
\gamma_1 & 0 \\
0 & -\gamma_2 \\
0 & \gamma_1
\end{pmatrix}, \quad \text{(13)}
\]

The coefficient of reflection is then \( r = \frac{\gamma_1^2\gamma_0 - \gamma_2\gamma_1}{\gamma_2^2\gamma_0 + \gamma_1^2} \) and the reflectance at normal incidence for quarter-wave thickness is \( R = \left( \frac{n_0n_s - n_i^2}{n_0n_s + n_i^2} \right)^2 \) which gives \( n_i = \sqrt{n_0n_s} \) when zero reflectance occurs. Therefore, when designing an antireflecting two layer system students know to look for materials with indices of refraction that satisfy the condition above at a specific wavelength.

**Example #2**: A double layer of quarter-wave layers of CeF\(_3\) (\( n_1 = 1.65 \)) and Nd\(_2\)O\(_3\) (\( n_2 = 2.0 \)) are deposited on a glass substrate (\( n_s = 1.52 \)). The Nd\(_2\)O\(_3\) layer is in direct contact with the glass substrate. Determine the normal reflectance for light at the wavelength 550 nm.

Using the equation above the students can calculate reflectance to be 0.03%. But, by using the Mathcad program shown in Figure 3, they can easily analyze the reflectance and transmittance over the entire visible wavelength range to determine where the minimum reflectance and maximum transmittance occur. Building on the previous program they have to include the constants associated with the second layer (thickness, index of refraction, and transfer matrix) and perform the computation.

Other cases that could be studied are double layer films built with combination \( \lambda / 4 \) and \( \lambda / 2 \) that broaden the wavelength range with low reflectance. The next step is to increase the number of layers to three. For each quarter-wave thickness, the zero reflectance occurs when \( \frac{n_1n_s}{n_2} = \sqrt{n_0n_s} \).

### 3.3 High-reflectance layer

One can go to higher number of layers for high-reflectance coatings (such as the dielectric mirrors) and students are encouraged to practice on these films as well. In this case the order of the quarter-wave films is high index-low index with the stack repeated \( N \) times. The transfer matrix in this case is:
\[
M = \left( M_H M_L \right)^N = \begin{pmatrix}
\cos \delta(H) & i \sin \delta(H) \\
i \gamma_H \sin \delta(H) & \cos \delta(H)
\end{pmatrix} \begin{pmatrix}
\cos \delta(L) & i \sin \delta(L) \\
i \gamma_L \sin \delta(L) & \cos \delta(L)
\end{pmatrix}^N
\]

and can be used in its general form in the Mathcad program as shown in Figures 4 and 5.

**Example #3**: A high-reflectance stack incorporates six double layers of SiO₂ (n=1.46) and CeO₂ (n=2.35) films on a glass (n=1.50) substrate. What is the reflectance for light of 550 nm at normal incidence?

In this example the students analyze the high-reflectance stack (dielectric layer) in which the order of the quarter-wavelength films is air – (high index – low index)ₙ – substrate. Through simple computation students can determine that R=99.1%. However, by using Mathcad, students are now able to vary the number of stacks and analyze rapidly the change in the reflectance when N changes from 2 in Figure 4 to N=6 in Figure 5. Building on the previous Mathcad program for a double layer, the student has only to change the order of the layers (high index-low index) and how many times the double layer is repeated (N=2 or 6 in this example).

4. **CONCLUSION**

In this paper we presented a Mathcad modeling exercise aimed to help students better understand the relation between thin films and transmission, reflection, interference, and their applications as related to optical filters. In addition, the exercises allow for a meaningful practice of their Mathcad skills acquired in their programming course.

5. **REFERENCES**


6. **ACKNOWLEDGEMENTS**

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This program calculates a single layer reflectance.

### Parameters and constants

- $\lambda = 350 \ldots 850$ nm (Wavelength range in nm)
- $n_0 = 1.0$ (Index of refraction - air)
- $n_1 = 2.40$ (Index of refraction - coating)
- $n_s = 1.50$ (Index of refraction - substrate)
- $t = 50$ nm (Thickness of coating in nm)

### Define necessary constants

- $\varepsilon_0 = 8.85 \times 10^{-12}$ F/m (Permittivity of free space)
- $\mu_0 = 4\pi \times 10^{-7}$ H/m (Permeability of free space)

### Constants

- $\gamma_0 = n_0 \sqrt{\varepsilon_0 \mu_0}$
- $\gamma_s = n_s \sqrt{\varepsilon_0 \mu_0}$
- $\gamma_1 = n_1 \sqrt{\varepsilon_0 \mu_0}$

### Phase difference

$$\delta(\lambda) = \frac{2\pi}{\lambda} n_1 t$$

### Transfer Matrix

$$M_\lambda = \begin{pmatrix}
\cos(\delta(\lambda)) & i\sin(\delta(\lambda)) \\
-i\gamma_1 \sin(\delta(\lambda)) & \cos(\delta(\lambda))
\end{pmatrix}$$

### Transmission and reflection coefficients

(Coefficients)

- $T_\lambda := \frac{2\gamma_0}{\gamma_0 \gamma_1} \frac{M_\lambda}{1,1} + \frac{\gamma_0 \gamma_s}{\gamma_1} \frac{M_\lambda}{1,2} + \frac{\gamma_s}{\gamma_1} \frac{M_\lambda}{2,1} + \frac{\gamma_0}{\gamma_1} \frac{M_\lambda}{2,2}$
- $R_\lambda := \frac{2\gamma_0}{\gamma_0 \gamma_1} \frac{M_\lambda}{1,1} + \frac{\gamma_0 \gamma_s}{\gamma_1} \frac{M_\lambda}{1,2} - \frac{\gamma_s}{\gamma_1} \frac{M_\lambda}{2,1} + \frac{\gamma_0}{\gamma_1} \frac{M_\lambda}{2,2}$

### Transmittance and Reflectance

- $T_\lambda := 100 \left( \left| T_\lambda \right|^2 \right)$ (Transmittance)
- $R_\lambda := 100 \left( \left| R_\lambda \right|^2 \right)$ (Reflectance)

Figure 2. Mathcad calculations of reflectance and transmittance for a single layer.
This program calculates a double layer reflectance and transmittance.

### Parameters and constants

- \( \lambda = 350 \ldots 850 \) (Wavelength range in nm)
- \( n_0 = 1.0 \) (Index of refraction - air)
- \( n_1 = 1.65 \) (Index of refraction - coating 1)
- \( n_2 = 2.0 \) (Index of refraction - coating 2)
- \( n_s = 1.52 \) (Index of refraction - substrate)
- \( t_1 = 83.333 \) (Thickness of coating 1 in nm)
- \( t_2 = 68.75 \) (Thickness of coating 2 in nm)

### Define necessary constants

- \( \varepsilon_0 = 8.85 \times 10^{-12} \) (Permittivity of free space)
- \( \mu_0 = 4\pi \times 10^{-7} \) (Permeability of free space)

### Constants

- \( \gamma_{on} = \varepsilon_0 \mu_0 \)
- \( \gamma_{os} = \varepsilon_0 \mu_0 \)
- \( \gamma_{1n} = \varepsilon_0 \mu_0 \)
- \( \gamma_{2n} = \varepsilon_0 \mu_0 \)

### Phase difference

- \( \delta_1(\lambda) := \frac{2\pi}{\lambda} n_1 t_1 \)
- \( \delta_2(\lambda) := \frac{2\pi}{\lambda} n_2 t_2 \)

### Transfer Matrix

Here the transfer matrix is the product of the two individual transfer matrices.

\[
M_{\lambda} := \begin{pmatrix}
\cos(\delta_1(\lambda)) & i \sin(\delta_1(\lambda)) \\
-i \sin(\delta_1(\lambda)) & \cos(\delta_1(\lambda))
\end{pmatrix} \begin{pmatrix}
\cos(\delta_2(\lambda)) & i \sin(\delta_2(\lambda)) \\
-i \sin(\delta_2(\lambda)) & \cos(\delta_2(\lambda))
\end{pmatrix}
\]

### Transmission and reflection coefficients

(Coefficients)

- \( T_{\lambda} := \frac{2 \varepsilon_0}{\gamma_{on}} M_{\lambda} \begin{pmatrix} 1, 1 \\ 1, 2 \end{pmatrix} + \varepsilon_0 M_{\lambda} \begin{pmatrix} 1, 1 \\ 2, 1 \end{pmatrix} + \varepsilon_0 M_{\lambda} \begin{pmatrix} 1, 2 \\ 2, 2 \end{pmatrix} \)
- \( T_{\lambda} := \frac{100 \left| T_{\lambda} \right|^2}{} \) (Transmittance)

- \( R_{\lambda} := \frac{2 \mu_0}{\gamma_{on}} M_{\lambda} \begin{pmatrix} 1, 1 \\ 1, 2 \end{pmatrix} + \mu_0 M_{\lambda} \begin{pmatrix} 1, 1 \\ 2, 1 \end{pmatrix} + \mu_0 M_{\lambda} \begin{pmatrix} 1, 2 \\ 2, 2 \end{pmatrix} \)
- \( R_{\lambda} := \frac{100 \left| R_{\lambda} \right|^2}{} \) (Reflectance)

**Figure 3.** Mathcad calculations of reflectance and transmittance for a double layer.
This program calculates a multiple layer reflectance and transmittance.

**Parameters and constants**

- $\lambda$ := 350 . . 800 (Wavelength range)
- $n_o$ := 1.0 (Index of refraction - air)
- $n_L$ := 1.46 (Low index of refraction - coating 1)
- $n_H$ := 2.35 (High index of refraction - coating 2)
- $n_s$ := 1.50 (Index of refraction - substrate)
- $t_H$ := 58.511 (Thickness of High index coating in nm)
- $t_L$ := 94.178 (Thickness of Low index coating in nm)

**Define necessary constants**

- $\varepsilon_0$ := 8.85 $10^{-12}$ (Permittivity of free space)
- $\mu_0$ := 4 $\pi$ $10^{-7}$ (Permeability of free space)

**Constants**

- $\gamma_o$ := $\sqrt{\varepsilon_0 \mu_0}$
- $\gamma_s$ := $n_s \sqrt{\varepsilon_0 \mu_0}$
- $\gamma_L$ := $n_L \sqrt{\varepsilon_0 \mu_0}$
- $\gamma_H$ := $n_H \sqrt{\varepsilon_0 \mu_0}$

**Phase difference**

- $\delta_L$ := $\frac{2\pi}{\lambda} n_L t_L$
- $\delta_H$ := $\frac{2\pi}{\lambda} n_H t_H$

**Transfer Matrix**

$$M_A := \begin{bmatrix} \cos(\delta_L) & \frac{i \sin(\delta_L)}{\gamma_H} \\ -\frac{i \gamma_H \sin(\delta_L)}{\cos(\delta_L)} & \cos(\delta_L) \end{bmatrix}$$

Here the transfer matrix is $N$ time the product of the High and Low transfer matrices for each layer.

**Transmission and reflection coefficients**

- $T := 100 \left( |r_A| \right)^2$ (Transmittance)
- $R := 100 \left( |r_A| \right)^2$ (Reflectance)

Figure 4. Mathcad calculations of reflectance and transmittance for a high-reflectance multiple ($N=2$) stack.
This program calculates a multiple layer reflectance and transmittance.

### Parameters and constants

\[
\begin{align*}
\lambda &: 350..800 \\
no &: 1.0 \\
nL &: 1.46 \\
nH &: 2.35 \\
nS &: 1.50 \\
tH &: 58.511 \\
tL &: 94.178
\end{align*}
\]

(Wavelength range)

(Index of refraction - air)

(Low index of refraction - coating 1)

(High index of refraction - coating 2)

(Index of refraction - substrate)

(Thickness of High index coating in nm)

(Thickness of Low index coating in nm)

### Define necessary constants

\[
\begin{align*}
\varepsilon_0 &= 8.85 \times 10^{-12} \\
\mu_0 &= 4 \pi \times 10^{-7}
\end{align*}
\]

(Permittivity of free space)

(Permeability of free space)

### Constants

\[
\begin{align*}
\gamma_{oo} &= \frac{2\pi}{\lambda} \sqrt{\varepsilon_0 \mu_0} \\
\gamma_{os} &= \frac{2\pi}{\lambda} \sqrt{\varepsilon_0 \mu_s} \\
\gamma_{ls} &= \frac{2\pi}{\lambda} \sqrt{\varepsilon_s \mu_0} \\
\gamma_{HL} &= \frac{2\pi}{\lambda} nHtH \\
\gamma_{L} &= \frac{2\pi}{\lambda} nLtL \\
N &= 6
\end{align*}
\]

\[
\begin{align*}
\delta_L &= \frac{2\pi}{\lambda} nLtL \\
\delta_H &= \frac{2\pi}{\lambda} nHtH \\
\end{align*}
\]

### Phase difference

### Transfer Matrix

\[
M^{\lambda} = \begin{pmatrix}
cos(\delta_L) & -i\sin(\delta_L) \\
i\gamma_L \sin(\delta_L) & \cos(\delta_L)
\end{pmatrix}
\begin{pmatrix}
cos(\delta_H) & -i\sin(\delta_H) \\
i\gamma_H \sin(\delta_H) & \cos(\delta_H)
\end{pmatrix}
\]

Here the transfer matrix is \(N\) time the product of the High and Low transfer matrices for each layer.

### Transmission and reflection coefficients

\[
\begin{align*}
T^{\lambda} &= \frac{2\gamma_o}{\gamma_o M_{1,1} + \gamma_o \gamma_s (M_{1,2} + M_{2,1}) + \gamma_s M_{2,2}} \\
R^{\lambda} &= \frac{-2\gamma_o}{\gamma_o M_{1,1} + \gamma_o \gamma_s (M_{1,2} - M_{2,1}) - \gamma_s M_{2,2}}
\end{align*}
\]

### Transmittance and Reflectance

![Transmittance Graph](Figure 5. Mathcad calculations of reflectance and transmittance for a high-reflectance multiple (N=6) stack.)

![Reflectance Graph](Figure 5. Mathcad calculations of reflectance and transmittance for a high-reflectance multiple (N=6) stack.)
New microscopy based on liquid crystals and its application to students’ education and researches

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ABSTRACT

The optical microscope operation is limited with illumination distribution detecting on the object surface in reflective regime and absorption object parameters detecting in transparent regime. The functions are increased by observation the objects in polarizing light. The inside tension and optical activity in transparent materials becomes visible. Optical polarizing microscopy is powerful tool for investigations in many fields of science and technology. But it is helpless in detecting invisible physical fields’ distribution on the object surface. The combination of optical polarizing microscope with liquid crystal spatial light modulator in contact with objects’ increases its functions.

The novelty of microscope consists in LC layer introduction in optical scheme to observe its local deformations in real time. LC applied as recording media has to be in contact with the surface under investigation. In this case LC detects the invisible physical fields on the object’s surface: intermolecular interactions, electrical, magnetic fields, etc. The results were obtained with high optical resolution and sensitivity.

The operation with new microscope is very simple. The unique information was received in examination the surfaces of solid crystals, minerals, metals, semiconductors, polymers, glasses, optical coatings. The most valuable information was obtained in biophotonics.

The simplicity of new microscopic methods made possible to recruit for serious scientific investigations the students from first to fifth year of education. Students’ participation helps to get rich statistic results and to check their reproducibility. The students also got experience in oral presentations of the results.

Keywords: polarizing microscope, liquid crystals, visualization, invisible physical fields, students’ experiments, seminars and oral presentations, scientific publications.

1. INTRODUCTION

The education becomes most effective when the teacher excite the deep interest of pupils to the subject of investigation. The achievement of such result becomes possible if the learner takes place in real scientific problem creative search. The collaboration of supervisor with students gives fruitful results for both sides. Students’ participation helps to get rich statistic results and to check their reproducibility. The students got experience in oral presentations of the results. They also receive practical skills in righting abstracts and paper under teacher’s guidance. The active scientific studies at early ages usually give the main direction for whole future field of activity.

In our paper we will share with our experience on collaboration with the students from first to fifth year of education. The program for the 4-th year of education in physics and material science consist the special discipline called training students investigation that include theoretical study, experiments and oral presentations at department seminar. The seminars are organized as serious scientific action including critical opponent’s remarks and common discussion of results. The results obtained during five months of training course become often the subject of diploma investigation.

In such case the choice of optical scientific problem is very important task. We decided to use for students training new optical polarizing microscope based on nematic liquid crystals (NLC) with very wide field of application. In our paper we discuss the idea of new microscope, its applications in science and high
technologies and investigation results obtained together with the students. We consider the studies fulfilled with new optical microscope as a good example of education and training in optics and photonics.

2. THE BASIC PRINCIPLE OF NEW OPTICAL POLARIZING MICROSCOPE BASED ON NLCs

Optical microscope functions are limited by illumination distribution observation on the objects’ surface in reflexion regime or absorption observation in transmissive regime. Polarizing microscope functions are expanded: internal tensions or optical chirality’s in transparent material becomes visible. Unfortunately traditional optical microscopy doesn’t give the possibility to detect the distribution of invisible physical fields such as electric, magnetic fields or structure inhomogeneities on the surface under investigation.

We suggested new type of optical polarizing microscope (OPM) with more expanded functions that gives the possibilities to observe and detect the distribution of invisible physical fields and structural defects on the materials surface. The new instrument opens new possibilities in optical metrology for detecting the quality of materials in science, technology and commercial products.

The recording of the physical fields at the surface of investigation and surface structural inhomogeneities becomes possible if the NLC deformed layer is illuminated in transmissive or reflective modes and observed through OPM and appearing figure is compared to the background structure. NLCs are more sensitive to physical fields influence in comparison with cholesteric and smectic LCs having super molecular structure.

The principle scheme of the NLC technique in combination with polarizing microscopy is shown on fig.1.

\[ I(x, y) = I_0 \sin^2 \left( \frac{\delta(x,y)}{2} \right) \]

Fig.1. Optical scheme: 1-light source, 2-collector, 3-aperture, 4-mirror, 5-polarizer, 6-condenser lens, 7-object, 8-LC SLM, 9-microscope lens, 10-analyzer, 11-prism-cube, 12-ocular, 13-CCD-sensor, 14-computer, 15-prism, 16-aperture, 17-ocular. B, C, D - defects types. D - real size of defect. D' - image size of defect in NLC.

New OPM may be also combined with interference, phase-contrast and even near-field microscopes. The light intensity over NLC layer \( I(x,y) \) modulated by deformed NLC structure is described by equation:
The phase delay \( \delta(x,y) \) caused by the NLC birefringence is equal to:

\[
\delta(x,y) = \frac{2\pi}{\lambda} \left[ -n_0 \cdot H + \int_0^H n(x,y,z) dz \right]
\]  

(2)

Here \( H \) is the thickness of NLC film; \( n(x,y) \) is the film reflective index of deformed zone; \( n_0 \) is the refractive index of a non-deformed layer. If the orientation field has no twist deformation then only orientation bending occurs, hence:

\[
n(x,y,z) = \left[ n_o^2 \sin^2 \varphi(x,y,z) + n_e^2 \cos^2 \varphi(x,y,z) \right]^{1/2}
\]

(3)

Here \( \varphi(x,y,z) \) is the deflection angle of the long axis of the molecules with the respect to the surface normal; \( n_o, n_e \) are the refractive indices of NLC layer for ordinary and extraordinary polarization. The usual value of NLC optical anisotropy has the value 0.05…0.2 but in extreme cases it may be up to 0.4. It permits to use very thin layers to obtain sufficient value of phase delay\(^1\).

Summarizing the principle of OPM operation we observe in polarized light not the invisible structural defect \( D \), but only the deformations in LC layer \( D' \) induced by defect (fig.2, left). In non polarized light we observe the real structural defect \( D \) through transparent LC layer and see nothing (fig.2, right).

The theory of LC layer deformations near the structural defects or obtained by magnetic or electrical fields is developed and described in papers\(^2,3\).

The most interesting and practically important case is structural inhomogeneities detecting (fig.1C). The theory gives the distribution of LC molecules orientation near the structural defect (fig.3).

Fig.2. The principle of OPM operation.

Fig.3. Solitary structural defect and local orientation of LC molecules induced by it
The NLC molecules orientation induced by structural inhomogeneity is described by equation:

\[
\pi \frac{\phi(x, y) - \phi_z}{\phi_a - \phi_z} = \arctg \frac{sh(D - X) \cotg Y}{ch(D - X) + 1} + \arctg \frac{Sh(D + X) \cotg Y}{ch(D - X) + 1},
\]

(4)

\[
X = \frac{\pi l}{H}, \quad Y = \frac{\pi x}{H}, \quad D = \frac{\pi d}{H}.
\]

The theory was used for explanation the results of experimental structural defects examination on the surface of different materials.

The recording process is simple, obvious and informative. One may optimize the image contrast by rotating polarizer and analyzer. The main and virtually the sole operation are to put a uniform NLC layer on the substrate surface. Such layer may be applied using a rotating table or even a simple paintbrush. The heating of NLC up to the temperature of transition to isotropic phase makes the film after cooling more uniform in thickness. The resolution of the NLC layer depends on its thickness and approximately is equal to 2000 lines/mm. The wetting conditions may be changed by special dopants and surfactants. The reliable results in visualizing the defects on the surface are obtained by repeatable applying and removing NLC layers and observing the stable defects images. The NLC layers are easily removed by a solution of alcohol or acetone. The NLC film distorts the real images of the defects because of its elasticity. To receive the information about the real size of the defects when only the size of their images is known a theory was developed. The theory describes in a simple analytic form the defect’s image formation process and its relation to NLCs.

Another problem of LC vision theory is the sensitivity of the NLC technique. It is apparent that such sensitivity depends on the experimental conditions, physical nature of defect origins and the sort of NLC material. On the first stage the phase delay that appears during the radiation transport through the NLC layer was theoretically considered. It was regarded as function of the surface interaction energy fluctuations induced by surface defects. We have to take into account the average interaction energy. In this case the sensitivity \( S \) is given by derivative:

\[
S = \frac{d\Phi}{dE},
\]

Here \( E \) is the fluctuation of interaction energy, \( \Phi \) is phase delay. But for final sensitivity determination the methods of information theory of optical image are to be applied. They permit to take into account the thermal LC-noise as well as that of surface itself, the regular surface pattern spectrum and recording device transfer function. This approach gives the limits of NLC technique sensitivity and resolution in visualizing the defects.

Simplicity, efficiency and high sensitivity have given an opportunity of LC vision application in material science, mineralogy, crystallography, thin film technology, medicine and biology. The operation with OPM and NLCs as recording media is very simple process and not need the high quality experts for making the experiments. The students receive necessary practice after few days of study. It takes a short time to make experiments but a long time to understand the results. The main results in student researches are published in papers.

3. THE MAIN RESULTS IN STUDENTS’ RESEARCHES BASED ON NEW OPM APPLICATION

For students’ researches illustration we select the investigations devoted to the most attractive results in the field of biophotonics: grippe virus, cancer and erythrocyte pathology detecting.

3.1. Grippe viruses detecting

The problem of grippe viruses detecting is important because of its possible dangerous epidemic and pandemic scale all around the world. There are some methods of grippe viruses detecting based on application of dyes and fluorescence technique. Unfortunately all these methods are impossible to visualize directly the grippe virus modifications. They also need few days for detecting and consists many steps of operation. In order to avoid the disadvantages we suggested to apply new contact technique based on liquid crystal (LC) application: LC vision.
The first effective results of LC application in viruses detecting were described in patent\textsuperscript{11}. Its main particularity was in usage of polyaniline (PA) layer to obtain a good adhesion of antibody material to the glass plate. Another technique based on deficit lyotropic LC application was described in paper\textsuperscript{12}. The technique is expensive and also impossible for direct visualization the gripe virus modification.

In our paper we suggest a simple, expressive and informative method based on cheap nematic LC application that didn’t need the usage of PA layer. On glass plate the antibody-viruses sandwich was placed and coated with thin LC layer of mixture MBBA:EBBA. In the case of antibody-viruses unconformity the complimentary reaction doesn’t take place that may be directly observed through polarizing microscope (fig.4). In the case of antibody-viruses conformity the complimentary reaction takes place that visualize quite different surface structure with crystal-like segments (fig.5). The student Michailova-Kad’ikova T.S took part in the experiments.

![Fig.4. The structure of the boundary antibody-viruses-LC layer in the case of their unconcomplimentary reaction. 100’](image1)

![Fig.5. The crystal-like structure of the boundary antibody-viruses-LC layer in the case of their complimentary reaction. 100’](image2)

Summarizing the results of our investigations it is possible to conclude that new simple and expressive technique based on NLC application to gripe viruses is developed\textsuperscript{8}. It promises the possibility for direct observation of the surface structures in the case of viruses mutation.

### 3.2 Malignant tumors detecting

The problem of malignant tumors is one of the most actual in modern medicine. It consists not only of the development of effective patients’ treatment methods but in objectification of microscopic neoplasm diagnosis. The routine diagnostic methods are based on optical microscopy modifications in view of spectral, luminescent and fluorescent features of the growth images. The essence of luminescent and fluorescent methods is based on the properties of some photosensitive materials to be collected in malignant tissues in the much greater degree, than the surrounded normal tissues, that under certain conditions allows receiving luminescent and fluorescent images of tumors. These methods are suitable for detecting malignant growth on outside surfaces of a body in dermatology and cosmetology, and also on internal surfaces observed with the application of endoscope’s technique. Advantage of the methods is an opportunity to study the efficiency of undertaken medicine measures in real time. However the methods are unacceptable for microscopic diagnosis.

For traditional histological diagnosis tissue sections of 4-5 μ thick are prepared of the block after freezing or embedding in paraffin. Then sections are placed on an object glass and treated with organic dyes. Haematoxylin and eosin are usually used as dyes and that impart different colors to the nucleus and cytoplasm in the cell. The malignant character of a tumor is verified by observing in light microscope cell atypism features and invasive particularities of malignant growths. The disadvantage of the method is, that the observable distinctions in some cases are too week, that the diagnosis is made in the greater degree on
intuition of the experts, rather than on objective criterion revealing. The absence of objective criteria for diagnosis can sometimes result in irreparable mistakes.

The new optical criterion for objective diagnosis of malignant growth in tissues of human beings and animals based on NLC technique is suggested and confirmed with experiments\textsuperscript{13, 14}.

The first experiments with NLCs on detection of the pathological changes in sections of human epithelial tissues have given the positive results (Fig.6). The experiments discovered different concentration of keratin in ripe and "young" cells that was distinguished by different orientation of NLC molecules.

![Fig.6. The sections of epithelial tissues observed through light microscope (A) and with NLC technique (B), visualized the different concentration of keratin in cells.](image)

That was the reason why the regular comparative investigations of malignant and benign tumors were carried out (Fig.7).

![Fig.7. LC vision in detecting renal cancer (upper rank) and stomach cancer (low rank). A – tissues decorated with dyes. B – tissues decorated with NLC.](image)

Only frozen tissue sections were suitable for experiments. Routine histology was used for identification of malignant areas in micro preparations. In order to avoid the NLC molecules orientation induced by plotting operation the mixture of NLC and the solvent were used. The solvent transferred NLC to isotropic phase. After the mixture was plotted on the tissue surface the solvent evaporated and NLC orientation was obtained only by structural topography.

Through a light microscope with crossed analyzer and polarizer in all investigated cases malignant growth decorated with NLC looked black (except for clear distinct vessels and elements of linkage skeleton). At the same time NLC molecules on normal tissues and benign tumors always looked white or color. The similar pictures were observed in dog and human tissues.
The essentially new result was the proof of an opportunity of LC vision use for diagnostics of tissues in vivo (Fig. 8). The revealed phenomenon was suggested as a new objective diagnostic criterion for malignant growth. To confirm the reliability of the offered criterion it was necessary to realize careful analysis and many of experiments.

Fig. 8. Malignant smear of a mouse tissue decorated with MBBA (dark area). Magnification 25x.

It is known, that the orientation conditions of NLC molecules on a solid surface depends on relation between the surface tensions on the boundary of the materials. When the surface tension of liquid crystal \( \gamma_{LC} \) is bigger than the surface tension of a substrate \( \gamma_S \), the NLC molecules exhibit homeotropic alignment. If \( \gamma_{LC} < \gamma_S \) the NLC molecules alignment is tilted. When viewed through a microscope in crossed analyzer and polarizer the areas with homeotropic alignment of molecules look black (no light passes through the analyzer). If the molecules have orientation close to planar, such areas look white (intensity of light in connection with the arisen phase delay is distinct from zero) (Fig. 9a, b).

Fig. 9. Photo of rectal cancer (adenocarcinoma): malignant (left) and benign (right) tissues decorated by NLC layer (a). The model of NLC molecules orientation on tissues (b).

All this implies that NLC layer is a unique recording medium for visualizing the distribution of surface tension over the investigated surface. As structural defects cause the local change of surface tension the NLC technique gives the unique possibility to observe directly the regions of the surface with local defects. The specified property allowed us to formulate a new biophysical criterion for objective diagnosis of malignant
tumors. Thus the orientation of NLC molecules on the substrate is the micro molecular characteristic of the surface determined energy of NLC molecules coupling with the substrate. The different NLC molecules orientation on investigated tissues means a difference in anchoring energy of NLC molecules on a surface of malignant and not malignant tumors. For confirmation the reliability of entered criterion it was necessary to confirm the distinction of surface characteristics by independent experiments on macromolecular level, for example in direct measurement of malignant and not malignant tissues surface tension.

It is known, that on a number of biophysical and biochemical characteristics the malignant tumors differ from normal tissues. However in the scientific literature there is no information on their surface tension value.

The research of tissue surface tension was made by wetting contact angles definition of investigated surfaces on the boundary with reference liquids. The photographic method allowing to a drop's profile at counter illumination was used for receiving its shadow image. The samples were fixed in 10% formalin solution, of which on freezing microtome 5-7 μ thick sections were prepared. Some sections contained boundary areas of malignant and not malignant tissues, which could be observed simultaneously. Till two consecutive sections from each sample were used. One of them was exposed to traditional dyes processing for revealing malignant areas. Another section was located on subject glass, and after drying on it one drop (or several drops) 1-2 mm in diameter of a reference liquid was plotted. The sample was located on a table, which could smoothly move in vertical and two perpendicular horizontal directions. The drop was shined with a collimated beam for recording with camera. For absorption of an infrared range of radiation the light source equipped with special filter. Water and MBBA were used as reference liquids.

The profile of a drop with current of time changed, as the researched tissues absorbed some part of a liquid. There for the recording of a drops profile was carried out repeatedly through the certain intervals of time after their drawing (through ½, 2, 5 and 10 minutes). The reflective mirror was used for tangent construction to the drop profile up to complete sphere, which allowed measuring contact angles with the increased accuracy (Fig.10).

The results of contact angles measurements of reference liquids on the surface of various types of malignant tumors, through the fixed intervals of times after drawing droplet are given in Table 1.

The comparative experiments carried out on 10 samples of tissues have shown, that in all cases the wetting contact angles of reference liquids on healthy tissues were more, than on malignant tumors. The difference makes essential size reaching on the average 30% from absolute value of measuring parameter.

For the surface tension $\gamma_{SV}$ calculations of malignant and normal tissues Young and Newman equations were used:

$$\gamma_{SL} = 2(\gamma_{LV} \times \gamma_{SV})^{1/2} e^{-0.00015 (\gamma_{LV} - \gamma_{SV})^2}$$

where $S$ - index of solid surface; $L$ - liquid; $V$ - vapor.
\[ \gamma_{SL} = \gamma_{SV} - \gamma_{LV} \cos \theta \]  

(6)

From our experiments \( \gamma_L \) for MBBA at room temperature is 30 dyn/cm\(^2\). The results of calculations are: \( \gamma_{SV} = 26 \) dyn/cm\(^2\) for malignant tissues; \( \gamma_{SV} = 32 \) dyn/cm\(^2\) for healthy tissues. The results of calculations and experiments are in good agreement with F. Kahn rule: \( \gamma \) of malignant tissue (homeotropic orientation) < \( \gamma \) of MBBA < \( \gamma \) of normal tissue (planar orientation) \(^{16}\).

Table 1. Contact angles of reference liquids on surfaces of various tissues

<table>
<thead>
<tr>
<th>LIQUID SAMPLE</th>
<th>H(_2)O</th>
<th>MBBA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0,5</td>
<td>2</td>
</tr>
<tr>
<td>1 Abdominal desmoid (fibrous tissue malignant tumor of the abdominal wall)</td>
<td>79</td>
<td>74</td>
</tr>
<tr>
<td>2 Breast fibroadenoma (fibrous tissue benign tumor)</td>
<td>84</td>
<td>74</td>
</tr>
<tr>
<td>3 Breast fibrosarcoma (fibrous tissue malignant tumor)</td>
<td>71</td>
<td>70</td>
</tr>
<tr>
<td>4 Scar of the esophagus (overgrowth of normal fibrous tissue)</td>
<td>83</td>
<td>76</td>
</tr>
<tr>
<td>5 Sclerotic ovary (overgrowth of normal fibrous tissue)</td>
<td>90</td>
<td>84</td>
</tr>
<tr>
<td>6 Scirrhous breast cancer</td>
<td>60</td>
<td>48</td>
</tr>
<tr>
<td>7 Uterine leymyoma (smooth muscle tumor)</td>
<td>68</td>
<td>62</td>
</tr>
<tr>
<td>8 Skin melanoblastoma of the dog (malignant melanocytic tumor)</td>
<td>73</td>
<td>61</td>
</tr>
<tr>
<td>9 Human skin melanoblastoma (malignant melanocytic tumor)</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td>10 Normal dog skin fibrous tissue</td>
<td>86</td>
<td>78</td>
</tr>
</tbody>
</table>

To conclude the direct determination of malignant and not malignant surface tension values explain the different orientation of NLC molecules on their surfaces.

In our paper the new model for explanation the difference in surface tension value on the malignant and benign tumors is discussed. The model is illustrated by the figure below (Fig. 7).

![Fig. 11. The water on the surface of malignant tissues has much higher order parameter in comparison with the water on benign tissue](image-url)
Many scientists observed the interface layer of structural water on the surface of tissues. The explanation of the difference in surface tension values is based on the particularities of the different parts of the interface layer. It is known that the water on the surface of malignant tissues has much higher order parameter in comparison with the water on benign tissue. The difference is explained by higher concentration of the protein and less concentration of lipids in the water on malignant tissues. It means that the anchoring energy of NLC on the surface of such water must be higher in comparison with anchoring energy on the surface of the water on benign tissue. In the first case the NLC molecules have the homeotropic orientation in the whole thickness of NLC layer while in the second case the surface Fredericks transition is observed.

The application of LC vision in medicine opens new horizons in cancer nature investigations. The first experiments demonstrated that LC vision seems to be useful for leukemia express detecting. The student Efimova T.A. took part in the experiments.

3.3. Erythrocytes pathology detecting

It was suggested to use OPM for detecting the erythrocytes behavior in NLC matrix. The smear of human blood was dried up at the open air without pollution admittance. The thin layer of NLC was applied on the blood smear and observed in OPM. The results of NLC structure investigation are presented at fig.12. It was demonstrated that healthy erythrocytes in NLC matrix having previously oval form change their configuration to rectangle form. The reason of form change is explained by forces of intermolecular interactions in system. Erythrocytes with pathology were deformed because of their elasticity violation.

![Fig.12. Blood smear image after applying NLC thin layer. The boundary divides erythrocytes with (left) and without NLC (right). The normal erythrocytes formed the rectangle figures while erythrocytes with pathology formed deformed rectangle figures. 5CB, t=20°C, 250x.](image)

The results were confirmed by independent laser diffraction experiments. LC vision is a new independent technique for erythrocytes pathology detecting. The post-doc Smirnova I.G. took part in the experiments.

Summarizing the results of our investigations it is possible to conclude that new simple and expressive technique based on OPM with NLCs application testify to wide possibilities in examination the surface properties of biological objects.

We can recommend the studies of new objects and materials surfaces with new optical microscope for education and training in optics and photonics.
References

A Simple Wavelength Division Multiplexing System for Active Learning Teaching

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The active learning project consists in a series of workshops for educators, researchers and students and promotes an innovative method of teaching physics using simple, inexpensive materials that can be fabricated locally. The objective of the project is to train trainers and inspire students to learn physics. The workshops are based on the use of laboratory work and hands-on activities in the classroom. The interpretation of these experiments is challenging for some students, and the experiments can lead to a significant amount of discussion. The workshops are organized within the framework of the project “Active Learning in Optics and Photonics” (ALOP) mainly funded by UNESCO, with the support of ICTP (Abdus Salam International Centre for Theoretical Physics) and SPIE. ALOP workshops offer high school, college or university physics teachers the opportunity to improve their conceptual understanding of optics. These workshops usually run for five days and cover several of the topics usually found in any introductory university physics program. Optics and photonics are used as subject matter because it is relevant as well as adaptable to research and educational conditions in many developing countries [1].

In this paper, we will mainly focus on a specific topic of the ALOP workshops, namely optical communications and Wavelength Division Multiplexing technology (WDM). This activity was originally developed by Mazzolini et al [2]. WDM is a technology used in fibre-optic communications for transmitting two or more separate signals over a single fibre optic cable by using a separate wavelength for each signal. Multiple signals are carried together as separate wavelengths of light in a multiplexed signal. Simple and inexpensive WDM system was implemented in our laboratory using light emitting diodes or diode lasers, plastic optical fibres, a set of optical filters and lenses, prism or grating, and photodiodes. Transmission of audio signals using home-made, simple, inexpensive electronic circuits was also demonstrated. The experimental set-up was used during national ALOP workshops. Results are presented and discussed in this paper. Current explorations to further develop these and other closely-related experiments will also be described.

Demonstration of spin-orbit interaction of a photon in a multimode rectilinear optical fiber

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ABSTRACT

An experimental set up for demonstration and investigation of the spin-orbit interaction of a photon under polarized light propagation through a multimode rectilinear optical fiber is proposed. The influence of the trajectory on the light polarization can be observed under linear polarized skew ray’s propagation. The angle of plane polarization rotation depends on the angle of incidence. The influence of the light polarization on the trajectory can be observed under circular polarized skew ray’s propagation. The angle of the speckle pattern rotation under circular polarization sign change depends on the angle of incidence too.

Keywords: spin-orbit interaction of a photon, multimode optical fiber, light polarization.

1. INTRODUCTION

The spin–orbit interaction of a photon manifests itself in two effects. The first one is the influence of the trajectory on the light polarization. The second one is the influence of the polarization on the trajectory of light.

It has been shown1–4 that the plane of the light polarization rotates under the light propagation along the non-planar trajectory. If vectors tangential to this trajectory at the input and exit points are parallel, then the angle of rotation (in radians) is numerically equal to the solid angle \( W \) (in steradians) subtended by the trajectory tangential vector at the unit sphere2. The same result3 has been obtained on the basis of the adiabatic theorem (geometric phase) of M. Berry4. The change in the azimuth of linear polarized light has been observed experimentally under light propagation through a helical (coiled into a spiral) single mode fiber5. This effect has also been observed in a nonplanar Mach-Zender interferometer6.

The influence of the light polarization on the trajectory was demonstrated for the first time under total internal reflection. It was shown that a reflected ray suffers a longitudinal shift7,8. The value of the shift \( L_L \) is on the order of the light wavelength and depends on the azimuth of linear polarized light. Experimental observation of this shift was made by Goos and Hanchen9,10. It has been shown that in addition to the longitudinal shift a transverse shift should be also observed and the direction (sign) of that shift depends on the sign of circular polarized light11,12. The value of the transverse shift \( L_T \) is related to the longitudinal shift \( L_L \) as follows: \( L_T = a L_L \), where \( a < 1 \). The experimental observation of this effect was made in papers13-15 under light propagation through a triangle prism.

It should be stressed that the longitudinal and transverse shifts of a ray under total internal reflection and the influence of the light trajectory on its polarization were not considered as the manifestation of the spin-orbit interaction of a photon. For the first time the influence of the trajectory on the light polarization and the influence of the polarization on the trajectory were considered as mutually inverse effects in 199016. This consideration has led to the prediction of a new effect: rotation of the speckle pattern in a multimode optical fiber under the change of circular polarization from left-handed to right-handed. The effect is known as the optical Magnus effect and has been observed for the first time under light propagation through rectilinear multimode optical fiber17. In terms of quantum mechanics this effect has been regarded as an interaction between the orbital momentum of photon (photon trajectory) and its spin (polarization)17.

Computer modeling of circular polarized light propagation through a multimode optical fiber and thorough experimental investigation of the optical Magnus effect has been carried out in paper16. The influence of the trajectory on the

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light polarization and the influence of the polarization on the trajectory in the frame of the unified Hamiltonian were considered in paper\textsuperscript{19}.

The name of optical Magnus effect is connected with the following analogy\textsuperscript{18}. By looking at a rotating ping-pong ball falling down through the air, we can see that it is deflected from the vertical due to the Magnus effect. If we assume that a circularly polarized photon propagating in a waveguide is like our rotating ball, we can expect it’s deviation from the initial trajectory.

Influence of the trajectory on the light polarization was observed in a single mode optical fiber coiled into a spiral\textsuperscript{5}, and the optical Magnus effect, that is the influence of the light polarization on the beam trajectory, was observed under light propagation through a multimode rectilinear optical fiber\textsuperscript{7,18}. If these two effects are mutually inverse, they should be observed under identical conditions, i.e. in the same optical fiber.

Let us consider “skew rays” propagation through a rectilinear multimode optical fiber (Fig.1). The “skew rays” can be exited in the multimode optical fiber if light is fallen at any angle \( \theta \) to the fiber axis. The rays form a helical trajectory and we can expect a rotation of the polarization plane after light transmission through the fiber\textsuperscript{20}. The notion of a ray is taken from geometric optics and cannot be applied to the light propagation through the multimode optical fiber. The mode approach, however, is suitable, but some results can be obtained in the frame of geometrical optics. The interference of the different fiber modes produces a speckle pattern at a screen after the transmission of the light through the fiber. The speckle pattern looks like a narrow ring (Fig. 2), and the optical Magnus effect can be observed under change of the circular polarization sign\textsuperscript{21}.

Here we are going to show how it is possible to demonstrate the influence of the trajectory on the light polarization and the influence of the polarization on the trajectory under light propagation through a rectilinear multimode optical fiber.

![Fig. 1. Helical trajectory of “skew rays” in a rectilinear multimode optical fiber](image1)

![Fig.2. Speckle pattern of the light transmitted through multimode optical fiber under none zero angle of the light incidence at the fiber input for left- (a) and right- (b) handed circular polarized light.](image2)
2. LIGHT PROPAGATION THROUGH A MULTIMODE FIBER WITH A STEP-LIKE REFRACTIVE INDEX PROFILE

Let us consider the propagation of the circular polarized light through an axially symmetrical fiber with a step-like refractive index profile \( n(r) \)

\[
n(r) = \begin{cases} n_{c}, & r/\rho < 1, \\ n_{a}, & r/\rho > 1. \end{cases}
\]

Here \((x,y)=r\) are the transverse coordinates, \(r=|r|\), \(r\) is the radius of the fiber core; \(n_{c}\) and \(n_{a}\) are the refractive indices of the fiber core and the cladding respectively.

The polarization is not coupled to the propagation of the beam in the zero paraxial approximation (approximation of weakly guided waveguide), corresponding to the scalar parabolic equation. More accurately, the spatial structure of the field and its polarization are coupled due to the inhomogeneity of the refractive index. Axial symmetry of the fiber allows these modes to be taken in the following form:

\[
\begin{align*}
\mathbf{e}_{m_\lambda}^{(1)}(r,\varphi) &= \left[ \cos(m\varphi) \mathbf{e}_x - \sin(m\varphi) \mathbf{e}_y \right] \cdot F_{\mu\lambda}(r), \\
\mathbf{e}_{m_\lambda}^{(2)}(r,\varphi) &= \left[ \cos(m\varphi) \mathbf{e}_x + \sin(m\varphi) \mathbf{e}_y \right] \cdot F_{\mu\lambda}(r), \\
\mathbf{e}_{m_\lambda}^{(3)}(r,\varphi) &= \left[ \sin(m\varphi) \mathbf{e}_x + \cos(m\varphi) \mathbf{e}_y \right] \cdot F_{\mu\lambda}(r), \\
\mathbf{e}_{m_\lambda}^{(4)}(r,\varphi) &= \left[ \sin(m\varphi) \mathbf{e}_x - \cos(m\varphi) \mathbf{e}_y \right] \cdot F_{\mu\lambda}(r).
\end{align*}
\]

Here \(\mathbf{e}_x, \mathbf{e}_y\) are unit vectors, \(x=r\cos \varphi, y=r\sin \varphi, m=0,\pm 2,\pm 3,\pm 4,\ldots\) is the orbital momentum, and \(N=1,2,3,\ldots\) is the radial quantum number, \(F_{\mu\lambda}(r)\) is the radial function:

\[
\begin{align*}
F_{\mu\lambda}(r) &= J_{\mu}(W_{\lambda}r), & r/\rho < 1, \\
F_{\mu\lambda}(r) &= K_{\mu}(W_{\lambda}r), & r/\rho > 1,
\end{align*}
\]

where \(J_{\mu}(U_{\lambda}r)\) is Bessel function and \(K_{\mu}(W_{\lambda}r)\) is MacDonald function. The values \(U_{\lambda}\) and \(W_{\lambda}\) for given \(m\) are determined from the equation:

\[
\begin{align*}
U_{\lambda} J_{\mu+1}(U_{\lambda}) &= W_{\lambda} K_{\mu+1}(W_{\lambda}), \\
U_{\lambda} J_{\mu}(U_{\lambda}) &= W_{\lambda} K_{\mu}(W_{\lambda}),
\end{align*}
\]

where \(V^2 = W^2 + U^2\), \(V = \rho k n_{\text{a}} (2\Delta)\) is a dimensionless parameter (\(V \equiv 1\) for a multimode fiber), \(\Delta = (n_{c}^2 - n_{a}^2)/2n_{a}^2 \simeq (n_{c} - n_{a})/n_{c} = \Delta n/n_{c} \equiv 1\), \(k = 2\pi/\lambda\), and \(\lambda\) is the wavelength of light in the air.

Any linear combinations of modes \(\mathbf{e}_{m_\lambda}^{(1)}(r,\varphi)\) and \(\mathbf{e}_{m_\lambda}^{(2)}(r,\varphi)\) for all values of \(m\) and any linear combinations of modes \(\mathbf{e}_{m_\lambda}^{(3)}(r,\varphi)\) and \(\mathbf{e}_{m_\lambda}^{(4)}(r,\varphi)\) for \(m \neq 1\) are also eigenmodes. It is easy to show, that a combination of modes \(\mathbf{e}_{m_\lambda}^{(1)}(r,\varphi) \pm i\mathbf{e}_{m_\lambda}^{(3)}(r,\varphi)\) and \(\mathbf{e}_{m_\lambda}^{(2)}(r,\varphi) \pm i\mathbf{e}_{m_\lambda}^{(4)}(r,\varphi)\) \((i = \sqrt{-1})\) are homogeneously polarized eigenmodes with circular polarization:

\[
\begin{align*}
\mathbf{e}_{m_\lambda}^{\pm}(r,\varphi) &= \mathbf{e}_{m_\lambda}^{(1)}(r,\varphi) \pm i\mathbf{e}_{m_\lambda}^{(3)}(r,\varphi) = \left[ \mathbf{e}_+ + i\mathbf{e}_- \right] \cdot \exp(i m \varphi) \cdot F_{\mu\lambda}(r), \\
\mathbf{e}_{m_\lambda}^{\pm}(r,\varphi) &= \mathbf{e}_{m_\lambda}^{(1)}(r,\varphi) \mp i\mathbf{e}_{m_\lambda}^{(3)}(r,\varphi) = \left[ \mathbf{e}_+ - i\mathbf{e}_- \right] \cdot \exp(-i m \varphi) \cdot F_{\mu\lambda}(r), \\
\mathbf{e}_{m_\lambda}^{\pm}(r,\varphi) &= \mathbf{e}_{m_\lambda}^{(2)}(r,\varphi) \pm i\mathbf{e}_{m_\lambda}^{(4)}(r,\varphi) = \left[ \mathbf{e}_+ - i\mathbf{e}_- \right] \cdot \exp(i m \varphi) \cdot F_{\mu\lambda}(r), \\
\mathbf{e}_{m_\lambda}^{\pm}(r,\varphi) &= \mathbf{e}_{m_\lambda}^{(2)}(r,\varphi) \mp i\mathbf{e}_{m_\lambda}^{(4)}(r,\varphi) = \left[ \mathbf{e}_+ + i\mathbf{e}_- \right] \cdot \exp(-i m \varphi) \cdot F_{\mu\lambda}(r).
\end{align*}
\]

Let us consider now the important specific case in which we illuminate the fiber with right- and left-handed circular polarization in turn, but with strictly the same modal distribution \(C_{s,m,N}\) at the input. It is interesting to compare the field
distributions for right- and left-handed circular polarization in some cross-section $z$. The field at the fiber input has the following distribution:

$$E^+(r, \varphi, z = 0) = (e_z \pm ie_r) \cdot \left[ \sum_{m=N} C_{-m,N} e^{im\varphi} F_{|m\rangle} (r) + \sum_{m=-N} C_{m,N} e^{im\varphi} F_{|m\rangle} (r) \right].$$

In the case under consideration it is possible to take into consideration only modes with $m > 1$. Really, in order to obtain ring like speckle pattern we should to excite only modes with high values of $m$. In that particular case the circular polarization of the wave, right- or left-handed, is conserved during the propagation and we obtain the following field distribution at the fiber output:

$$E^+(r, \varphi, z) =
(e_z + ie_r) \cdot \left[ \sum_{m=1} C_{-m,N} e^{im\varphi} F_{m,N} (r) \exp\left[ iz\left( \beta_{m,N} + \delta \beta^{(2)_N}_{m,N} \right) \right] + \sum_{m=1} C_{m,N} e^{im\varphi} F_{m,N} (r) \exp\left[ iz\left( \beta_{m,N} + \delta \beta^{(1)_N}_{m,N} \right) \right] \right].$$

(1)

$$E^-(r, \varphi, z) =
(e_z - ie_r) \cdot \left[ \sum_{m=1} C_{m,N} e^{im\varphi} F_{m,N} (r) \exp\left[ iz\left( \beta_{m,N} + \beta^{(2)_N}_{m,N} \right) \right] + \sum_{m=1} C_{-m,N} e^{im\varphi} F_{m,N} (r) \exp\left[ iz\left( \beta_{m,N} + \beta^{(1)_N}_{m,N} \right) \right] \right].$$

(2)

Here $\beta_{m,N}$ are propagation constants, $\delta \beta^{(i)_N}_{m,N}$ and $\delta \beta^{(i)_N}_{m,N}$ are polarization propagation corrections:

$$\delta \beta^{(1)_N}_{m,N} = \delta \beta^{(2)_N}_{m,N} = \frac{(2\Delta)^{1/2} W_x U_y^3}{2\rho} K_m(W_x),$$

$$\delta \beta^{(i)_N}_{m,N} = \delta \beta^{(i)_N}_{m,N} = \frac{(2\Delta)^{1/2} W_x U_y^3}{2\rho} K_m(W_x).$$

Eq. (1) and Eq. (2) can be used to calculate the field distribution of different sign of circular polarization at the fiber output. To simulate narrow beam propagation one should select the narrow range of values of $m$. To compare two field distribution and to extract the pure rotation from the whole change of the speckle pattern the correlation function should be calculated:

$$K_\psi (\psi, z) = \int I_i (r, \varphi, z) I_j (r, \varphi + \psi, z) dr d\varphi,$$

$$I_i (r, \varphi, z) = |E^i (r, \varphi + \psi, z)|^2 \quad (i = +, -; \quad j = +, -).$$

The angle $\psi$ is the angle of the speckle pattern rotation.

Detailed analytic investigation of the influence of the polarization on the light trajectory has shown that the peripheral parts of the speckle pattern are shifted by a larger angle compared with the central part. The angle of rotation of the speckle pattern depends on the angle $\beta$ between the fiber axis and the direction of propagation of the beam incident on the fiber input end:

$$\psi = \frac{\lambda \beta^2}{\pi n_p^2 \rho^2} L.$$  

(3)

Here $L$ is the fiber length. The peripheral parts of the speckle pattern correspond to the largest angles of ray entry into the fiber and the central parts of the speckle pattern correspond to the smallest angles of rays entry into the fiber, so the difference in propagating length can results in the different angles of speckle pattern rotation.

3. THE ROTATION OF THE PLANE OF POLARIZATION UNDER LIGHT PROPAGATION THROUGH A RECTILINEAR MULTIMODE FIBER WITH A STEP-LIKE REFRACTIVE INDEX PROFILE

Let us consider a skew ray with impact parameter $b$ (the distance between the point of the ray entry and the fiber axis) and the angle $a$ between the direction of a ray propagation $S_i$ inside the fiber and the fiber axis $z$. 

The angle \( \alpha \) can be regarded as small, i.e. \( \tan \alpha \approx \sin \alpha \approx \alpha \). As the ray is skew, the fiber diameter does not lay in the plane of incidence and impact parameter \( b \neq 0 \). The propagation of the ray in the section \( AB \) (Fig. 2) in the coordinates space (\( r\)-space) corresponds to a point \( S_1 \) (Fig. 3) on a unit sphere in the directions space (\( S\)-space). The point \( S_1 \) lies on a circle of radius \( a \) with it’s center at the point \( O \). This point corresponds to the direction of the fiber axis \( z \) in the coordinate space. After total internal reflection at a point \( B \) (Fig. 2) the ray assumes the direction \( S_2 \) corresponding to the point \( S_2 \) in the \( S \)-space. This total internal reflection is localized at the point \( B \) in the coordinate spaces, but it corresponds to the line \( S_1 S_2 \) in the direction space. The point \( S_2 \) still lies on a circle of radius \( a \), but its azimuth changes by an angle \( \beta = 2g \), where \( \sin g = b/r \). As a result of a single total internal reflection the plane of polarization of the ray rotates by \( \gamma \), which is numerically equal to the area of the spherical triangle \( OS_1 S_2 \). This area of a spherical triangle \( OS_1 S_2 \) can be replaced with the area of plane triangle \( OS_1 S_2 \) in the approximation of small angles. Then

\[
y_1 = \frac{1}{2} a^2 \sin(2\gamma).
\]

Taking into consideration that \( \sin g = b/r \) we get:

\[
y_1 = a^2 \frac{b}{r} \sin \frac{\beta}{2} \cos \frac{\beta}{2}.
\]

The ray passes the distance

\[
l = 2 \frac{\beta}{a} \frac{1}{2} \sin \frac{\beta}{2} \cos \frac{\beta}{2}.
\]

in \( z \)-direction between two process of the total internal reflection, and the number of such elementary acts at the unite distance is \( N = 1/l \). The angle of the plane polarization rotation at the length \( L \) is

\[
y = Ny_1 = \frac{a^3}{2r^2} b L.
\]

If \( \beta \) is the angle between the fiber axis and the direction of propagation of the beam incident on the fiber input end, then

\[
y = \frac{b^3}{2n_0 r^2} b L.
\]

It is possible to derive Eq. (4) on the base of the wave theory\(^3\).
4. EXPERIMENTAL SET UP FOR DEMONSTRATION OF SPIN-ORBIT INTERACTION OF A PHOTON IN A MULTIMODE RECTILINEAR OPTICAL FIBER

Figure 4 shows experimental set up for demonstration of spin-orbit interaction of a photon in a multimode rectilinear optical fiber. Linearly polarized light of a laser can be transformed into circular polarized light or linear polarized light with any azimuth by polarization system and was focused on the fiber input by a lens. Figure 5 shows optical scheme of the polarization system installed before the fiber input. It should be stressed that adjustable quarter wave plate, used in the polarization system, allows obtaining circular polarized light of very high quality.

![Experimental set up](image)

**Fig. 4.** Experimental set up.

![Polarization system](image)

**Fig. 5.** Polarization system for investigation of the plane polarization rotation (a) and investigation the optical Magnus effect (b).

The direction of the plane polarization rotation under the skew beam propagation coincides with the direction of the motion of $S_1$ points at the unit sphere (Fig. 3). If the beam is incident from the left side, we can change the direction of the plane polarization rotation illuminating the top or the bottom part of the input fiber end. A microscope is needed to control the illumination of the fiber input. The most convenient way to observe the fiber end is to use reflected light. Really we should deal with small angles of incidence, and a semitransparent mirror should be installed on the way of the linear polarized beam. Unfortunately linear polarized light transmitted through that mirror suffers depolarization. As a result the depolarized light is incident at the fiber input end and it can lead to fake effects. It is possible to solved this problem in the following way. It was found that intensity of the light focused at the fiber input is sufficient in order to observe the light scattered by micro inhomogeneities of the fiber end. So it is possible to observe the scattered light under the microscope by means of a side metal mirror. It allows controlling the illumination of the fiber input without disturbing the beam polarization.
As for a multimode optical fiber, a fiber with the following parameters was used in papers\textsuperscript{20,21}. The length of the quartz fiber under investigation was $L = 7.5 \text{ cm}$, the diameter of the fiber core was $2\rho = 100 \mu\text{m}$, the difference $\Delta n$ between the refractive indices of the core $n_\text{co}$ and the refractive indices of the cladding $n_\text{cl}$ was $\Delta n = n_\text{co} - n_\text{cl} = 0.016$. The value of $\Delta n$ defines the maximum angle of incidence $\beta_{\text{max}}$ when the meridional ray is confined to the fiber:

$$\beta_{\text{max}} = \frac{2n\Delta n}{\rho} \approx 12.7^{\circ}$$

The angle of the input beam divergence $\theta_0$ in the air measured by the criterion $e^{-1}$ of the intensity at maximum was $\theta_0 = 0.5^{\circ}$, i.e. $\theta_0 \leq \beta_{\text{max}}$.\textsuperscript{20,21} The value of the radius of the illuminated spot at the fiber input end $a_0$ calculated from $\theta_0$, was $a_0 = (k\theta_0)^{-1} \approx 1.5\mu\text{m} \leq \rho$, where $k = 2\pi/\lambda$. Really, it is possible to chose any multimode optical fiber, but the fiber length should be so that linear polarization does not change and the fiber diameter should be so that $2\rho \leq a_0$. The angle of the input beam divergence $\theta_0$ in the air and a lens should be chosen in such a way that the value of the diameter of the illuminated region at the fiber input end $a_0 \leq 2\rho$.

As was mentioned above, the notion of a ray can not be applied to the case under consideration. As a result a speckle pattern in the form of a narrow ring is observed after light transmission through a multimode optical fiber. The radius of the ring allows calculating the angle $\beta$ of the beam incidence at the fiber input. To obtain more accurate results the external radius $R_a$ and the internal radius $R_i$ of the ring should be measured, then:

$$\beta = \frac{R_a + R_i}{2D}, \quad \text{(5)}$$

where $D$ is the distance between the output end of the fiber and the screen. The full illumination of the ring and the presence of a speckle pattern within it do demonstrate that the notion of a ray does not work. Using analyzer at the fiber output one can observe, that the azimuth of output linear polarized light $y_{\text{out}}$ does not coincide with the azimuth of input plane polarized light $y_{\text{in}}$. The angle of the plane polarization rotation should be determined as $\psi = y_{\text{out}} - y_{\text{in}}$. One can see that the value of $\psi$ does not depend on the angle $y_{\text{in}}$. The illumination of the fiber input should be controlled and compared with the direction of the plane polarization rotation. That direction should coincide with the direction predicted from the theory.

The same experimental set up can be used for the optical Magnus effect demonstration and investigation. In order to observe the optical Magnus effect the analyzer installed after the fiber should be removed. The polarization system (Fig. 5) allows changing the sign of circular polarization by rotating of the adjustable quarter wave plate.

5. INVESTIGATION OF THE ROTATION OF THE POLARIZATION PLANE AND THE OPTICAL MAGNUS EFFECT

The described experimental set up allows to investigate the dependence of the angle of linear polarization plane rotation and the angle of speckle pattern rotation on the angle of rays incidence $y(\beta)$ and $\psi(\beta)$. The procedure of the investigation is the following. Changing the angle of incidence $\beta$ one should determine the value of the angle by measuring the radii $R_a$ and $R_i$ of the speckle pattern at the screen and using Eq. (5). It should be determined what part of the fiber input, top or bottom is illuminated. Using the analyzer and the first scheme of the polarization system one should change the azimuth of linear polarized light falling at the fiber input and to determine the angle of the linear polarization plane rotation.

Using the second scheme of the polarization system and removing the analyzer one can record the speckle pattern of left-handed and right-handed circular polarized light transmitted through the fiber. To determine the angle of the speckle pattern rotation the special software is needed.

To check the dependence of the direction linear polarization plane rotation on the sign of the ray trajectory helicity one should readjust experimental set up to illuminate another part of the fiber input end and repeat the investigation. It is possible to check that the optical Magnus effect does not depend on the sign of the ray trajectory helicity.
Changing the value of the angle $\beta$ the experimental dependencies $y(b)$ and $\psi(\beta)$ can be obtained. The experimental points should lie at the theoretical curves predicted by Eq. (4) and Eq. (3).

In conclusion, we have proposed the experimental set up which allows to demonstrate spin-orbit interaction of a photon under the same condition in the same fiber and to investigate the dependencies $y(b)$ and $\psi(\beta)$.

REFERENCES

Design and development with educational purposes of an Optical Spectrum Analyzer for the visible range and of an Optical Time Domain Reflectometer for the second window

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ABSTRACT

We present in this paper the detailed design, development, and implementation of two optical measurement systems that serve as teaching devices for undergraduate students. The building of both prototypes has been carried out by several students for their undergraduate thesis project. Both systems are highly modular and each of their functional blocks are clearly separated and labeled so that students can immediately identify their constituent parts. In both cases, the hardware consists of optoelectronic devices and mechanical parts that are fully automated and controlled by the corresponding Windows application developed ad hoc. Our Optical Spectrum Analyzer is, as far as we know, the first system designed for highly multimode polymer optical fibers operating in the visible region. As for the Optical Time Domain Reflectometer, it is not only suitable for educational experimental measurements, but it can also be compared with commercial systems, since it works in the second transmission window.

Keyword list: Fiber optics; Fiber measurements; Fiber optics and optical communications.

1. INTRODUCTION

Optical Spectrum Analyzers (OSAs) and Optical Time Domain Reflectometers (OTDRs) are two optical measurement systems widely used by the scientific community as well as in telecom applications. The former separate the optical signal into its constituent wavelengths, allowing the measurement of the spectral profile of the signal as a function of the wavelength, whereas the latter measure the power loss with the distance within optical fibers, enabling the detection of faults, splices, and bends in optical links.1

A wide variety of commercial solutions is currently available from different manufacturers, ranging from modest equipments to extremely sophisticated devices. Nevertheless, the compact designs exhibited by most of these commercial solutions are not suitable from a didactic point of view: they do not serve to show undergraduate students the underlying functional blocks that made up each measurement system and the relationships between them.

For this reason, we have coordinated the design and development of two didactic prototypes (an OSA and an OTDR), with their functional blocks clearly separated and labeled. Being the size and complexity of this problem appropriate enough for undergraduate students, we have entrusted several students with the task of implementing and building both prototypes for their undergraduate thesis project.

In this paper, we will explain, concisely, the structure of both prototypes, the specifications of the main components that constitute each prototype, and how these components are interrelated. These explanations will be supported by several block diagrams and photographs.

2. OPTICAL SPECTRUM ANALYZER

One of the most remarkable features of our OSA prototype is that it has been specifically designed to handle optical signals obtained from highly multimode polymer optical fibers operating in the visible region and in part
of the near-infrared region (400 – 850 nm). This OSA prototype consists of three main components, as shown in Fig. 1.

Figure 1. Overall block diagram and photograph of the OSA prototype.

- Spectrometer: the optical part that separates the optical signal into its constituent wavelengths and converts it to an electrical signal.
- Control and processing unit: a general purpose Digital Signal Processor (DSP) with custom-made electrical circuits that controls the spectrometer and processes the electrical signal obtained from the latter.
- “OSAgui” Windows application: a graphical user interface that manages the DSP and displays the measurement results.

2.1. Spectrometer

The main purpose of the spectrometer is to separate the optical signal into its constituent wavelengths. Figure 2 shows the design and final implementation of the spectrometer.
The main components of the spectrometer can also be separated into three main blocks:

- **Input/Collimation:** It leads the incoming optical signal to a Thorlabs F230SMA-A aspheric collimator. This aspheric lens ensures that the optical signal impinging on the following block consists only of parallel beams regardless of the light launching conditions at the optical input.

- **Wavelength separator:** The incoming optical signal from the aspheric collimator impinges on a Newport 10D20ER.1 concave mirror and then it is directed to a reflective holographic grating. This holographic grating, a NT43-225 model from Edmund Optics with a resolution of 2400 grooves per millimeter and suitable for the visible region, is the core component of the spectrometer: it separates the incident light into its constituent wavelength components, being each wavelength reflected into a different direction according to the grating equation

\[ a \left( \sin \theta_m - \sin \theta_i \right) = m \lambda, \]  

where \( a \) is the spacing of the grooves (i.e., \( a = 1/2400 \text{ mm} \)), \( \theta_i \) the angle of incidence, \( m \) the order number (\( m = 1 \) in this implementation), and \( \theta_m \) the reflected angle at which the wavelength \( \lambda \) has its maximum.

A second Newport 10D20ER.1 concave mirror placed in front of the holographic grating ensures that only one of the reflected wavelengths (the one travelling in the same direction as that given by \( \theta_m \)) will be directed to the detector. An RS Components 440-420 unipolar stepper motor changes the direction of the holographic grating relative to the second concave mirror, making it possible to select the wavelength directed to the detector. The position of the stepper motor is controlled by the control and processing unit, which also implements a microstepping technique based on pulse width modulation (PWM) in order to increase its angular resolution (which, in turn, leads to an improvement in the spectral resolution of 1 nm). The reference position of the stepper motor is provided by a Fairchild Semiconductor H21A2 optocoupler. It is placed on the stepper motor and it triggers a signal to the control and processing unit whenever the stepper motor turns to this reference position. This reference position is used to calibrate the spectrometer each time the prototype is started up.

- **Detector:** The detector consists in a Thorlabs PDA-55 Si photodetector. It converts the optical beam coming from the wavelength separator into an electrical signal. Finally, the converted electrical signal is sent to the control and processing unit.

Figure 3 shows the spectral properties of the performance of the main optical components involved in the spectrometer. These characteristics will be taken into account by the "OSAgui" Windows application in order to compensate for the differences in the electrical output as a function of the detected wavelength.

![Figure 3. Normalized reflectance, absolute efficiency, and responsivity of the concave mirrors, the reflective holographic grating, and the photodetector, respectively, against the wavelength.](image)
enter or exit the DSP. Figures 4 and 5 show the block diagram and the photographs of the electronic circuits, as well as a general view of the final implementation.

Figure 4. Block diagrams of the electronic circuits and of the control and processing unit.

(a) Optocoupler and stepper motor bias circuits.  
(b) Signal conditioning circuit.

(c) Control and processing unit (DSP).  
(d) General view. Both the electronic circuits and the control and processing unit are interspersed with several power supply units.

Figure 5. Photographs of the electronic circuits and of the control and processing unit.
The DSP has been programmed using the Code Composer Studio, an integrated development environment provided by the manufacturer. The structure of the software (shown in Fig. 4) is described as follows:

- **Data acquisition unit:** it is responsible for digitalizing the electrical output of the spectrometer (previously conditioned by the signal conditioning circuit) and for processing this digitalized signal. Depending on the strength of the electrical output, the data acquisition unit sends the appropriate control signals (via I/O signal generation unit) to the signal conditioning circuit to increase or reduce the gain accordingly.

- **Communication unit:** it links the DSP and the “OSAgui” Windows application installed on the PC together (the physical connection is made through the parallel port). It interprets the commands sent by the “OSAgui” Windows application (according to the requests made by the user) and sends the measurement results provided by the data acquisition unit to the “OSAgui” Windows application (so as to display them to the user).

- **Position control unit:** it is responsible for controlling the angular position of the stepper motor during the spectral sweep by sending the appropriate PWM signals.

- **Calibration unit:** it calibrates the spectrometer when the prototype is started up. For this purpose, the DSP changes sequentially the angular position of the stepper motor until the optocoupler triggers a signal; this angular position is assigned to the reference wavelength.

- **Control unit:** it controls and coordinates each one of the units, monitors the status of the DSP, and synchronizes in real time the different tasks that have to be carried out.

### 2.3. “OSAgui” Windows application

The “OSAgui” Windows application is the interface between the user and the control and processing unit: on the one hand, it gathers the requests made by the user and sends the corresponding commands to the control and processing unit; on the other hand, it receives the measurement results from the control and processing unit, performs a further processing, and displays the final results to the user. “OSAgui” is a user-friendly application and it has been developed in Visual Basic 6.0. Figure 6 shows its logical structure and a screenshot displaying the power spectrum of a white light emitting source.

“OSAgui” is structured as follows:

- **Communication layer:** it performs the required operations to establish, maintain and stop the bidirectional communication with the DSP. It sends the pertinent commands to the DSP and receives the data containing the measurement results from the DSP.

- **Arithmetic layer:** it processes the data provided by the communication layer. Its main task is to compensate for the variation in the obtained spectral power with the wavelength (see subsection 2.1 and Fig. 3 for further details). If requested by the user, it also filters the compensated measurement results and performs a Fast Fourier Transform.10

- **Data storage layer:** it stores the data provided by the arithmetic layer in the hard disk and vice versa.
- Interface layer: it is the layer that interacts with the user. On the one hand, it prompts the user to enter the analysis parameters and other required data in the fields provided by the corresponding dialog box. On the other hand, it displays the obtained measurement results to the user.
- Control layer: it distributes the tasks to the corresponding layers and coordinates them, processes the data for its graphical representation by the interface layer, and monitors and handles every error and exception thrown during a certain operation.

3. OPTICAL TIME DOMAIN REFLECTOMETER

The designed OTDR prototype is suitable to characterize 9/125 μm single-mode optical fibers operating in the second transmission window (1310 nm). This prototype has a maximum measuring range of 15 km, a distance resolution of 20 m, and an attenuation measurement resolution of 0.2 dB. Figure 7 summarizes the four main components that constitute the OTDR prototype:

- Optical unit: the optical part that injects optical pulses into the fiber under test and converts the backscattered optical power from this fiber to an electrical signal.
- Electronic unit: a set of devices and custom-made electrical circuits that adapt the electrical signal provided by the optical unit and sample it to a discrete signal.
- Control and processing unit: a general purpose DSP that controls the optical and electronic units. It processes the sampled data provided by the electronic unit.
- “Otdr” Windows application: a graphical user interface that manages the DSP and displays the obtained results.

Figure 7. Overall block diagram and two photographs of the OTDR prototype.
3.1. Optical unit

The main components of the optical unit are the laser diode, the optical circulator, and the photodetector. The block diagram of Fig. 8(a) shows the layout of the optical unit. Additionally, Figs. 8(b)-(d) show photographs of each component.

- Laser diode: it consists in a Mitsubishi FU-427SLD-F1M54 module that operates at 1310 nm. The laser diode transforms the electrical pulses generated by the control and processing unit into optical pulses.
- Optical circulator: this is a polarization insensitive optical circulator from AC Photonics, which transfers the optical pulses from its first port to its second port (i.e., to the output of the OTDR) and the backscattered power from its second port to its third port (i.e., to the photodetector).
- Photodetector: this is a very high speed Thorlabs D400FC InGaAs photodetector. It converts the backscattered power from the optical fiber under test into an electrical signal, which is sent to the electronic unit.

3.2. Electronic unit

The electronic unit consists of two main components (Fig. 9):
3.3. Control and processing unit

The control and processing unit is a Texas Instruments TMS320C6416 DSP. Figure 10 shows the logical structure of the software implemented in this DSP (using the Code Composer Studio environment):

- **Data acquisition unit:** It reads the digitalized data from the A/D converter and processes them according to the parameters given by the configuration unit (this digitalized data represents the backscattered power as a function of the distance, from now on, the OTDR trace). Due to high speed requirements, the data acquisition unit makes use of the Enhanced Direct-Memory-Access built-in controller (via Memory Expansion Connector).

- **Communication unit:** It links the DSP and the “Otdr” Windows application installed on the PC together. Its purpose is to receive the commands sent by the “Otdr” Windows application and to send the OTDR traces back to the Windows application. The physical connection is made through the USB port.

- **Laser diode pulse generation unit:** It sends the signal pulses to the optical unit by means of the General-Purpose Input/Output peripheral (via Peripheral Expansion Connector). The duration of the pulses is set according to the parameters given by the configuration and control unit.
- A/D converter and laser diode biassing unit: it controls through the Peripheral Expansion Connector the biassing of the A/D converter and the laser diode.
- A/D converter control unit: it generates the clock signal and sends it to the A/D converter through the Peripheral Expansion Connector.
- Configuration and control unit: it initializes the DSP, interprets the commands provided by the communication unit, and configures and coordinates the memory, the external peripherals, and the rest of the units with the appropriate parameters in order to carry out the reflectometry measurements.

3.4. “Otdr” Windows application

The “Otdr” Windows application is the interface between the user and the control and processing unit. Its purpose is two-fold: to handle the requests from the user so as to send the appropriate instructions to the control and processing unit and to receive the measurement results from the latter in order to process them and display the OTDR trace, along with the detected events. The structure of this application, which has been developed in Visual C++ 6.0 using the Microsoft Foundation Class library, is shown in Fig. 11.
• Communication layer: it is responsible for the bidirectional communication between the “Otdr” Windows application and the DSP. On the one hand, it sends the pertinent commands to the DSP to carry out the measurements; on the other hand, it receives the OTDR trace from the DSP.

• DSP start-up layer: this layer dumps the DSP routines to the RAM of the DSP each time the prototype is switched on. This is accomplished by running a script from the Code Composer Studio.

• Arithmetic layer: first of all, it converts the trace provided by the communication layer to logarithmic units (for efficiency reasons the DSP only handles linear data). Afterwards, it filters the trace in order to increase the signal-to-noise ratio and, finally, scans the trace for events.\(^{19}\)

• Data storage layer: on the one hand, it stores/retrieves the trace in/from the hard disk; on the other hand, it performs the corresponding operations in order to export the measurement results to a spreadsheet, such as Microsoft Excel, or to MATLAB.

• Interface layer: it allows the user to enter the analysis parameters in a very intuitive way (using very simple dialog boxes, menus and toolboxes). It also displays the OTDR trace and information about the detected events (fiber losses, insertion losses, etc.) and it provides the user with tools such as markers that enable the analysis of single events.

In this application, each layer is responsible for the task it has been designed for. Accordingly, any error or exception is handled by the corresponding layer.

4. CONCLUSIONS

We have described in detail the design, structure, and implementation of two optical measurement systems, an OSA and an OTDR. The modular design of both prototypes allows a straightforward identification of the constituent parts, as well as a clear separation of the different tasks they are involved in. These features make both prototypes suitable for educational purposes and allow easy upgrade to include new functionalities or to improve existing capabilities.

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REFERENCES AND LINKS


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Abstract

The State of Florida has recently established a new center of excellence in advanced core laser technologies, associated with the College of Optics & Photonics. This center, dedicated in 2007 in tribute to the pioneering work of Charles Townes, whose insight lead to the development of the maser and the laser, will invest in next generation laser technologies for applications to medicine, advanced manufacturing and defense. It joins the cluster of photonics-related centers at UCF, adding a focused national center for the education and training of scientists and engineers in laser technology. This paper describes the mission and objectives of the Townes Institute, the educational and training programs it is creating, its current investments and opportunities, and the future institutional and industrial partnerships and global reach it hopes to create.