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Design of an Inexpensive Optics Demonstration/Experimentation Kit for Middle School

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Abstract

An inexpensive and user-friendly optics kit has been designed and a working prototype built for middle-school teachers for demonstration and for middle-school students for experimentation in light reflection, refraction, absorption, and transmission. The end product integrates the disciplines of industrial design, engineering, engineering technology, and business, and it demonstrates the iterative processes of engineering design and product development. It is also the sum of the creative efforts of first-year engineering students, senior Industrial Design students, junior business students, and senior industrial and manufacturing students. Finally, this project is an example of the products and services of the Engineering Design Center for Service-Learning located at Western Michigan University to enhance K-12 mathematics and science teaching and learning.

Introduction

The subject of light reflection, refraction, absorption, and transmission is first introduced in the middle-school science curriculum (often taught in 7th grade). However, middle-school textbooks give incomplete and sometimes even incorrect impression of these phenomena by describing light reflection, refraction, absorption, and transmission as discrete and separate – see Figure 1 (a) and (b) below. In reality, these phenomena take place concurrently in materials such as quartz – see Figure 1 (c) -- in fiber optics communication.

This paper will describe the work by first-year engineering students, senior Industrial Design students, junior business students, and senior industrial and manufacturing students in designing, testing, revising, and building a working prototype OPTX (Optical Phenomena Teaching and eXperiment kit), which can be used by teachers to demonstrate or by students to experiment with light reflection, refraction, absorption, and transmission. The paper will conclude by describing the Western Michigan University Engineering Design Center for Service-Learning which sponsors the project.

The Initial Design

In the mid-to-late 1990's when the primary author was an associate professor of mechanical engineering at University of South Alabama, he adopted the service-learning pedagogy in teaching the first- year "Introduction to Mechanical Engineering"[1]. In ME 101, students worked in teams to design and build laboratory equipment and instructional materials that meet the needs and specifications of middle-school teachers for the purpose of engaging middle-school students in active, hands-on learning of mathematics and science. One of the earlier design requests was laboratory equipment to demonstrate light reflection, refraction, absorption, and transmission.

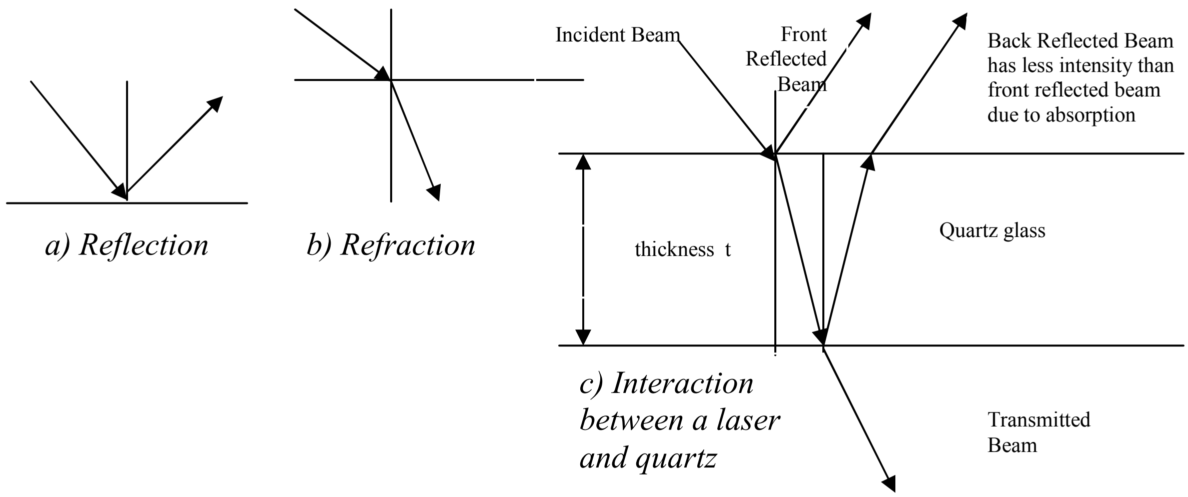

Figure 1. Light Reflection, Refraction, Absorption, and Transmission

A team of first-year mechanical engineering students researched materials that can demonstrate concurrent occurrence of light reflection, refraction, absorption, and transmission and arrived at a design involving glass plates, a laser pointer, an optical fiber, and screens to detect the light beams. In the demonstration, there would be multiple reflected beams from a laser point from the front-face as well as the back-face of a single glass plate, and multiple transmitted beams. Furthermore, the intensities of the second and third reflected beams and the second transmitted beam are lower than the first reflected beam and first transmitted beam due to absorption. Thus, all four optics phenomena can be demonstrated to take place concurrently. Furthermore, the number of glass plates used to interact with the laser can be increased from one to two to three to four, and the number of reflected and transmitted beams would increase accordingly due to multiple reflections from the front- and back-faces of the glass plates. The first-year mechanical engineering students proposed an experimental set up as shown in Figure 2 in which retort stands hold the glass plates and screens to capture the reflected and transmitted beams.

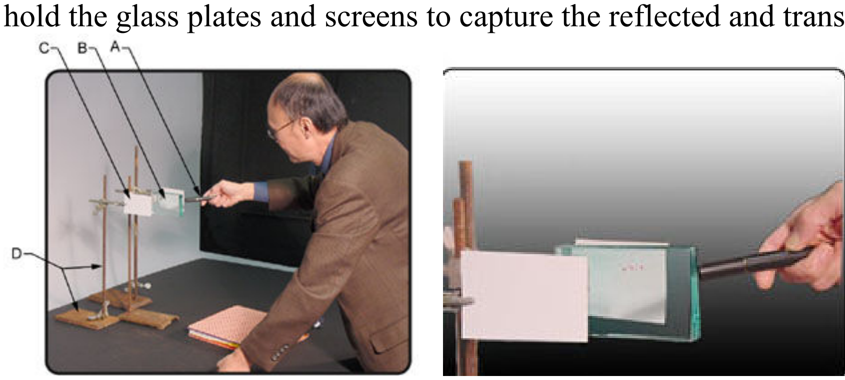

Figure 2 (Left) Experimental set-up: (A) laser pointer; (B) glass plate; (C) screen; (D) stand. (Right) Multiple reflections of a laser beam, shown by the red dots, are captured on a screen.

Unfortunately, after the mechanical engineering students have demonstrated their solution to the teacher and her class, the equipment was not used again the following year. Interview with the teacher discovered that while her students were fascinated by the demonstration, the teacher said the 30-minute set-up time and storage of the components were obstacles to using the equipment to perform the demonstration again.

Design Revision

The obstacles to using the proposed design by first-year engineering students to demonstrate the concurrent occurrence of light reflection, refraction, absorption, and transmission -- storage and setting up the laboratory equipment – were presented to a group of senior industrial design students. They were charged with designing a carrying case that would house and set-up the optical components for the demonstration in ID 443/447, "Industrial Design Thesis and Project Studio," during the 2002-2003 academic year. Industrial design is concerned with the functionality and aesthetics of a product. Industrial designers apply marketing research to identify the features that appeal to customers, and they use their aesthetic sense and knowledge of manufacturing and materials to create the most functional and appealing products.

The solution proposed by the industrial design students is OPTX (Optical Phenomena Teaching and eXperiment kit)[2], which is a portable, compact carrying case (0.372m x 0.244m x 0.065m) housing all the optical components – see Figure 3.

Figure 3. The OPTX Carrying Case

The optical components, which are laid out ready for demonstration or experimentation, consist of: (A) a laser pointer on a track to vary the angle of incidence; (b) four (4) hinged glass plates that can be rotated into position to interact with laser light; (c) an optical fiber; and (d) screens to record the reflected- and transmitted-beams -- see Figure 4.

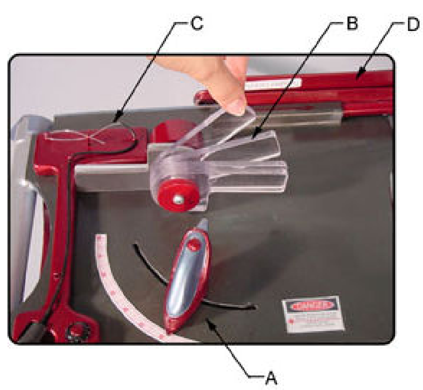

Figure 4. Optical Components: (A) laser pointer lying on a track; (B) glass plates; (C) optical fiber; and (D) holder for screen to detect laser beam.

In the design, the covers of the carrying case turn into legs to display the optical components by pushing a spring-loaded opening device – see Figure 5 below.

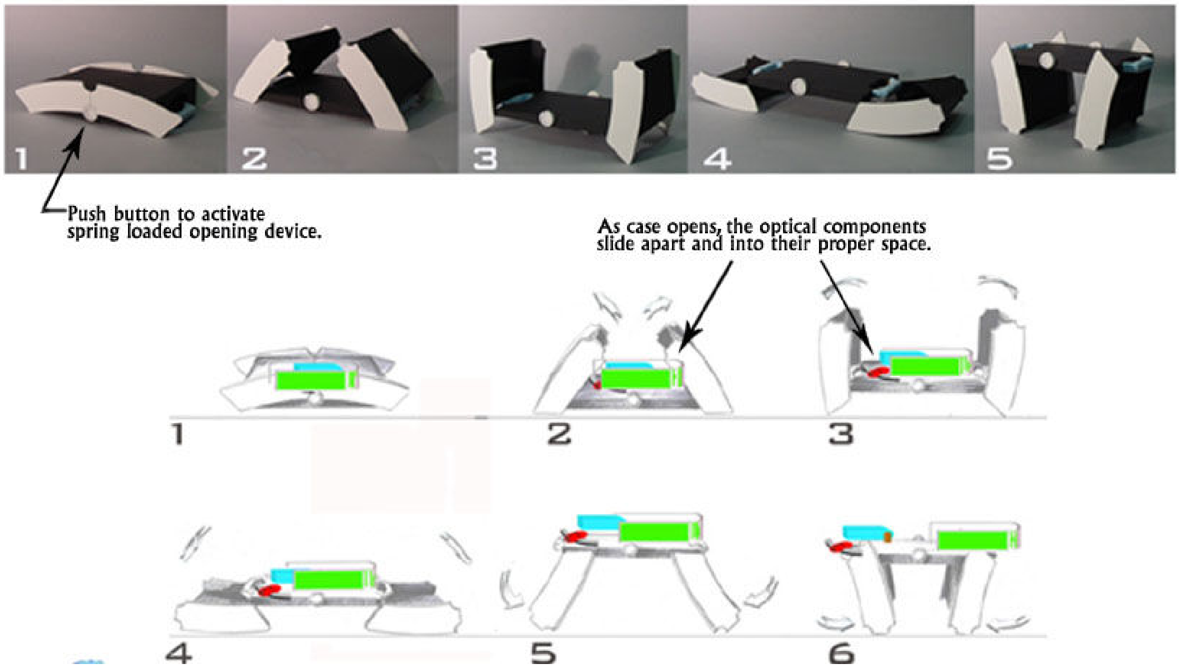

Figure 5. The optical components are set up ready for demonstration or experimentation by opening the carrying case with a spring loaded opening device.

OPTX is safe because the power source for the laser pointer is separate so that the laser is inoperable if students removed it from the kit. The battery can be charged by stacking OPTX on top of each other – see Figure 6.

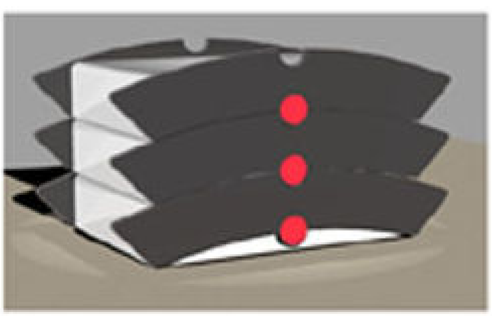

Figure 6. The battery for the laser can be charged by stacking OPTX one on top of another.

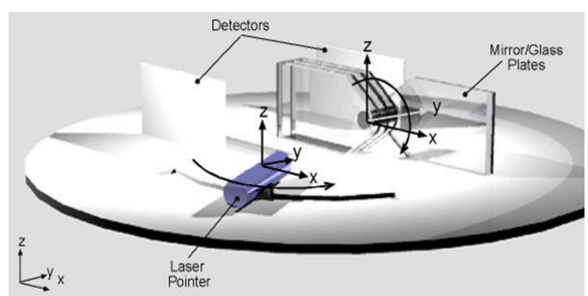

Figure 7. The laser lies on the x-y plane and rotates about the z-axis; the glass plates lie on the x-z plane and rotates about the y-axis.

The design of OPTX is different from U.S. Patent No. 6,382,982, "Educational Tool Comprised of Selectable Optically-Linked Modules." This patent claimed "a learn system comprising a plurality of optical modules" and "means for aligning….*onto a common optical axis*, wherein

said plurality of optically linked modules are *operatively connected to operate as a system for teaching principles of optics*"[3]. In OPTX, the optical modules/components are *not* connected nor aligned on a common optical axis but on *two, separate axes lying on two different planes*. The laser source lies on the x-y plane and rotates about the z-axis, while the glass plates lie on the x-z plane and rotate about the y-axis -- see Figure 7. To demonstrate the law of reflection, the laser, plate/mirror, and the detectors cannot be connected or aligned on a common optical axis.
A prototype OPTX was built by the industrial design students: The side panels, the base plate, and the shells of the carry case were fabricated by thermal forming ABS plastics. The Bill of Materials is given in Table 1 below:

Table 1. Bill of Materials for OPTX

Name	*Materials*	*Quantity*
Carrying Case		
Shell	ABS	2
Side Panel	ABS	4
Base Plate	ABS	1
Activation Button	Acrylic	2
Handle	Coated Plastic	2
Hinge Mechanism		1
Optical Components		
Plates	Acrylic	4
Tube	Plastic	1
Laser		1
Laser Base	ABS	1
Laser Tracck		1
Screen	Card Stock	2
Optical Fiber		1

Market Study

Following the construction of a prototype, a group of business students enrolled in MGMT 301, "Project Management," conducted a market study during Summer 2003 to assess the market potential of OPTX. A letter survey was sent to 100 private and public middle-school teachers in three geographic (rural, suburban, and urban) areas of Michigan. Forty-nine responses were received (49% return rate). Sixteen percent of the respondents have taught between 1-to-5 years, 31% 6-to-10 years, 22% 11-to-15 years, and 24% 16 years or more.

The major findings of the survey were:

1. All respondents agreed a new approach is needed to teach light reflection, refraction, absorption, and transmission;
2. 90% of all respondents stated OPTX would be useful for multiple lessons;
3. 12% of all respondents stated they would use OPTX for demonstration, 18% for experimentation by students, and 67% for both demonstration and experimentation;
4. 78% of all respondents wanted a product such as OPTX to teach light reflection, refraction, absorption, and transmission; and

5. 84% of all respondents stated the ideal price range is between $50-100 for an individual kit based on their school budget; and
6. 88% of all respondents reported their school budget would allow for the purchase of OPTX, if it were priced in the range selected.

The team concluded: "Based on the information from the surveys, there is an apparent market for the OPTX Demonstration Kit. Considering the number of school districts in West Michigan alone, we feel the market possibility for this product is considerable"[4]. Furthermore, the business students found "years of experience by teachers surveyed do not affect their support for the kit…In conclusion, survey results show that although schools are different in terms of funding and teaching styles, most are interested in OPTX to teach reflection, refraction, absorption and transmission."

The business students also made an in-person presentation with a College of Education professor, whose expertise is elementary- and middle-school science education, to gather insight on the use of OPTX. The science educator agreed to the importance of teaching the concepts that OPTX illustrates, and felt that there is a need for a new way to teach the principles of light reflection, refraction, absorption, and transmission. The science educator also indicated he likes the fact that OPTX is self-contained and that no set-up is needed for the demonstration or experimentation. In order for the kit to be successful, the science educator recommended that it would be important to provide a very comprehensive teacher training program on the use of OPTX beyond a manual. Other than his concern with teacher training, the science educator was very excited about OPTX and felt it would be a useful tool in the middle-school curriculum.

The average annual budget for new equipment in elementary- and middle-schools in North America has been determined to be $5,500. Assuming a class size of 24 and students work in teams of three, the business students determined that a school can spend less than 20% of its annual budget for new equipment ($1,000) and purchase 10 units of OPTX to equip a lab, based on a unit price of $100.00. If OPTX can be produced at a cost of $75.00 per unit for a batch size of 5,000, the business students concluded that this would bring a return of $125,000 for an initial investment of $375,000 (33.3% return on investment).

The business students also recommended targeting school principals and school district science curriculum coordinators at regional and national science fairs, because they are the decision makers to make purchase at the school and district levels.

Next Generation Prototype

A new design team is re-designing and researching fabrication techniques for OPTX as part of IME 491/492, "Multidisciplinary Senior Project in the Department of Industrial and Manufacturing Engineering," and building a working prototype during the 2003-2004 academic year. This is in response to the market study to reduce the production cost to $75.00 or less for a batch size of 5,000. The new design team is modifying the design of the carrying case for manufacturability to reduce production cost and to strengthen the handle of the carrying case. The team is consisted of a manufacturing engineering technology student (plastics option) and two engineering graphics and design technology students.

During Fall 2003, the team conducted literature review of fabrication processes including injection molding, thermoforming; drape forming, cavity/straight forming, and billow/bubble forming; materials selection and properties; and modeling and simulation of various fabrication techniques, including proper gate location and design for injection molding and the associated material behaviors, and cooling analyses. Preliminary findings during Fall 2003 included: (1) Use injection molding to create the base; (2) Use thermoforming to create the shell and legs; and (3) The other components could be purchased through independent suppliers for final assembly of OPTX. The team has also identified the following tasks for Spring 2004: (1) Finish detailed drawings to document all the design specifications of the final parts; (2) Create full 3-dimensional CAD model of OPTX and its components for evaluation of fit and function, and for vendors to evaluate manufacturability and pricing; (3) Perform mold flow analysis of flow characteristics associated with the parts to be made with injection molding to improve manufacturability of the part; (4) Perform finite element analysis of the stress capacity of the components; and (5) Conduct fabrication & testing of pre-production units.

Future Work

The next task after completion of the re-design and building of a second-generation prototype is to make 12 copies of it to distribute to middle-school science teachers for use in the classroom. Feedback from field use will serve as the final phase of design and market testing prior to scale-up production.

Engineering Design Center for Service Learning

The Western Michigan University Engineering Design Center for Service Learning was created in Summer 2003 to provide an environment where engineering students and faculty and education students and faculty can collaborate to design and build laboratory equipment and instructional materials to enhance teaching and learning of mathematics and science in K-12. Three one-credit hour courses, ENGR 202, 303, and 404 are being created so students can receive academic credits while engaging in multi-year, multi-disciplinary service-learning projects. Community service provides the context for students to develop and grow skills in engineering design, teamwork, and communication.

Another function of the Engineering Design Center for Service Learning is to support WMU student volunteers, which numbers approximately 400 students about half of whom are education students, to lead after-school activities based on science, technology, engineering, and mathematics (STEM) at Boys and Girls Club and Navigator Academy. Children participating in Boys and Girls Club or attending Navigator Academy traditionally have little exposure to or participation in STEM activities.

It is anticipated that a significant majority of the products and services of the Engineering Design Center for Service Learning will be customized to one client's need, but it is expected that five to ten percent of the design requests will have potential for scaling up, such as OPTX, to impact teaching and learning in mathematics and science at a larger scale in K-12.

Acknowledgement

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References

1. Tsang, E., Van Haneghan, J., Johnson, B., Newman, J.E., and Van Eck, S. (2001). "A Report on Service-Learning and Engineering Design: Service-Learning's Effect on Students Learning Engineering Design in 'Introduction to Mechanical Engineering'." International Journal of Engineering Education, Vol. 17, No. 1, p. 30-39.
2. Nielsen, K., and Reinhart, P. (2003). “Capstone Design Report for ID 443/447 – OPTX”
3. U.S. Patent No. 6,382,982, “Educational Tool Comprised of Selectable Optically-Linked Modules.
4. OPTX Optical Demonstration Kit, June 11, 2003. Submitted as part of MGMT 301, Department of Management, Haworth College of Business, Western Michigan University.

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