An optics education program designed around experiments with small telescopes

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ABSTRACT

The National Optical Astronomy Observatory has led the development of a new telescope kit for kids as part of a strategic plan to interest young children in science. This telescope has been assembled by tens of thousands of children nationwide, who are now using this high-quality telescope to conduct optics experiments and to make astronomical observations. The Galileoscope telescope kit and its associated educational program are an outgrowth of the NSF sponsored "Hands-On Optics" (HOO) project, a collaboration of the SPIE, the Optical Society of America, and NOAO. This project developed optics kits and activities for upper elementary students and has reached over 20,000 middle school kids in afterschool programs. HOO is a highly flexible educational program and was featured as an exemplary informal science program by the National Science Teachers Association. Our new "Teaching with Telescopes" program builds on HOO, the Galileoscope and other successful optical education projects.

Keywords: optics education, telescope, kits, outreach

1. INTRODUCTION

The National Optical Astronomy Observatory education and public outreach group has been charged with providing leadership and service to the national optics and astronomy education community. In order to do this effectively we have had to address a variety of educational questions related to optics education. Some of these planning questions include:

- At what age can students be taught about optics?
- What are the core concepts that should be addressed at each age?
- What is an appropriate scope and sequence for optics education?
- How can we assist schools (formal education system) in optics education?
- How can we assist museums, after school programs, and other informal, free-choice oriented institutions in optics education?
- What role shall we play in conducting professional development?
- How can we design professional development that serves both the formal and informal education communities?
- What resources are currently available and which are the best ones?
- What resources still need to be developed and how can we plan for their development?

To address these complex questions, we have utilized our science education team with considerable expertise and experience in optical physics and engineering, educational materials development, teacher professional development, museum and planetarium education, early childhood education, multicultural education, educational evaluation, and educational research. As necessary, we have supplemented our team expertise with outside experts and collaborative partnerships since almost all educational projects rely on strategic partnerships.

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We have incorporated the answers to many of these questions in our Galileoscope educational telescope kit project and its follow-on project “Teaching with Telescopes”. These two projects represent a general attempt to answer these educational design questions. Our approach on these projects is fundamentally about how best to get the most educational utility through proper realistic educational planning. Our goal is to help support and improve the existing science education system in general, and optics education, in particular. Some brief answers to some of the questions are now given to set the stage for these projects. Again, these answers represent fundamental parts of the planning for both of these projects.

2. DESIGN CONCEPT: TARGET AGE

Our experience has been in teaching and working with people of all ages, and especially in the development of educational programs for children.[1] We have explored and taught optics with pre-school age children, with K-16 students, and with adults in their eighties. We have also worked with optics leaders[2] and regional professional societies to further their educational work.[3] These experiences indicate that awareness of optics can start very young. At each age optical awareness can be fostered. We generally view optics concept development as something that occurs in developmental stages. These stages represent the process of obtaining basic information about light and color that sets the stage for further learning. We view most of these stages, and the optics concepts particular to each stage, in the framework of exploratory activities that have active involvement in manipulating tangible objects. Thus concept knowledge is not acquired passively but rather created through active exploration.

For example, in predicting how light will reflect from a series of flat mirrors, the acquisition of this knowledge usually comes first from exploration and experimentation. Later these explorations can be crystallized or summarized as the “Law of Reflection”. However, memorizing the law of reflection without an opportunity to explore will not generally allow a student to retain this knowledge. Thus most core concepts need to be acquired through some set of active operations and demonstrations. The assessment of acquired knowledge is usually done using some form of authentic assessment, where further applications of the knowledge can be demonstrated and objectively measured to show mastery. Although higher order abstract knowledge can be obtained through books, most children cannot learn deeply without exploration.

Great care must be taken to avoid fostering optics misconceptions.[4] Often misconceptions arise from incomplete exploration of concepts or through rather hurried, incomplete, or inaccurate explanations. Without a thorough opportunity to explore optics concepts, students often will form poor, incomplete, or wrong optics concepts. Once embedded, these concepts may be difficult to remove.[5]

What are the most appropriate concepts to teach to a particular age of student? This is very difficult to determine, but has been addressed well elsewhere in research on children’s ideas about how light behaves.[6] The general rule of thumb we have followed is that if there is a demonstration or experiment that can produce clear (generally visual) evidence, then the potential for concept development in this topic probably exists, regardless of the age of the student. Note that we are talking about core notions or concepts rather than abstract laws. For example, in a study of shadows cast by the sun (i.e. with a light source emitting nearly parallel rays) anything that can be demonstrated can help build a concept of how shadow look and form. However, when multiple, confusing (or apparently contradictory) experiences are given in close proximity, there is a good possibility for confusion.

In the formal education system, science can be emphasized at any age. Because physical science is often not taught often or well in the early grades (K-3) we consider fourth and fifth grades to be ideal grades for optics education. Waiting until the higher grades is dangerous in case the student receives little physical science education or experience in the meanwhile. It is difficult to start building optics experiences in middle school if there is little prior exposure to optics-related experiences. Middle school is too late for most students because of this lack of prior exposure to basic optics.

Conclusion: At any age, awareness can be built of basic optics concepts. The Galileoscope telescope kit was designed so that it could be assembled (with adult supervision) by children older than 5 years old. It was designed particularly to be used by elementary school children, especially those in grades 5 and 6. The optics teaching units with the Galileoscope were designed, like our Hands-On Optics program, for grades 5 to 7. At this age, basic optics knowledge and concepts can be constructed.

3. DESIGN CONCEPT: CHOICE OF TELESCOPES AS A TOPIC

Although we might debate in detail which are the core concepts in optics, it is perhaps more useful just to list some of the key areas in optics that have experiments, observations, or demonstrations that allow aspects of these areas to emerge in a concrete, demonstrable form, thus making them highly accessible to students. Some of these areas are given below, and are suitable for K-12 programs exploring optics.[7]

Table 1: Summary of Basic Optics Concepts

Electromagnetic Waves	Quantum Nature of Light
Shadows, Eclipses	Lasers
Pinhole Cameras	Formation of Images
Propagation of Light: Reflection	Holography
Propagation of Light: Refraction:	Misconceptions about Optics
Fiber Optics, Total Internal Reflection	Ocean Optics
Dispersion Phenomena	Polarization: Polarizers, Dichroism
Atmospheric Phenomena	Birefringence
Geometrical Optics, Aberrations	Scattering and Polarization
Cameras and Photography	Interference and Interferometers
Film	Fourier Optics
Human Eye	Optics in Literature
Visual Processing	Optics in Films
Color	Optical Coatings
Diffraction	Optics in Entertainment
Energy concentrators	Fluorescence
Light sources and detectors	Microscopes and Telescopes

In each topic area, there are key concepts that can be taught at an age-appropriate level. These concepts explain and elucidate a wide variety of optics phenomena. They also allow predictions to be made about similar phenomena that have not been experienced already. Although there may be exceptions, key concepts at this basic level are typically the ones that lend themselves most easily to demonstration and observable phenomena.

Developing lessons around the function of a telescope and how optical systems form images provides an ideal way to cover a large number of these topics. About 2/3 of these topics are generally addressed when building and using a telescope and exploring image formation. Therefore, we have made a program on "teaching with telescopes" a key part of how we want to teach optics. Of course, teaching about telescopes is a key area in astronomy education and meshes well with the educational functions of the observatory.

Our Galileoscope project is an outgrowth of Module 3, "Terrific Telescopes", in the Hands-On Optics project. The HOO project was an informal science education project targeted at middle school-aged students in afterschool settings and science centers. The project developed inquire-oriented materials that explored six areas of optics in depth. Students worked for about 5-7 hours on each module. Each activity had a culminating activity that served as a form of authentic assessment. We developed an extensive array of educator-friendly support materials. The first module explored simple reflection while the last one investigated communication over a beam of light. Each kit contained all of the materials needed to teach a module with a full class of students.

The HOO materials were based on a variety of previous education efforts and lessons learned in optics education. The development of the materials relied heavily on previous work in the UC Berkeley GEMS program. Each module was extensively field tested in a variety of informal and formal settings. Each module was also tied to national science, math, and technology standards. HOO reached over 20,000 students and was featured as an exemplary project by the National Science Teachers Association. The modules are summarized below.[8]

Table 2: Hands-On Optics Module Summary

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 a micro-rough diffusely reflecting surface 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 of a lens • Magnification of different lenses • 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	• 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	• Construction of a colored window using layers of birefringent material. • Testing for stress in common materials using polarization.

• 3-D images using filters and using polarization	in plastic materials. • Viewing 3-D images	
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.

In module 3 students learned about image formation and constructed small refractors from the Project STAR telescope kits.[9] While students responded very well to making their own telescopes, the telescopes they constructed were not particularly useful for making their own observations.[10] This motivated us to design a higher quality telescope that could be used for detailed astronomical observations (the Galileoscope). For example, the Galileoscope was engineered to be able to view the rings of Saturn and incorporated a number of advanced design features.[11] The building and using of the newly developed telescope coupled with optics experiments that accompany its construction were well suited to provide a fairly comprehensive program that covered on many of the topics listed above.

4. DESIGN CONCEPT: IMPORTANCE OF USING KITS

At NOAO we have been committed to the development of high-quality educational kits. This ensures that we can use the best quality materials that we feel are critical for each concept or lesson. It also ensures that the process of science can be taught and modeled by allowing students to work with well-chosen tools of science. Educational kits provide a hands-on experience, give children a sense of involvement and ownership in what they build, and also ensure that the teacher or museum educator does not need to round up items in order to teach a lesson. The use of kits has much in common with laboratory instruction. The importance of laboratory instruction in science education is well known and documented. Current research in science laboratory instruction shows how lab sessions can have several advantages over more conventional presentations and can promote gains in student learning:[12]

- The investigations will aid students' development of inquiry skills and give them an appreciation of the scientific enterprise and the interplay between technology and science.
- The investigative approach promotes the development of cognitive skills such as problem solving analysis, generalizing, critical thinking, applying, synthesizing, evaluating, and decision-making.
- Investigational, organizational, and communicative skills are used regularly and developed.
- Investigations provide a concrete experience and opportunity to confront student misconceptions (or *alternative* conceptions, as the case may be).

- The data manipulation and analysis activities provide an understanding of the continuity of the scientific process.
- The concrete props and opportunities for manipulation of physical objects is valuable for students with kinesthetic learning styles.
- The cooperative learning environment promotes an examination of the data from different perspectives and provides strong motivation for students to stay on task.
- The investigational environment provides ample opportunity for building and communicating values concerning the nature of science.

Kits are a key part of providing these advantages of laboratory instructions. A variety of resources are available for teaching optics to elementary and middle school students.[13] Some of the resources have been developed and tested as part of national instructional materials development programs such as programs for teaching about the electromagnetic spectrum.[14,15] For the Galileoscope teaching kits we relied on the work done at NOAO for the International Year of Astronomy 2009.[16]

Each Galileoscope teaching kit comes in a special bag containing sets of lenses of shorter and longer focal lengths, vellum screens for showing projected images, an instructor's manual of well-tested activities, and various demonstration devices. These include a green laser and an acrylic block for demonstrating refraction, 3 red lasers, and a large double convex lens for demonstrating convergence of light rays as they come to a focus. The kit also includes a tripod for mounting the Galileoscope and a special asymmetric light source (a neon-light type palm tree) used for demonstrating and facilitating an understanding of image formation.

5. THE GALILEOSCOPE AS A VERSATILE TEACHING TOOL

The Galileoscope is a 50 mm diameter objective refracting telescope kit capable of being used at 25X magnification power or at 50X magnification using a 2X Barlow lens. The Barlow lens can also be used to create a Galilean eyepiece in order to create an erect 17X image. This latter configuration can be used to illustrate what Galileo saw and to appreciate his observations and drawings made with this very small field of view. The objective lens, the symmetrical Plössl eyepiece, and the Barlow lens are all achromatic. Like the Project STAR telescope kit used in the Hands On Optics program, students have greatly enjoyed making the Galileoscope. Because of the quality of the telescope system, they have also enjoyed using the telescope at night to observe the Moon, planets, and brighter nebulae (e.g., Orion) and star clusters (e.g., Pleiades). For basic optics lessons, they can do experiments to understand the basis of refraction and image formation. They also understand the concept of using two lenses of different focal lengths to create a telescope.

Figure 1: Assembled Galileoscope teaching kit

To assist in doing optics experiments we have created a Galileoscope Optics Guide. This guide has hands-on experiments tied to the National Science Education standards, the national technology standards, and the National Council of Teachers of Mathematics standards. In our teacher guide there is also a list of misconceptions, and a glossary. We have also created a Galileoscope Observing Guide, which describes which astronomical objects are most visible during each month and gives further advice on using the Galileoscope. Both the Optics Teaching Guide and the Observing Guide are available in pdf format at www.teachingwithtelescopes.org.

The “Teaching with Telescopes” web site is a support web site designed mainly for educators but also can be of use by families, home schools, and individuals. The web site has educational materials and plans for educators on how to use the Galileoscope for a variety of different time periods. It also shows how teachers and others delivering professional development can run a workshop on the Galileoscope. It includes a specific week-long program for teachers to follow when using the Galileoscope in the classroom. Teachers can also contribute to the web site to give advice to others on using the Galileoscope in a variety of teaching settings. The web site has assembly videos, videos of people using the telescope, and photos taken through the Galileoscope.

The Galileoscope has also been used in a variety of special events designed to garner interest in science in general and astronomy and optics in particular. The Galileoscope was used at the White House for its first (ever) star party.[17] The Galileoscope has been used at other large, public events. For example, NOAO and its partners sponsored a special program where nearly 500 students built Galileoscopes in one day as part of an educational program in collaboration with Raytheon of Tucson. In collaboration with Science Foundation Arizona, a special star party for kids was held at the Arizona state capitol complex in Phoenix as well. Similar star parties are planned for Flagstaff and Yuma, Arizona where we are planning for every 5th grade student in these cities to be able to build and use a Galileoscope. To achieve these goals, our professional development program for teachers and museum educators in these cities must be robust. The Galileoscope is also being used in many international programs, and over 200,000 Galileoscopes are being used worldwide at this time.

6. CONCLUSION

The NOAO program to teach with telescopes builds on many previous optics education programs at NOAO and elsewhere. It also builds on many formal and informal education programs for pre-K to college students. It also builds on our extensive professional development experience in Hands-On Optics with afterschool and museum educators. The Galileoscope program combines many useful features of previous programs. Among these features are robust instructional materials, high-quality comprehensive and well-thought out kits, extensive testing with a variety of audiences, and a commitment to reach underserved groups. The “Teaching with Telescopes” program combines many of the best features from these existent optics education programs and provides an on-line professional development support system for families and educators using the Galileoscopes.

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