The Hands-On Optics Project:
A Demonstration of Module 3–Magnificent Magnifications

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ABSTRACT

The Hands-On Optics project offers an example of a set of instructional modules that foster active prolonged engagement. Developed by SPIE, OSA, and NOAO through funding from the U.S. National Science Foundation, the modules were originally designed for afterschool settings and museums. However, because they were based on national standards in mathematics, science, and technology, they were easily adapted for use in classrooms. The philosophy and implementation strategies of the six modules will be described as well as lessons learned in training educators. The modules were implementing with the help of optics industry professionals who served as expert volunteers to assist educators. A key element of the modules was that they were developed around an understanding of optics misconceptions and used culminating activities in each module as a form of authentic assessment. Thus student achievement could be measured by evaluating the actual product created by each student in applying key concepts, tools, and applications together at the end of each module. The program used a progression of disciplinary core concepts to build an integrated sequence and crosscutting ideas and practices to infuse the principles of the modern electro-optical field into the modules. Whenever possible, students were encouraged to experiment and to create, and to pursue inquiry-based approaches. The result was a program that had high appeal to regular as well as gifted students.

Keywords: optics education, educational systems, educational reform, technology education, outreach

1. INTRODUCTION TO THE HANDS-ON OPTICS PROGRAM

The Hands-On Optics program was a National Science Foundation educational project originally designed for afterschool programs for middle school students and hands-on science and technology centers. Since its inception, it has also been used in school classrooms and in a variety of other informal education venues. The project was created in response to an assessment of national needs in optics and photonics education.[1] The modules developed at the National Optical Astronomy Observatory were designed to encourage an active and prolonged engagement with optics and optical technology.[2] The modules targeted and addressed reasoning difficulties and naïve conceptions of students. This was an important aspect of the program. Students often have difficulties in experts consider quite elementary. For example, optics concepts like simple plane reflection[3] or basic understandings of the nature of light are often difficult areas for novices.[4] The program had a strong emphasis on professional development of the afterschool teachers or museum educators with the realization that their pedagogical knowledge and active involvement in encouraging the scientific process was critical to the experience of the students.[5] The program was designed with the understanding that optics concepts and content knowledge are not always quickly or easily grasped by educators who do not possess a strong science background.

To provide content knowledge, the program trained optics industry professionals (called Optics Resource Volunteers or ORVs) to play an important role in the program. They served as subject matter resource experts who assisted the program educators. The ORVs were teamed with science center and afterschool program educators. The educator would handle the educational pedagogy while the ORV provided background into the optics concepts and the actual practice of optical engineering, research, and manufacturing. Thus the educator less familiar with optic concepts and technology would have a backup resource person to provide assistance. The relationship between the ORV and the educator relied on a clear separation of roles and on mutual professional respect. The ORV did not need to become an education expert and vice versa. The ORVs worked well with the educators. The program facilitated a positive working relationship by training them together to use the Hands-On Optics materials and by encouraging them to use their complementary skills.

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The original setting for Hands-On Optics was in an informal or "free choice" environment, such as that found in museums and afterschool programs. This environment has been shown to be very powerful in stimulating student interest in science and in improving science literacy.[6] The program has now been adapted for more formal classroom environments and has been used successfully in upper elementary and middle school classrooms.

Each of the HOO modules had a content theme (such as simple reflection or polarization) and consisted of a sequence of activities that build basic (conceptual) knowledge and science process skills in this area. The modules also had demonstrations to illustrate basic principles or to excite student interest. At the end of each module is a culminating activity that also serves as a form of authentic assessment. This final activity combines many of the principles learned in that module in a way that reinforces the lessons learned from previous activities.

Figure 1: Most of the Hands-On Optics activities were designed for collaborative groups of 3 students (shown here doing an activity on reflection and symmetry from Module 2.

Although educators could rely on ORVs for help in understanding the more complicated optical concepts, each educator was also expected to advance his or her knowledge of optics though a professional development program and through the use of a resource book published by the National Science Teachers Association that has an excellent treatment of basic optics principles for teachers.[7] This book served as a reference for the educators we trained and was included in the kit. Each of the modules has a teaching guide on the activities as well as a kit that can serve about 30 students. This guide references the concepts and is tied to the national teaching standards. It also has a glossary and worksheets for the students that can be copied and distributed. The guide also has advice for the educator and of course describes any safety concerns.

2. PROGRAM GOALS

The Hands-On Optics program has well-defined programmatic goals that arose from partner discussions about the state of optics education. The modules were designed for use in a playful, exploratory way. The program goals are well-delineated and were described in an National Science Teachers Association publication:[8]

Table 1: Hands-On Optics Goals and Approaches

Goal 1: To create links between the professional optics community and the informal science education community. <u>Approach</u>: The project partners established strong linkages with the Association of Science Technology Centers and with after-school programs (e.g., the Mathematics, Engineering, Science Achievement (MESA) program, and the Boys and Girls Clubs).
Goal 2: To reach underrepresented middle-school-age students with informal material about optical science and technology. <u>Approach</u>: Through careful partnering, the project reached a diverse, national audience of underrepresented middle-school age students.
Goal 3: To provide opportunities for underrepresented youth to succeed in collaborative learning and problem solving through inquiry-based, hands-on applications of optical and engineering skills and knowledge. <u>Approach</u>: The project designed materials and activities that emphasize these areas.
Goal 4: To increase science and technology knowledge for students, and to increase awareness of optics as a discipline and career that crosscuts numerous fields. <u>Approach</u>: The project provided an extended learning opportunity for a large number of students and created and distributed career education materials. We also provided optics industry volunteers to work with educators.

3. HANDS-ON OPTICS MODULES

Each of the modules in the program covered one general topic. The modules were designed to build on each other, though modules could be used independently with some thought. Module 3 is situated in the sequence after studies of basic reflection and multiple reflections.

Table 2: Module Concepts and Activities (adapted from reference 8)

Module Title **Key Science/Engineering Concepts**	**Sample Activities**	**Primary (Culminating) Authentic Assessment Activities**
1. Laser Challenges • Laser safety. • Law of reflection: angle of incidence equals angle of reflection. • Reflection off of a plane mirror. • Specular and diffuse reflection- similarities and differences • Reflection from micro-rough, surfaces as simple reflection from multifaceted surfaces.	• Measuring angles using protractors. • Tracing rays using string. Viewing reflection in milky water to trace angles. • Ray tracing from source to detector and vice-versa. • Focal point of a flat mirrors place on a curve • Focal point and rays tracing for curved mirror surface using Mylar®.	• “Hit the Target” challenge. Challenge is to position two mirrors and a laser using protractors, string, and other tools available to hit a small stationary target, without turning on the laser.
2. Kaleidoscope Adventures • Reflection off of multiple plane surfaces. • Symmetry of objects • Principles behind the simple kaleidoscope • Principles behind the periscope.	• “Titanium Dioxide symmetry paradox. • Ray tracing. • Symmetry and the alphabet • Experiments with nearly parallel mirrors, hinged mirror experiments • Building a kaleidoscope • Periscopes and mirror rotation	• Construction, use, and understanding of kaleidoscopes. • Using teleidoscopes, which have an open view of the world (no beads).
3. Magnificent Magnifications • Formation of images using lenses and curved mirrors. • Focal length of lenses • Focal length of curved mirrors • Concepts of magnification and resolution. • Concave versus convex mirrors	• Lasers and light as seen through acrylic blocks • Finding the focal length. Magnification of a lens • Forming images with lenses • Arranging lens to build a refracting telescope • Three lens systems for upright image • Measuring telescope resolution • Using Fresnel lenses • Forming images with mirrors	• Construction of a simple refracting telescope similar to Galileo’s and measurement of its resolution and magnification. • Proper use of this telescope.

4. Peculiar Polarizations • Waves and linearly polarized light • Polarization by reflection • Polarized sun glasses and how they work • Polarized light and corn syrup • Polarization and stress testing of plastic forms • Polarization of skylight • 3-D images using filters and using polarization	• Using springs and waves to demonstrate polarization • Polarization through low-angle reflection • Producing colors through optically active materials such as corn syrup • Using polarizing materials and polarizers to construct artwork of different colors. • Using polarizers to observe stress in plastic materials. • Viewing 3-D images	• Construction of a colored window using layers of birefringent material. • Testing for stress in common materials using polarization.
5. Ultraviolet and Infrared Light • Understanding waves, wavelength, and amplitude • Electromagnetic spectrum • Effects of ultraviolet light • Detection of infrared light • Differences among luminescence, fluorescence, and phosphorescence	• Large number of experiments using phosphorescent, luminescent, and fluorescent materials • Experiments with ultraviolet sensitive beads. • Using a passive infrared thermometer. • Use of infrared thermometer and Leslie's Cube	• Numerous embedded assessments. • Experiments with Leslie's Cube. • Identification of minerals using its fluorescent signature.
6. Communicating on a Beam of Light • Encoding of information. • Laser light and the concept of coherence • Coding of information, Morse code • Laser transmission of information • Fiber Optics	• Construction of a laser transmission system for voice communication. • Use of fiber optics for information transmission	• Students are challenged to communicate by laser over the largest distance using combination of lenses and mirrors. • Students can apply all previous modules and equipment in all previous modules. Culminating module.

The scope of these modules is extensive and each module was designed to be an intensive foray into a particular optical area. In general the activities of the modules averaged about 6 hours each. Given the large amount of time that it would take to do all of the activities, the professional development of our educators was a key concern for the project. Without training, it would be difficult for educators to feel comfortable with the material.

The professional development workshops served as both a recruiting and training tool. Educators with interest in the program signed on for the workshops and received training before committing to the program. If they committed to using the modules they received the educational materials and kits. Over 25 professional development workshops were conducted across the country. Most of these workshops were two days in length and covered three modules. To assess the gains in concept knowledge a pre-test/post-test approach was used. Our NSF project evaluator measured educator concept and knowledge development as a result of the two-day workshop, where educators used the kits, explored the concepts, and worked with their volunteers. The educators made very significant gains in optics knowledge as exhibited by pre-test/post-test results. These results are seen in Table 3.

Table 3 Assessment of educator knowledge before and after the professional development program run by NOAO for Modules 4, 5, and 6. Significant gains were seen after each training.

Site (Number of Educators)	Pretest Mean*	Post Test Mean*	Percent gain
California Science Center (Los Angeles, California) (11)	62	81	31
Lawrence Livermore National Laboratory, California (12)	59	75	27
Tucson, Arizona (18)	62	75	21
Longmont, Colorado (15)	71	88	24
Baltimore, Maryland (15)	61	80	28
Overall (71)	63	80	26

- = Percent correct

4. MODULE 3: MAGNIFICENT MAGNIFICATIONS

This module has activities related to arranging lenses to magnify a distant object. The approach we take is to use an inquiry-based method to encourage student investigation. This approach uses a number of features of inquiry appropriate for middle school students, as outlined in the National Science Education Standards:[9]

- Learners are engaged by scientifically oriented questions
- Learners give priority to evidence
- Learners formulate explanations
- Learners evaluate their explanations based on scientific knowledge
- Learners communicate and justify explanations

While pursuing their areas of inquire, the students will have the opportunity to discover:

- In air (or a uniform medium), light will travel in a straight path.
- When light hits a boundary between two different substances (e.g., air and water), its path can change.
- A convex lens can cause parallel rays of light to converge.
- Converging lenses can be used to project an inverted image onto a screen.
- Converging lenses can be used to magnify an object.
- The amount of magnification is related to the focal length of the lens.
- The point at which an image “flips” is the focal point.
- Focusing can be done by adjusting the distance between two lenses.
- For greatest magnification, the most curved lens (shortest focal length lens) can be used closest to the eye.
- The two-lens system will invert the image.
- The first lens creates an inverted, real image on the screen.
- The second lens acts as a simple magnifier, making the image larger.
- How to assemble a simple refracting telescope.
- How to estimate the magnification of a refracting telescope.
- Resolution is a measure of how much detail can be observed.
- How to determine the resolution of objects.
- Fresnel lens construction, common applications.

Some of the basic activities of Module 3 are (in sequence):

A. Light Through an Acrylic Block
(Demonstration) Starting with a laser shining at normal incidence to an acrylic block, the teacher will slowly increase the incident angle. The students will observe that the path of the light changes as the incident angle increases.

B. Three Lasers Converging at a Focal Point
(Demonstration) Students predict the path of the rays through an acrylic block and through a lens, then determine if they are correct by using a mister or chalk dust to expose the laser beams.

C. Finding the Focal Length Using a Distant Object
When looking at a brightly colored lamp on one side of the room, students will measure the focal length of a lens by forming an image of the light on a screen and measuring the distance between the lens and the screen.

D. Simple Magnifiers
In this activity, students will explore the magnifying properties of the lenses and notice the connection between how much the lens is curved and its ability to magnify. The students can also see how a juice bottle filled with water can be used as a magnifier as well.

E. Build a Refracting Telescope I
This is the first of several activities relating to refracting telescopes. Students will first determine how to arrange two lenses so that when they look though them they will see a magnified image of a distant object.

F. Build a Refracting Telescope II
Using the configuration of lenses that they found previously, students will create a magnified image of a distant object. By placing the velum screen in varying locations, students will determine the function of each lens in a basic refracting telescope.

Figure 2: Using velum screens to study image formation by a convex lens.

5. THE GALILEOSCOPE

In the final activity, the students build their own refracting telescope from a kit. When Hands-On Optics was first developed, the kit we had available for this activity was the Project STAR telescope kit developed at Harvard and distributed by Learning Technologies, Incorporated. This kit was used very successfully to teach optical principles but did not allow students to mount the telescope at night for observing of astronomical objects. The Project STAR telescope is seen in Figure 3and is described in more detail in papers reviewing the development of telescope kits for the International Year of Astronomy 2009.[10] The Project STAR telescope performance is reviewed elsewhere.[11]

Figures 3 and 4 The Project STAR telescope (left) and the Galileoscope telescope (from Galileoscope.org). The Galileoscope is robust, easy to assemble, tripod-mountable, and of high optical quality.

The Galileoscope telescope kit (in Figure 4) soon replaced the Project STAR telescope as the culminating activity of Module 3. With the high performance of the telescopes (good enough to see the rings of Saturn), students had a great desire to use the telescope at night as part of a star party or observing session. Programs to use the Galileoscope are described in detail in this volume and elsewhere.[12] Some effort was also made to design the telescope so that its components could be used in studies of refraction. In this sense the telescope (when partially assembled) could be used as an optical bench.

In order to be accepted by classroom teachers and schools, the Module 3 activities were correlated to the various U.S. national education standards. These included the national science education standards, the national technology education standards, and the National Council of Teachers of Mathematics standards. With the recent introduction of the "Common Core" standards and the "Next Generation Science Standards" the modules must be updated to include them.[13] For the Galileoscope component of the program, we have also created a specific teaching guide and an observing guide. The Galileoscope Optics Teaching Guide and the Galileoscope Observing Guide are available in pdf format at an NOAO-sponsored web site for educators: www.teachingwithtelescopes.org.

6. CONCLUSION

Module 3 of the Hands-On Optics program has been well received by formal and informal educators alike. The activities with lasers and lens have been greatly enjoyed by students. Because these activities have a strong basis in inquiry and are tied to national education standards they are widely accepted as progressive lessons. The Galileoscope component has become a favorite activity for students and has been used in many universities outreach programs.

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