

The Evolution of Optics Education at the U.S. National Optical Astronomy Observatory

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ABSTRACT

The last decade of optics education at the U.S. National Optical Astronomy Observatory will be described in terms of program planning, assessment of community needs, identification of networks and strategic partners, the establishment of specific program goals and objectives, and program metrics and evaluation. A number of NOAO's optics education programs for formal and informal audiences will be described, including our Hands-On Optics program, illumination engineering/dark skies energy education programs, afterschool programs, adaptive optics education program, student outreach, and Galileoscope program. Particular emphasis will be placed on techniques for funding and sustaining high-quality programs. The use of educational gap analysis to identify the key needs of the formal and informal educational systems will be emphasized as a technique that has helped us to maximize our educational program effectiveness locally, regionally, nationally, and in Chile.

Keywords: optics education, technology education, adaptive optics, illumination engineering, educational reform

1. INTRODUCTION

The National Optical Astronomy Observatory (NOAO) serves the professional astronomical community by providing state-of-the-art ground-based telescopes and instruments for scientific research. NOAO's key observatories are at Kitt Peak National Observatory near Tucson, Arizona, and Cerro Tololo Inter-American Observatory near La Serena, Chile. NOAO also represents the U.S. Community in the international Gemini Observatory with telescopes in Hawaii and Chile. As a federally funded research and development center (FFRDC) funded by the U.S. National Science Foundation (NSF) NOAO has a strong set of educational responsibilities.

The education mission of the NSF was described in the law forming the National Science Foundation.¹ This act set forth NSF's mission and purpose by authorizing and directing NSF to initiate and support science and engineering education programs at all levels and in all the various fields of science and engineering. Three of NSF's four current overall strategic goals are relevant to NOAO EPO:²

- "Prepare and engage a diverse STEM workforce motivated to participate at the frontiers.
- "Enhance research infrastructure and promote data access to support researchers' and educators' capabilities and enable transformation at the frontier."
- "Keep the U.S. globally competitive at the frontiers of knowledge by increasing international partnerships and collaborations."

The various FFRDCs funded by NSF have incorporated these educational goals to a great extent and have been encouraged to develop core competencies that are responsive to the NSF goals. These core competencies include the creation of informal science education kits in the fields of optics³, citizen science programs that relate to light pollution and illumination engineering⁴, and the creation of special year-long programs to engage the public in science⁵. They also include a vigorous undergraduate student-based mentoring and outreach programs. To create these programs, NOAO has aligned its programs with national education resources⁶ and has created materials that describe pedagogical best practices for teachers⁷. NOAO has also studied and evaluated optics teaching resources that are available for teachers⁸, and the techniques for exploring both topical content knowledge and the most advanced pedagogical content knowledge⁹. NOAO was also involved in the International Year of Astronomy 2009 and in the creation of telescope kits for

IYA2009.¹⁰ This involvement in large, worldwide, public engagement projects was an invaluable experience in leveraging strategic partnerships.

Most of these projects have required an understanding of optics misconceptions¹¹ and of cross cultural factors¹². Of particular value in understanding the level of conceptual knowledge of optics already present in students are formative assessment probes¹³. These educational tools have been used extensively by NOAO in the design of programs to teach illumination engineering¹⁴ and the design and use of a high-quality student telescope kit¹⁵. This paper describes how NOAO has built its optics education program and how it has evolved since the turn of the century.

2. ASSESSMENT OF COMMUNITY NEEDS

The National Optical Astronomy Observatory has an obligation to serve local, regional, and national audiences in science education. Our efforts address the educational needs of young children, high school and university students, and the public at large. What are the needs of these different audiences and how can we participate in the improvement of scientific literacy and the development of a workforce based on science and technology competency?

The educational situation in the state of Arizona was described in a 2008 report¹⁶ by the Arizona Department of Commerce's Aerospace and Defense Committee. The committee assessment of Arizona educational quality was:

“Arizona graduates only 75% of its high school students, compared with a national average of over 85%, and ranks 49th in the nation [in this category]. “ They further indicated their concern over this ranking:

“Arizona's economic future depends on the quality of our workforce – it's the number one priority for businesses considering expansion or location. A highly skilled workforce, supported by a well-developed community college and university system, allows companies to produce goods and services marked by innovation, knowledge and quality.”

The needs of the State of Arizona led to a concerted effort to improve science education in Arizona. The plan for this is described in a previous paper¹⁷. NOAO also has an obligation to serve Chilean education, particularly in Region IV, the Región de Coquimbo, where our observatories are located. In Chile, the student population also has great needs concerning science education.

In both the U.S. and Chile, the educational community needs often center on the need for better access to educational materials and laboratory kits, more process and activity-oriented curricula, more challenging materials, teacher professional development, and teacher support. More public engagement or informal science programs, the need is often for instructors skilled in both content and pedagogy, and the need for broad programs to give access to science to a large number of people.

3. STRATEGIC PARTNERS

Given the daunting nature of the problems in science education, the formation of strategic alliances is critical. Figure 1 shows a diagram of NOAO's partners in these education efforts. This diagram includes most of our current partners and partners we have worked with in the past and may work with in the future. This diagram is much more extensive today than it would have been a few years ago. Each project adds new partners, so unless a partner proves unreliable, they usually remain as a resource for current and future projects.

Although the diagram seems to imply that NOAO is at the center, it must be remembered that each project has its own structure and network of audiences, partners, evaluators, and so on. NOAO is not the lead on every project! In each project the observatory must find its proper role or place in the project hierarchy. In the State of Arizona there are many fine partners and resources available, especially in the area of optical engineering education. In particular, the University of Arizona, in Tucson is a leader in the optical sciences. It is also a leader of related areas such as astronomy, planetary sciences, and astronomical instrumentation. Southern Arizona (where Tucson is located) is also home to the world's largest collection of optical telescopes at Kitt Peak National Observatory, which is run by the National Optical Astronomy Observatory (NOAO).

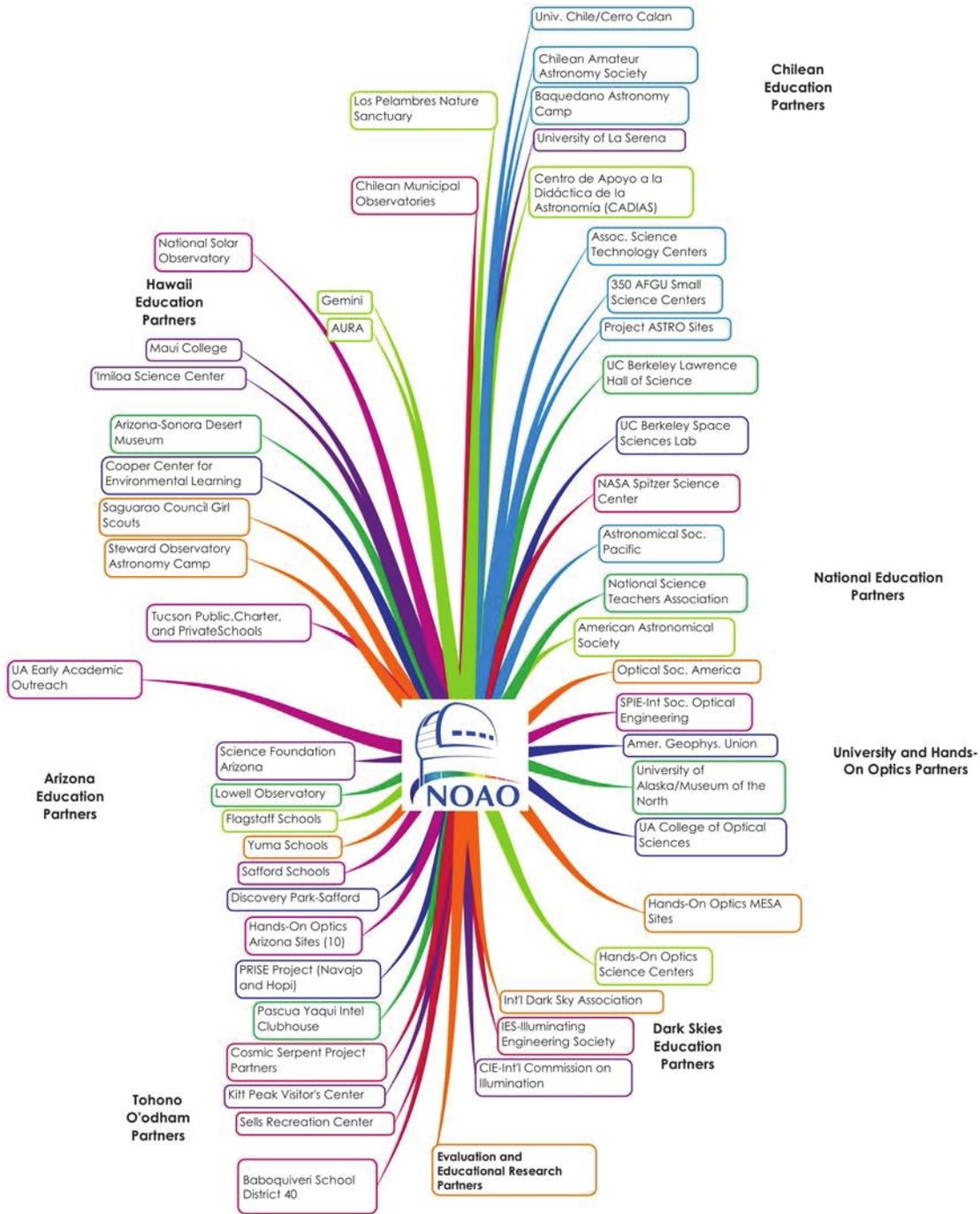


Figure 1: Network map of NOAO education partners. Note that NOAO is not the lead or in the center of every project but that all institutions are current or past partners of NOAO. These strategic partners are great resources for project planning.

Other partners include Science Foundation Arizona, an organization that provides funds for technology education in Arizona and the Arizona Optics Industry Association. The latter is composed of optics companies that have a strong commitment to science education.

National partners include, among many others, SPIE—the International Society for Optical Engineering, the Optical Society of America, the American Astronomical Society, and the Astronomical Society of the Pacific. The latter organization is dedicated to in astronomy and science education.

4. PROGRAM GOALS: GAP ANALYSIS

In Arizona and the United States there is a particular concern about education in the primary or elementary school. In the first five or six years of a child’s education, there is tremendous pressure placed on teachers through testing mandated by the “No Child Left Behind” Act. The requirements placed on schools by the law have discouraged the teaching of science in primary grade schools. Teachers in these schools often do not receive adequate training in teaching science. For this reason, NOAO has identified the upper elementary grades, and 5th grade classrooms in particular, as an important target audience for our programs. The national education standards also point to the 5th grade level as the appropriate time to teach astronomy and the tools of the astronomer—namely optical sciences.

Another gap in science education centers on the integration of physical science, environmental sciences, and energy education. NOAO has sought to fill this gap through education about energy, using light pollution as a key area. By teaching about light pollution, a program can be created that also teaches the basics of illumination engineering. NOAO has chosen to teach in this area offering a citizen science program, professional development, and special teaching kits that merge environmental and physical science.

A further gap occurs in undergraduate education where many science students receive little or no training on teaching or working in outreach. This lack of science communicators among science majors may lead to professors who are not comfortable with communicating science to the public or in employing the latest pedagogical techniques in the college classroom. To attempt to remedy this situation NOAO employs and mentors students who can do outreach in schools or who can aid the Education and Public Outreach Department in working with schools.

In general, in the U.S., optics and photonics education is rarely done at the pre-college level. NOAO has decided to interject optics and photonics education into nearly every program. In particular, our program “Teaching with Telescopes” has provided and opportunity to do optics education on a very wide scale. Our efforts in darks skies education have also led us to take an active role in promoting an understanding of illumination engineering in schools.¹⁸

5. PROGRAM EVOLUTION

The National Observatory’s education programs have evolved towards optics education with the addition of successful programs that have developed our capability in this area. Most of the NOAO education staff members have advanced degrees in physics or engineering so teaching and designing materials for optics and photonics has been possible. Our experiences have shown that optics is a very accessible area of physical science in order to reach students and to attract them to science. Astronomy is also very attractive to students so complementing our astronomy education programs with optics education has been very effective.

The table below describes NOAO programs that have taken place since 2001. While not every program is centered on optics there are aspects of optics education in each program. The programs have highly varied audiences, with many of the programs aimed at the general public. In this case, the NOAO responsibility is often to train museum and other informal education practitioners on best practices in optics education. For school-based programs, we have gotten an excellent return on investment from programs where training teachers is an important component. Since teachers are the gatekeepers to improving science education programs, it is often more effective to work with the teachers to improve their science education knowledge and to provide them new teaching materials than it is to work directly with their class. Teaching the teachers ensures that longer-term gains will be made in the classroom. A counterpoint to this argument is that there is a very high turnover of teachers. Additionally many elementary and middle school teachers shift classes and teach different classes each year. This means that some of the professional development might be considered (at least by some) to be wasted. With high turnover, professional development becomes even more important.

Table 1. Educational Programs of the National Optical Astronomy Observatory that Have Optics and Photonics Education Components

Program Title	Funding Agency Type of Project	Program Dates	Optics and Photonics Education Components	Program Challenges and Expertise Acquired
Teacher Leaders in Research Based Astronomy	NSF Teacher Enhancement	7//2001 – 7//2005	Tools of the astronomer. Research with telescopes, CCD instruments, image processing, and calibration	Extensive on-line professional development. Transfer of research from observatory to research in the high school classroom
Revealing the Invisible Universe: From Nanoscope to Telescope	NSF NSF Public Engagement and Informal Science	5/2002 – 4/2005	Infrared imaging, astronomical imaging, basics of nanomaterials, microscopy, and remote sensing	Training of non-science interns. Creation of museum exhibits for the general public in technology areas.
Spanish Language Astronomy Materials Center	NSF Resource Creation	4/2003-2005	Finding physical science and optics books in Spanish for any grade level. Preschool to first two years of college.	Finding the materials. Survey and review of about 500 books and other resources. Creation of a public library in Chile with an emphasis on science and especially astronomy materials.
Hands-On Optics: Making a Difference with Light	NSF Informal Science Education	09/2003 – 08/2007	Developed six modules on reflection, image formation, telescopes, polarization, fluorescence, and optical communication.	National nature of project. Multiple partners and venues in both science centers and afterschool classrooms. Kit development and production. Finding a long-term commercial distributor of the kits.
Collaboration to Advance Teaching, Technology and Science (CATTS)	NSF Graduate Teaching Fellows in K-12 Schools	5 years, 1/2004 – 12/2009	Trained large number of science graduate students to do outreach. The NOAO CATTS Fellows did optics and astronomy related outreach.	Training and supervising large number of Fellows. Coordination with schools and teachers.
Investigating Astronomy: A Unique High School Curriculum for All Students	NSF Instructional Materials Development	4 years, 4/2004 – 3/2008	Many parts of the book and supplemental materials relate to telescope, optics, nature of light, and light from astronomical objects.	Large, complex project as it was the first new NSF-funded textbook project in this area in about 20 years.
Astronomy from the Ground Up: Building Capacity in Smaller Informal Science Education Institutions	Funding Agency: NSF Informal Science Education	4 years, 4/2004 – 3/2008	NOAO developed the light and color units and kits that explored the basics of color, filters, spectroscopy, image formation, and telescopes.	The project involved over 300 small science centers and had a large kit component and training component.

Hands-On Optics in Hawaii	NSF Informal Education	8/2006-2007	Providing Hands-On Optics kits to 'Imiloa Science Center in Hilo, Hawaii	Mainly logistical as the science center had a reorganization of its education program during out project.
Promoting Inquiry in Science Education (PRISE)	Arizona Dept. of Education Math Science Partnership Professional Development	4/2007 – 5/2008	Training teachers on the Navajo and Hopi Nations on teaching basic physical science including optics using the Great Explorations in Math and Science program (GEMS).	Some cultural challenges. Some logistical challenges as the teachers were located about 8 hours of driving time away.
Adaptive Optics Kit Development	NSF Resource Development	2007-2009	Developing an adaptive optics teaching kit for high school use.	Funding for distribution of the kits was not available. Finding best way to present material.
Expanding the Hands-On Optics Program in Arizona	Science Foundation Arizona	6/2007-5/2011	Bring the Hands-On Optics program to 10 Boys and Girls Clubs in Arizona	Geographic reach of program. Training the new leaders given the high turnover at many of the clubs.
Expansion of GLOBE at Night Program	NSF Citizen Science	2008-2009	Citizen science program addressing light pollution issues.	Effectively dealing with massive amounts of data. Cross-calibration of different types of data.
International Year of Astronomy 2009 in the United States	NSF Public Engagement	9/2008 – 2/2009	Included many projects (e.g., the Galileoscope) and a dozen dark-skies related projects, such as GLOBE at Night and Dark Skies Rangers activities	Funding was only for coordination of the overall project. Individual projects such as the Galileoscope Project were unfunded and conducted by volunteers.
Chilean Municipal Observatory Program	NSF (core) Informal Science Education	2009-present	Collaboration with municipal observatories on teaching with telescopes and binoculars	Municipal observatories are highly resource limited and optics equipment is very expensive in Chile.
Research Experience for Undergraduates	NSF Astronomy	Summers 2010-2013	Undergraduate research projects in optics and light pollution	Limited to one summer period for each student. Continuity of research is a challenge.
Arizona Galileoscope Project	Science Foundation Arizona Teacher Professional Development, Students	5/2011 – 5/2012	Project for 5 th grade students and teachers around the state of Arizona.	Travel to many locations located far from Tucson, including Yuma, Safford, Flagstaff, and Globe. Challenge of working with large number of students in each location.
Dark Skies Energy Education Program: Energy Awareness	Arizona Public Service Company Foundation	8/2012 – 8/2013	Project on illumination engineering and energy conservation. Teaching kits	Project takes place in Yuma Arizona with 6 th grade teachers of varying

for a Sustainable Future	Professional Development of Teachers		were developed that included light meters, camera, and various lights.	experience with science and technology.
Ciencia, Educación y Sustentabilidad para el Desarrollo Turístico en la Región de Coquimbo" (Science, Education and Sustainability for the Touristic Development of the Region of Coquimbo)	Centro de Estudios Avanzados en Zonas Áridas (CEAZA)	2012-2015	Development of scientific tourism with one key component being astronomical. Heavy emphasis on dark skies education.	The involvement of a wide variety of partners and audiences (schools, tourism organizations, national parks, and museums). Blending education with economic development.
Collaborative Research: Project STEAM: Integrating Art with Science to Build Science Identities among Girls	NSF Informal Science Education	4 years, 10/2012 – 10/2016	Project is for 6-8 th grade girls on “Colors on Nature.” Covers many aspects of the interaction of light with matter including spectrally selective surfaces, pigmentation, and color formed by micro-structures (i.e. interference and diffraction)	This project combines optics, art, biology, and educational research and require a large, diverse, and highly skilled team. Many of the activities needed to be developed by the team. The project is also spread geographically between Tucson and Fairbanks, Alaska.
Dark Skies Outreach to Sub-Saharan Africa	IAU Office of Astronomy for Development	2/2013 – 12/2013	Hands-on, minds-on activities on dark skies preservation and energy conservation for 6 th – 12 th grades; kit and guides	On-line professional development via Google+ Hangouts.



Figure 2: Left: Dark Skies/Illumination teaching kit for outreach to Sub-Saharan Africa. Right: Galileoscope teaching kit for 5th grade classroom teachers.

A closer look at the evolution of these programs shows that NOAO has taken on optics education projects with many varied audiences. We have also been able to design programs that serve many different audiences. When new materials need to be developed NOAO has developed and tested kits. NOAO has developed expertise in educational kit development. For example, a portion of the kit for the last project described in the previous table is shown in Figure 2.

6. PROGRAM ASSESSMENT

It is critical to assess each program against the overall program goals and objectives. This is a very different process than program “metrics” where the number of participants, the time on task, and other variables are counted. Program assessment should be designed to measure performance gains in conceptual knowledge, for example, or changes in attitudes that can be specifically attributed to a particular program. Of course, each program needs to set its own goals and deliverables. In many cases, programs can be designed through a “backwards design” process. In this process the program goals are established first and the ways to measure success are defined immediately. The assessment is also designed at the beginning of the project.

For example, a program to help students understand the optics of a telescope may have as its goal that students ought to be able to construct a simple eyepiece. If this were a goal, then the assessment could be very specific. For example, “students ought to be able to assemble a Plössl eyepiece from a collection of various types of lenses, and make this eyepiece function to form a real image when used with a 50 mm diameter, f/10 objective lens. In this case the assessment is quite specific and the program designer can now design a program that teaches about the different kinds of lens, the design of a Plössl eyepiece, the position of the eyepiece, what a real image is, and so on. This design would be quite different for a different assessment. If this assessment is driving the lesson in the wrong direction then it can be changed. The point is that the assessment is constructed before the instructional materials are created, rather than afterwards, at the end of a lesson, when a test is needed.

7. FUNDING FOR OPTICS EDUCATION PROGRAMS

Most of the programs in Table 1 were created through a competitive grant process where NOAO competed with other educational organizations to create programs. For these programs a professional, independent evaluator, is often a requirement. The evaluator can help the project principals clarify their vision of the project and what it might achieve. The evaluator can also help in the construction of a “logic model” that describes the programs inputs and outputs and checks to see the flow of the project makes sense. The evaluator can also provide formative assessment as the project progresses. Formative assessment provides a sense of whether the project is on course or needs adjustments.

Some foundations are often reluctant to help organizations build infrastructure or hire new people to do projects. An ideal project for them is one in which the educational team is in place and the foundation’s money can be used to provide program services to an audience of particular interest to them. They are very interested in outcomes and the presence of an evaluator is important. Other foundations may be interested in creating leading edge (or cutting edge) programs that, if successful, can serve as a model for other organizations. Finally, some foundation-funded projects create instructional materials that can be replicated and distributed widely.

The key to successful foundation-funded projects is to understand the needs and desires of the funder. Often they favor very particular audiences and types of programs. If these types of programs are not the strong point of the proposer then often it is better not to try to propose for these areas. The funder also wants confidence that the team is in place and can do the project. However, they often do not want to fund a current project that is in progress. A new variation of the project or a new audience is needed. The funder wants clarity on what they are funding, what new things will be accomplished, and what the outcomes and impacts of the work will be.

Ideally, the outcomes will need to be tracked over several years, as it is unlikely in many projects that measuring change at the end of a few weeks or a semester is adequate. Long-term tracking of students is very expensive, though, and privacy concerns in the U.S. make tracking difficult. Some middle ground on measuring short, middle, and long-term outcomes is needed, unless the funder or the proposing organization is prepared to support long-term studies of outcomes related to the educational interventions.

Another critical issue for projects is their alignment to state and national educational standards and to the “Next Generation Science Standards”.¹⁹ In the U.S. all national and state projects must be responsive to the current and near-future standards in mathematics, technology, and science education.

8. CONCLUSION

The National Optical Astronomy Observatory has been active in optics education for over a decade and is very proud of its partnership on a number of large national and international optics education projects. NOAO has a talented education group in the U.S. and in Chile with skills in optics material development, teacher and classroom optics kit development, optics and photonics teacher professional development, and informal science education to support optics education. These activities would not be possible without our tremendously talented partners including professional organizations such as SPIE–The International Society for Optical Engineering, the Optical Society of America, the American Astronomical Society, and the Astronomical Society of the Pacific. A very important partner for NOAO is the National Science Foundation, our primary funder for core activities and for grant-based projects.

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