Teaching Optics Concepts through an Approach that Emphasizes the "Colors of Nature"

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ABSTRACT

A wide variety of optics concepts can be taught using the overall perspective of "colors of nature" as a guiding and unifying theme. This approach is attractive and interesting with a wide appeal to children, nature enthusiasts, photographers, and artists. This approach also encourages a deep understanding of the natural world and the role of coloration in biology, remote sensing, the aurora, mineralogy, meteorology, in human-made objects, and astronomy, to name a few. Third, using this theme promotes a close look at optical phenomena at all size scales–from the microscopic (e.g. silica spheres in opals) to the mid-scale (the aurora), to the largest scale (astronomical phenomena such as gaseous emission nebula). Fourth, the natural and human-constructed world provides accessible and beautiful examples of complex phenomena such as interference, diffraction, atomic and molecular emissions, Rayleigh and Mie scattering, illumination engineering, and fluorescence. These areas can be explored successfully in the context of "colors of nature". Finally, using the "colors of nature" also promotes an understanding of technology, from flashlights to streetlights, from telescopes and binoculars, to spectrometers and digital cameras. For examples something as simple as how to set the white balance on a digital camera to get a realistic looking photograph can lead to a lengthy exploration of spectrally selective surfaces and their reflectance, the nature of different illumination sources, the meaning of color temperature, and role of calibration in a digital image.

We have used this approach of teaching using the colors of nature as an organizing theme in our NSF-funded project "Project STEAM: Integrating Art with Science to Build Science Identities Among Girls" (colorsofnature.org).

Keywords: optics education, instructional materials development

1. INTRODUCTION

Science education is a highly experimental process. New approaches need to be pursued continuously in instructional materials development, curriculum development, science center exhibit development, and in educator professional development. While pursuing these approaches, care must be taken to understand and be responsive to the stakeholders and their values.[1] Approaches to science education evolve over time to be responsive to the changing audience needs. As organizations with significant federal funding, the National Optical Astronomy Observatory (NOAO) and the Geophysical Institute both have a strong commitment to community engagement, and to meeting the needs of their education communities. This community includes the broader country, and Arizona and Alaska in particular. For NOAO the audience for community engagement also includes Chile, where the southern hemisphere station of the U.S. National Observatory is located.

What communities should be served by federally funded research and development centers? This is an important question in that there are many formal and informal education communities worthy and needy of assistance. The formal education community (preschool to graduate school) has students, teachers, and school administrators as its stakeholders. Its most pressing needs are often centered on teacher professional development, curriculum development, and instructional materials development, areas where the expertise of scientists can be put to good use. The informal

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education community encompasses children's museums, hands-on science centers, more traditional natural history museums, planetaria, and science facility visitor centers. This community focuses on free-choice, lifelong learning, and its diverse stakeholders include a variety of museums. Some museums defy categorization, but do have science components to their exhibits and their programs. For example, experimental museums that combine art and science, such as the American Visionary Art Museum in Baltimore, are a key stakeholder and a valuable community engagement partner.

Research and development institutions are in a unique position to provide creative, high-level services consistent with their strategic mission to both formal and informal institutions. Many of these services can be effectively provided by programs that utilize science education trained graduate students.[2] There is also a need to encourage joint efforts between formal and informal institutions as a recent report[3] emphasized. In particular, science-rich cultural institutions (e.g. Geophysical Institute, NOAO, and science natural history museums) might adopt certain perspectives when helping schools:

- Science-rich cultural institutions need to value their work with schools; schools and teachers should not be viewed only as a "market" for field trips or paid programs, but should be treated as a highly valued stakeholder audience, with deep collaborations with K-12 schools.

- Valuing of education by science-rich cultural institutions also involves working with the more diverse populations of science learners and their families that exist in local public schools rather than the much less diverse "paying audience". Science-rich cultural institutions should be committed to diverse community schools rather than schools that are more typically attended by the children of their employees.

- There is a need for science-rich cultural institutions to provide science pedagogical leadership in afterschool or youth settings, and to contribute to the co-development of K–12 science curricula, instructional materials, and activities. Science-rich cultural institutions have unique skills and uniquely qualified people who can contribute in substantial and unique ways to the development process. Again, science education programs and partnerships that rely on well-trained undergraduate science majors and graduate students (e.g., the NSF GK-12 programs) can be highly effective[4]. Scientist-teacher partnerships are particularly good at promoting deep community engagement.[5]

- The research base on how learning in formal or informal settings can affects the other environment can be expanded. There is much commonality in how learning takes place in schools and in afterschool programs. For example, the formation of a science identity (i.e. valuing and identifying with science) in young students often first takes place outside the classroom. Science institutions value research and are ideal partners with Schools of Education for research on science learning and how science identities are formed in students.

Thus science-rich organizations bring special expertise to education projects based on their extensive science and research experience. This type of collaboration has led to research on science identity formation that forms the basis for our current "Colors of Nature" program.[6]

2. NEW STRATEGIES FOR ADVANCING OPTICS EDUCATION

The National Optical Astronomy Observatory (NOAO) and the University of Alaska's Geophysical Institute are leaders in creating facilities that provide support for long-term scientific efforts. NOAO provides a new generation of telescopes, instruments, and software tools to meet the research challenges of the next decade. The Geophysical Institute maintains a number of research stations of vital national importance, including Poker Flat Research Range.

Both organizations are committed to finding innovative ways to improve the science literacy of students and the public, congruent with the NSF education mission as described in its charter[7] and in its strategic goals: [8]

- "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."

To achieve these goals NOAO has created a photonics education program in Arizona[9] and has directed the creation of six informal science education optics kits as part of the Hands-On Optics project[10,11]. It has also created a citizen science program called Globe at Night on light pollution and illumination engineering[12], a specialized yearlong program to engage the public in optics[13], and instructional kits for the International Year of Light 2015.[14]

NOAO has also evaluated a variety of optics teaching resources available for middle school teachers[15] and explored innovative techniques for presenting content knowledge and high-quality pedagogical content knowledge for teaching about the electromagnetic spectrum.[16] NOAO was also involved in the International Year of Astronomy 2009 and in the creation of the Galileoscope telescope kits for IYA2009, of which over 220,000 have now been used.[17] This involvement in large, worldwide, public engagement projects was an invaluable experience in leveraging strategic partnerships. A vigorous undergraduate student-based mentoring and outreach programs was created in 2003. NOAO has aligned its programs with exemplary national education programs and teacher resource books[18] and NOAO staff have partnered in to create materials that describe pedagogical best practices for science teachers.[19]

A key to these large or even worldwide projects is an understanding of cross-cultural factors that influence professional development.[20] We have also examined some area that may be useful in science education efforts with Native American students such as those from the Tohono O'odham Nation, on whose lands the Kitt Peak National Observatory is located.[21] We also have relied on a deeper understanding of optics misconceptions[22] and of how we can assess the student's conceptual knowledge of optics using formative assessment probes.[23] We also take into account the naïve theories and misunderstandings that have been studied and analyzed in the hope that we can prevent the formation or reinforcement of misconceptions.[24] These educational tools have been used extensively by NOAO in the design of programs to teach illumination engineering[25] and in the detailed optical design of a high-quality student telescope kit that is user-friendly to people of all ages.[26] A larger summary of the extensive optics-related education programs at the National Optical Astronomy Observatory is now available.[27]

The University of Alaska Fairbanks is a leader in the creation of summer educational experiences for middle and high school students. For the last 15 years, the University of Alaska College of Natural Science and Mathematics has sponsored the Alaska Summer Research Academy (ASRA). ASRA provides in-depth experiences in science and engineering. The university also offers a year-round Saturday outreach program, and an "ASRA to the Schools" program during the school year, which reaches communities across Alaska through Community Science Nights. The mission of ASRA is similar in many ways to the NOAO education mission. The program promotes intellectual curiosity through hands-on experiences in science, technology, engineering, and mathematics (STEM). These experiences stress creativity, student-driven investigations, and problem solving. The program also helps to raise awareness of the great variety of STEM-related careers that are available.

The program model uses collaborative groups with mentors to engage students in the scientific process. The ASRA courses are two weeks long and emphasize small teams doing project-based learning. The classes are very small, usually with two instructors and ten students. The ASRA courses are innovative and highlight University of Alaska research themes such as permafrost, engineering design of remotely operated vehicle, the engineering of extreme energy sources.

Although NOAO and the University of Alaska have created similar programs in a variety of areas, there is one new approach that is highly promising, but was not previously explored by either organization. This approach involves extending the traditional combination of Science, Technology, Engineering, and Mathematics (STEM) by adding art-related programs and approaches. This new combination, STEAM, is the basis for our new approach using the "colors of nature" as an organizing theme and starting point.

Under sponsorship from the U.S. National Science Foundation, the University of Alaska (the Geophysical Institute and the Museum of the North) have partnered with the National Optical Astronomy Observatory and the University of Washington-Bothell to create a new 4-year program seeking to bridge the gap between art and science, and in particular between art-interested girls and science. The program is called “Project STEAM: Integrating Art with Science to Build Science Identities among Girls”[28] and is funded under the NSF Advancing Informal STEM Learning (AISL) program. It represents a new approach that the project team believes is needed to attract talented female students into the physical sciences. The project is known colloquially as “The Colors of Nature” and includes kit and activity development, professional development, and the running of two-week long summer academies in Tucson, Arizona and Fairbanks, Alaska. This new project builds on the strength of the University of Alaska in summer academies and in using science education research for program design. It also builds on NOAO’s strength in photonics education. The University of Washington-Bothell is the third partner and brings additional expertise in science education research to the team.

3. THE GAP BETWEEN ART AND SCIENCE

Why is such a program combining art and science needed? In the United States there are many concern about science education in primary (elementary) schools. In these grades, grades 1-5 in the United States, there is currently great pressure placed on teachers to have their students perform well on testing mandated by the “No Child Left Behind” Act. This testing process has diminished the teaching of science in primary grade schools. The teachers also are undertrained in teaching science, and particularly in teaching the physical sciences. These factors not only influence science literacy but also influence workforce development.

There have been proposed approaches to further workforce development using photonics education[29] but the problem of keeping students in the STEM pipeline remains. The upper elementary grades are also where many students leave the STEM pipeline as they have effectively opted out of STEM careers, having never met a scientist or really understood what science and technology careers are all about. To be clear, not all children make decisions at this level to pursue a particular career but many make a decision at this time *not* to pursue certain classes of careers. In middle school, the science education situation for girls is exacerbated, and by high school, course selection (not choosing mathematics courses) has largely precluded STEM careers for many female students.

Visual spatial skills are an important skill set shared by many artists and scientist. The research literature indicates that girls who lean towards art may have strong visual-spatial abilities that are applicable to science. If so, then these skills would serve them well in future science or STEM-related careers. However, there is a contrast in how boys and girls utilize these valuable skills. Most girls with this strong visual-spatial ability do not stay in the pipeline and enter STEM careers.[30] There is strong research that shows that girls lose interest in science starting in middle school.[31]

In the K-12 grade classroom, there is little discussion, demonstration, or explicit instruction on how visual-spatial reasoning and other artistic practices can be used in science, despite the strong overlap. Scientists have been found to utilize artistic practices to further their creative scientific work,[32] but this connection between art and science is not made in formal education settings. Our project is designed to make explicit this connection in both formal and informal education settings.

4. THE COLORS OF NATURE PROJECT

A number of inspiring books have helped set the stage for our “Colors of Nature” education project. Cyril Stanley Smith’s classic *From Art to Science: Seventy Two Objects Illustrating the Nature of Discovery*[33] showed that going deeper to study an individual object of beauty was a powerful approach to learning about metallurgy, ceramics, and material science. The scientific photographic of Fritz Goro[34] provided numerous examples of how images can be used to teach science, inspire students and give insights the process of science. The beautiful auroral photography in Akasofu’s popular book on the aurora borealis[35] and the diagrams and explanations in *Color and Light in Nature*[36] make a convincing case for the power of these atmospheric phenomena to inspire and teach.

The Colors of Nature project has as its core a two-week summer academy, modeled on the Alaska Summer Research Academies held in Fairbanks. The summer academies are held in Tucson and Fairbanks each summer and admit 30 rising 4th, 5th, and 6th grade girls. To provide the level of attention needed to this group, a large number of junior and senior staff members are needed. For example in the 2015 Summer Academies, there are four science or art graduate students, two science or science education postdocs, four undergraduate students who are majoring in science, plus four senior science education staff members. There are also independent evaluators present as well.

The program relies heavily on the student investigations and works hard to convey a positive message about the field of science. It also encourages students to conduct experiments and provides a supportive experimental atmosphere. One of the first activities in the program involves making Suminagashi (Japanese marbling) art prints in a stochastic process that promotes an acceptance of the experimental process. The participants create notebooks that are a combination science lab notebook + journal where they can record their observations and experiments.

The girls pursue several engineering design projects and use powerful tools such as an Ocean Optics fiber-fed near IR/Visible, near UV spectrometer. They learn about the functions of color in biology and begin to understand how different animals see in the visible, near infrared, and ultraviolet regions of the electromagnetic spectrum. They produce an animation on the functions of color and explore how animals use color as part of a private signaling system. From the physical science side, they learn about light sources, the reflectivity of surfaces, and some aspects of linear polarization. By experimenting in a room illuminated only with monochromatic light, they learn about spectral reflectivity. They also learn about light detectors such as CCDs and about a variety of animal eyes.

The final project has the students choosing an animal and examining how these animals use color in their environments. The animals are often combinations of some of the animals that they have studied. The students then design and create a costume that simulates how the animals interact with light. As part of this project, the students take photomicrographs of different part of their costume and measure the spectral reflectance of some of the fabrics that they use. The results are presented in a poster session attended by their families and by local scientists.

Follow-on activities to the Summer Academies include science cafes and field trips to labs on the University of Alaska Fairbanks campus or field trips to scientific stations such as Kitt Peak National Observatory.

5. PROJECT PHILOSOPHY

Using art and the colors of nature to teach about optics is a powerful approach because of it great breadth. The subject matter spans biology, the earth sciences, atmospheric science, astronomy, and any number of technology areas. Our approach to teaching with the colors of nature utilizes the same organizing principle as the Hands-On Optics program: "knowledge and wonder". [37] (This is also the title of an excellent book by V. Weisskopf). The theme that knowledge and wonder are fundamental to the exploration process, and that scientists and artist enjoy the exploration process is well expressed in the famous quote from Francis Bacon:

> "For all knowledge and wonder (which is the seed of knowledge) is an impression of pleasure in itself."
> *Advancement of Learning. Bk. I.*

Thus, exploration and the enjoyment of learning are our basic starting point. This principle is also especially valuable in informal or free-choice learning environments. Tools for exploration are essential in any program that encourages the development of skills necessary to do science. For example, experience at the San Francisco Exploratorium hands-on science center indicates that there are several key tools in the exploration process.[38] These include:

- Paying attention to things that most people ignore
- Touching what other people won't
- Comparing things
- Asking questions
- Experimenting to test your ideas
- Bringing lab partners
- Making predictions and testing your guesses
- Measuring and counting
- Keeping track of your discoveries and writing it down
- Explaining what you see
- Sharing your experiences

We encourage the students in our summer academies to use these exploration tools. We encourage others running similar programs to make these tools a fundamental part of any program combining art and science.

6. SUBJECT MATTER AREAS ACCESSIBLE IN THIS APPROACH

What areas can be taught using this approach? One of the best starting points for an exploration of the colors of nature is the Exploratorium book *The Color of Nature.*[39] The book classifies the color of the natural world in a sensible, easy to understand way using the following categories:

- Steady
- Glowing
- Shimmering
- Scattered
- Celestial

There are many ways to approach optics education using this colors of nature theme. Many optical phenomena are accessible using this approach. The colors of crystals, rocks, minerals, and gems can be magnificent and scientifically intriguing. There are the colors of ice and snow, polarized views of ice, flame spectroscopy colors, and the colors of fireworks. The colors in astronomy are a topic that deserves a paper by itself, so will not be addressed here.

Here are a few areas that have proven to be useful.

A. Light Sources

The nature of ways that light can be produced is a fertile topic. Some basic investigations of sunlight, auroral light, incandescent bulbs, etc. can be a useful introduction to spectroscopy. We have found that using a spectrometer and printing out the spectral curves is particularly valuable, especially if the color of light associated with each wavelength can also be represented. Using a simple digital spectrometer (or even a hand-held non digital spectrometer) can be a wonderful way for students to investigate light sources. Some of the spectrometers we have used effectively are the Ocean Optics Red Tide Spectrometer (with spectral sensitivity from 350-1000 nanometers) and the Project STAR handheld spectrometer, which has a good grating and a scale that can be calibrated by aiming the spectrometer at fluorescent room lights (to measure the position of the Hg lines). Bioluminescent light sources are another exploration topic.

Figure 1: Creating light paintings using a time exposure image from a digital camera provides a creative way to understand light sources.

B. Coloration in Biology

The key biological area of how animals and plants use color is an interesting subject matter area. Some animals use color for camouflage, warning, mimicry, mate attraction, dazzle, temperature regulation, and counter shading, to name a few. Many interesting explorations can be made around the basic uses of coloration in biology. How animals see colors is an interesting area. It includes color perception by birds, insects such as bees, and intriguing animals such as mantis shrimp. The structure of animal eyes is also a rich topic. The absorption spectrum of the chlorophylls is a powerful starting point as well for understanding the color of plants. Skin color in humans is another important teaching topic that can be approached.

We have found that the use of a spectrometer sensitive to visible and near infrared light is valuable in these studies. Reflectance spectroscopy provides an easy technique to quantifying coloration in biology. However, it is very important to illuminate the object using a broad-spectrum light or to remove spurious signals from room lights.

C. Animal Eyes

The nature of animal eyes can be explored in detail. Both vertebrate and invertebrate eyes can be investigated and particular attention can be paid to the light sensing structures, the shape or nature of the pupil (if any), and the types of photoreceptors and their spectral sensitivity curves. Of particular interest in determining how the organism senses the world are the number and response curves of the photoreceptors. All of these topics can be related to the function of the eyes of a particular species. Eye dissection can be done for cow eyes, which are readily available from biology supply houses. Eyes of insects or invertebrates can also be studied or dissected, especially with the aid of a stereo microscope. The eyes of fish, scallops, and arthropods are particularly informative. The discussion can be broadened to discuss how digital cameras work, the nature of their filters and filter arrays, and the process by which digital cameras record color.

D. The Electromagnetic Spectrum

A discussion of the colors of nature that focuses only on the part of the electromagnetic spectrum that can be seen through human vision will be limiting. Given that many animals have a wider spectral sensitivity than humans, it is very useful to broaden the discussion to include the ultraviolet and infrared portions of the electromagnetic spectrum. To place the infrared, visible, and ultraviolet regions in context, the entire electromagnetic spectrum can be examined. With modern imaging devices, it can be very helpful to show illustrations of how the world might look in various wavelengths.

The book *Exploring the Electromagnetic Spectrum with Imaging Technology,*[40] though slightly dated by improvements in imaging technology, provides many fine examples of how objects appear in different wavelengths. The examples include visible and infrared images of paintings as well as typescript that give insights into art restoration and art forensics. The book also includes many visible plus near ultraviolet images of polar bears, skin cancer, arctic camouflage, Black-Eyed Susan flowers, butterflies, coral reefs, and fish. It also includes a number of images showing short-wave infrared, visible, and near ultraviolet images of the eye and a face.

There is also an extensive collection of thermal infrared images, as well as x-ray and gamma-ray based images. The concept of "alien vision" and "invisible light" are explored in detail in a way that encourages further experimentation and promotes an excitement about the uses of the electromagnetic spectrum. The Great Explorations in Math and Science (GEMS) program at University of California, Berkeley created a guide on the electromagnetic spectrum that is full of multi-wavelength images and explorations appropriate for a middle school audience.[41] This teacher's guide was extensively tested in classrooms and is widely used by classroom teachers and museum educators. A teaching kit with all of the needed teaching materials can also be purchased to accompany the guide.

Figure 2: Using shadows created by multiple lights is a basic light-oriented exploration with broad implications for studies of the colors of nature. In this case students were asked to find ways to create specific color shadow patterns.

E. Structural Color

Although color produced by the constructive and destructive interference of light might seem to be a difficult topic for young students, it is actually a very accessible area since examples of structural color are widespread. Soap bubbles are easy to experiment with and to examine in a white light or a monochromatic light environment. There are many ways to create to long-lived soap bubbles with glycerin so that they can be studied at leisure. Many materials with colors due to small, regular patterns can be studied as well. These include opals, iridescent feathers (such as in the barn swallow *Hirundo rustica*), mother of pearl materials (aragonite), and insect wings. In particular butterfly wings and damselfly wings are easy to study for interference effects, and scientific references on their detailed structure is readily available. Many fabrics are iridescent and rely on structural color to create their special effects.

F. Atmospheric Colors

Francis Bacon remarked that "The beholding of the light is itself a more excellent and a fairer thing than all the uses of it" (*Novum Organum, Book 1*). Modern day technologists may not agree, but there is a strong case to be made that one should develop an appreciation of light and color in nature through observation skills.[42] The range of possibilities is rather large. It includes the colors of the aurora, noctilucent clouds, airglow, colors in clear air and the blue sky, and various sunset and twilight phenomena such as the alpenglow and the green flash. It also includes optical phenomena from water drops such as rainbows, and polarization/depolarization effects. There are a variety of colorful phenomena such as glories, parhelia (sundogs), and pillars. Scattering effects produce a variety of colors and can create more unusual phenomena such as the "blue moon". Other phenomena include lighting, sprites and jets, and atmospheric ice effects.

G. Color in Art

The classic explorations of color in art are quite useful to explore deeply, and it leads into many scientific areas. The use of language to describe color is a deep issue with many scientific overtones. For example, why is the current system of naming of the colors in the spectrum used? Other basic topics include: additive and subtractive colors, the chemistry and the history of pigmented color, color illusions, Rayleigh and Mie scattering in painting, color blindness, and fluorescent materials in art.

H. The Making of Pigmented Color

Pigmented color (as opposed to color induced by nano-structures) is a fascinating topic. There are many good references in the area of historical ways to create the common colors. For example, the book *Color in the Making*[43] provides many excellent discussions of natural pigments and synthetic colors. The origin and preparation of natural pigments such as carbon black, ochre, lead white, azurite, malachite, orpiment, realgar, verdigris, vermillion, ultramarine, indigo, and woad make interesting starting points.

7. THE ZOOMING APPROACH

How does one approach teaching about structurally produced color? One approach to give structural color due to interference and diffraction their due is by using a zooming approach, through the use of scale. A zooming approach allows the student to observe the obvious large-scale phenomena first, and then to hone in on the origins of the colors. For example, take the colors of butterflies. First, it may be useful to explore the larger context of butterfly behavior and color. This would involve observing butterflies in the field to set them in a larger biological and environmental context. A deeper understanding of butterfly behavior and ecology can take place through the tools of exploration discussed earlier. Once the broader view of a butterfly is established, a close-up study of butterfly coloration can be done. This can then lead to an examination of coloration patterns using binoculars or hand lenses and then later to an examination of a butterfly wing using a light microscope. From these observations with a magnification of about 20 to 150 times, one can see the array of colored scales. Finally the surface microstructure of the wing can be studied using scanning electron microscope photos. These micrographs reveal the nano-structure and give a sense of how light might interact with these structures.

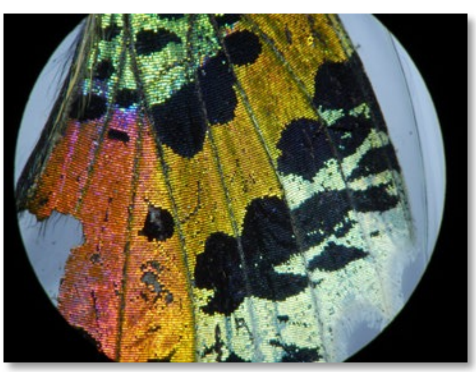

Figure 3: A zooming approach to studying a butterfly wing yields a remarkable image that can be studied in detail. This one was taken through a simple microscope using a basic digital camera. The butterfly wing scales on this image can be compared later to scanning electron microscope photos of the smaller structures inside the scale that diffract light can create iridescence.

The zooming approach encourages the use of varied tools and instruments. Being a scientist means utilizing scientific tools to amplify your effectiveness in the exploration process. These tools can be as simple as flashlights or hand-held magnifying lenses. They can be as sophisticated as telescopes, sensitive spectrometers, and electron microscopes. One very accessible area is to use basic available laboratory teaching tools. We have had great success integrating varied light sources (e.g. monochromatic lights), polarizers, binoculars, hand lenses, CCD-based spectrometers, and digital cameras into our explorations.

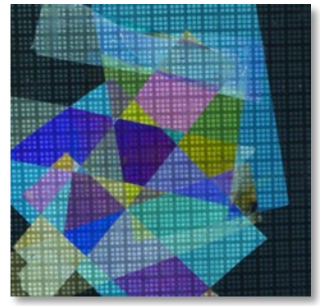

Figure 4: Basic polarization exploration activities using birefringent plastic materials and crossed polarizers are a prelude to more complex explorations using biological specimens or petrographic thin sections of rocks.

Technology explorations can also be used to address simple questions that lend themselves to deeper explorations. For example, something as simple as how to set the white balance on a digital camera to get a realistic looking photograph can lead to a lengthy exploration of spectrally selective surfaces and their reflectance, the nature of different illumination sources, the meaning of color temperature (correlated color temperature), and role of calibration in a digital image. Many of these explorations begin with he use of simple technology coupled with an understanding of the basic phenomena. Later, these approaches can be extended into more complex biological systems.

8. PROGRAM ASSESSMENT

Program assessment is important for any educational program. The program should be evaluated against the overall program goals and objectives (e.g. the acquisition of specific content knowledge). In addition to this there should be program "metrics" where the number of participants, the time on task, and other variables are counted. Program assessment ideally should be designed to measure specific performance gains related to a particular intervention. To keep a program on task with its goals, most 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 in detail before the program begins. Indeed the evaluation can be designed even before the program is designed in detail.

In the United States, a critical issue for science education projects is their alignment to state and national educational standards and to the "Next Generation Science Standards".[44] In the U.S., projects must be responsive to the current and near-future national standards in mathematics, technology, and science education or educators will not use them.

9. CONCLUSION

For the last decade, the National Optical Astronomy Observatory has been a key partner on a number of large national and international optics education projects with organization like SPIE–The International Society for Optical Engineering, the Optical Society of America, the American Astronomical Society, and the Astronomical Society of the Pacific. Over the last 15 years, the University of Alaska has created well-respected summer academies that encourage innovation and experimentation. Recently the two organizations have teamed with the University of Washington-Bothell to create an innovative program that combines art and science. We have developed this new project with the goal that we may make science more interesting and appealing to girls, and especially to girls with strong visual-spatial skills. By combining art and science through "The Colors of Nature", we hope to create a new approach that has wide appeal and significant utility to our efforts to create a more science literate society, and a more diverse scientific workforce.

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