Bringing the *Two Cultures* together through *A World of Light and Color*

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Abstract:

In the United States, the undergraduate general education curriculum by and large requires students take courses from the arts and humanities as well as the sciences in order to produce well-rounded or liberally educated individuals. This educational philosophy is in line with C. P. Snow's recommendation for increased communication between the "two cultures", though the exchange of ideas may not be optimal as one would like. Most colleges and universities expect undergraduate students to take introductory science courses, sometimes designed for non-science majors. In our experience, many of these students are inadequately prepared in science and mathematics, and have weak attitudes about the nature of science and scientific inquiry. We find students in traditional lecture classes eventually lose interest in these content-driven courses, fail to see the relevance of the material they learned, and miss out on the excitement of scientific discovery.

To address these concerns, we created a single-theme, general science course with the help of government and institutional funds in which non-science students engage in simple activities designed to help them understand basic light phenomena. In our course, *A World of Light and Color*, students learn how to think like scientists rather than simply learn about science. It is this sense of student ownership of learning coupled with carefully crafted curricular material inspired from physics education research that has made our course very successful and measurably effective. In this paper, we will present our development model, outline the structure of a typical class, provide examples of activities, and discuss assessment strategies and results.

Introduction

Fifty years ago, C.P Snow delivered his lecture, *The Two Cultures and the Scientific Revolution*, in which he spoke at length of the mistrust and differences between scientists and literary intellectuals. As a well-respected Cambridge physicist and novelist, Snow had all the credentials and experience to tackle this unspoken subject. That, of course, did not spare him from criticism, and four years later in 1963, he wrote a book *The Two Cultures: and a Second Look* as a follow-up to his lecture where he clarified some of his earlier statements and reemphasized his main thesis. Snow argued that the lack of communication between the two groups, better described in contemporary terms by intellectuals from the arts and humanities, and science and technology, poses a serious challenge to solving problems that plague society, and thus presents an obstacle to improving the quality of life locally and globally (Snow 1963, 90). In fact, he lamented not calling the original lecture "The Rich and the Poor" (p. 74), which would have preserved his end goal. As an academic, Snow viewed education as the key to bridging the communication gap between the two groups so that society as a whole can prosper (p. 23). He did realize that his vision was colored by his experiences in Europe, in general, and in the United Kingdom, in particular (p. 66). Snow noted the divide between and the different cultural mindset amongst the two groups was much smaller in the United States primarily because of the educational system (p. 66). Nevertheless, the divide was, and, to some extent, is still present.

In many parts of the world, students are required to choose their major field of study and then exclusively work in that field. This form of early career specialization has its advantages but has also lead to the kind of problem Snow describes in his lecture. In the United States, students follow a general education curriculum in high school all the way through their undergraduate degree after which point they specialize. The reduced rigor in a major field of study at the undergraduate level is remedied once students go to graduate school. Most colleges and universities have undergraduate general education curriculums that typically require students to take courses from the arts and humanities as well as the sciences in order to produce well-rounded or liberally educated individuals. We define a liberally educated person as one well grounded in the arts and humanities as well as science and technology and who is a global citizen capable of thinking critically and acting humanely. Whether the United States educational system is successful in producing such a student maybe debated, but at least the educational philosophy is in line with Snow's recommendation for increased communication between the "two cultures."

In the United States, science undergraduate students enroll in far more courses from social sciences, arts, and humanities than non-science majors do in science and mathematics. Perhaps nothing can be done about this inequality. However, if the courses non-science students enroll in sour them on science, then no good comes of this arrangement. A brief review of United States society shows that people with little or no scientific background are more likely to be policy and decision makers than science students. For example, a report from the Congressional Research Services for the 110th U.S. Congress (Amer 2008) shows that out of 540 members, there are only three physicists, three chemists, one microbiologist, and one biomedical engineer, which represents less than 2% of the total number of congressional delegates. There are 23 additional members who have professional degrees that require a science background; namely, thirteen medical doctors, three nurses, two dentists, two veterinarians, one psychologist, one pharmacist, and one optometrist. This represents another 4% of the total. That leaves well over 90% of the members of congress with little or no experience with science, technology, engineering, and mathematics (STEM). How can they make informed decisions and shape policies regarding complex and deeply science-based issues such as global warming or stem cell research? The composition of the United States Congress is, perhaps, a best reflection of the nation and so the same set of questions can be asked of any citizen. Clearly, if we fail to effectively and enthusiastically educate non-science students, we do so at our own peril.

The failure to act is a critically important problem. We have witnessed for years repeated calls to raise American students' scientific literacy and expand our STEM workforce. Almost two decades ago, the American Association for the Advancement of Science called for improving broad science literacy (Rutherford and Ahlgren 1989). More recently, the influential publication *Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* brought the issue of improving science literacy to forefront again (The National Academies 2007). A well-respected Professor of Physics, James Trefil in his book, *Why Science*, summarizes a bleak situation and calls for reform in education directed at augmenting our nation's scientific literacy (Trefil 2007). These are just a few of the many examples of concern raised by various individuals, commissions, and organizations. Despite this, nationally very few general science courses have been redesigned to specifically accomplish such objectives. In this paper, we present a novel and measurably effective pedagogical method that helps non-science students learn and appreciate science. The proposed method will increase our understanding of what can be done in college classrooms to improve the national level of science literacy and to draw more college students, particularly those from underrepresented groups, into the STEM pipeline.

Most colleges and universities in the United States expect undergraduate students to take science courses at the introductory level where the mathematical rigor is kept to a minimum. Sometimes, these courses are specifically designed for non-science students. In our experience, many of these students are inadequately prepared in science and mathematics, and have weak attitudes about the nature of science and scientific inquiry. Traditional science courses are content-driven and the instructors lecture and occasionally perform demonstrations. Non-science majors quickly lose interest in such courses, fail to see the relevance of the material they covered, and miss out on the excitement of scientific discovery. What is more shocking is that traditional lecture courses are by many measures ineffective. A whole new field has emerged about two decades ago in the physics community focusing on education research and there is a wide body of literature on the subject. For an in-depth review of the field, we recommend the *Physics Education Research Resource Letter* by L. McDermott and E. Redish (1999), and the *Millikan Award Lectures* by P. Laws (1997a) and E. Redish (1999).

To address these concerns, we created a single-theme, general science course with funds from the National Science Foundation and McDaniel College in which non-science students engage in simple activities designed to help them understand basic light phenomena. We had three major goals in developing this course: (1) help non-science students develop a positive attitude towards optics, in particular, and science, in general; (2) provide non-science students with a solid understanding of the scientific endeavor, to help them make intelligent and informed decisions regarding science-related issues; (3) improve students' critical thinking abilities and conceptual understanding of optics. We compiled students' reactions at the end of term, conducted focus-group interviews of students to improve course content and structure, had our entire project externally evaluated by an expert in the field of physics education research (Dr. Karen Cummings), closely studied improvements to their conceptual understanding of light and color, and analyzed changes in students' attitudes and beliefs about science.

In our course *A World of Light and Color,* students learn how to think like scientists rather than simply learn about science. They develop skills and gain confidence in their ability to investigate and logically postulate about the physical world. To accomplish this, we take students through a three-step learning process. First, students confront their ideas, which are often deeply held misconceptions, about various optical phenomena by making predictions of possible outcomes for a given activity. Such intellectual commitments help students clarify their thoughts on the matter; whether the predictions are correct or incorrect is not important. Second, students perform the experiment and record the outcomes as well as any differences between their predictions and the results. Finally, a class discussion helps establish the laws governing the optical phenomena under investigation.

This sense of student ownership of learning coupled with carefully-crafted curricular materials inspired by physics education research techniques has made our course very popular. Specifically, we fused the prediction-observation-discussion routine of Interactive Lecture Demonstrations (Sokoloff and Thornton 1997) originally designed for large classrooms, with the more intimate setting of Workshop Physics (Laws 1997b) and Tutorials in Physics (McDermott et al. 1998). We have measured the improvements in student's conceptual understanding of light and optical phenomena through a 15-item free-response survey. We also administered a 32-item attitudinal survey in order to assess whether our method of instruction positively affected the attitude of general science students concerning the acquisition of scientific knowledge and the nature of science. In this paper, we will present a detailed description of our curricular model, outline the structure of a typical class, provide examples of activities, and discuss assessment strategies and results.

Student Population and Course Enrolment

McDaniel College is a selective, four-year, residential, private liberal arts college with a long history of excellence in liberal arts education. The College has a diverse student body of about 1700 undergraduate students. As part of the "McDaniel Plan", each student must enroll in three courses from the natural sciences and mathematics. One of the hallmarks of a liberal arts college that distinguishes itself from large universities is the close interaction between students and faculty. This statement is exemplified by the small number of students permitted to enroll in a given course. At McDaniel College, most courses are limited to twenty students. In a *World of Light and Color*, we felt that having a maximum of twenty students working in groups of two would give us the level of interaction we desire while still serving the most non-science students. Enrolment in the course varied from 11 to 24 during the eight semesters it was offered as part of the NSF grant, and 75% to 100% of the students in any given class were non-science majors. For the past four years, we have exclusively offered this course as a First Year Seminar (FYS) for incoming students where the enrolment is limited to 15 students.

Course Structure and Composition

Our classroom has six long rectangular tables, each with sufficient room to seat four students and accommodate equipment and materials for two groups. The course meets for three, one-hour periods per week. Each activity or portion of an activity is designed so students have time to complete the task in an hour without feeling rushed and have ample time to engage in discussions. Since students have different abilities and progress at different rates, we sometimes hire learning assistants to help keep the class on track. Students work collaboratively as they progress through each step of the activity and the instructors try to ensure all students contribute more or less equally. In what follows, we will describe a typical day.

There are four components to each class activity: doing preparatory work, making predictions of experimental outcomes, recording observations, and discussing the results. Students must complete the Preparatory Work (PW) before coming to class whenever they begin a new activity. This occurs about every other class period. Each PW contains a relevant reading assignment and follow up questions about the optical phenomena they will be investigating in class. The questions in the PW are designed such that students cannot find the answers from the text directly; rather, they have to use their own understanding and what they gathered from the reading to answer the questions. The purpose of the PW is to help ensure fully students read the material before coming to class so they are familiar with the terms and have a rough idea of the main topic. At this stage, we do not expect insightful or necessarily correct responses and so we grade the PW leniently. It is a simple grading scheme ranging from a student receiving 0 (for no work), to 3 (for serious effort on the entire set). We collect, grade and a return each PW by the following class.

Students have two workbooks that they must bring to each class, one contains the Prediction Sheets (PS) and another contains the Procedure and Results Sheets (PRS). When class begins, the students open the PRS workbook and read the key questions to be addressed in the activity. They then go over the materials checklist, follow any safety procedure, and carefully read the activity instructions. Once students become familiar with the experimental setup and before they actually do the experiment, the PRS instructs them to make predictions in the PS workbook. At this point, the students enter the three segments of the *prediction phase*. In the first segment, students make a personal prediction on the PS; typically, the predictions take the form of a drawing, coloring, or short answers. In the second segment, students discuss and often debate their predictions with their table mates. Thereafter, students can modify their predictions if they are so inclined. The first two segments of the prediction phase are quite lively and the instructor walks around the room observing and engaging the students in dialogue regarding their predictions. The discussions eventually subside and the class enters the final segment of the prediction phase where the instructor solicits several predictions from different groups. The predictions are offered voluntarily and/or elicited by calling on specific students based on the dynamics of the class. Presenting public predictions can be daunting for some students, so to encourage them we do not require that they present their own predictions but, instead, can offer the consensus developed in their group or table. Time permitting the instructor records some of the predictions on a whiteboard at the front of the class. In this manner, students can be aware of the similarities and differences in the viewpoints held by their fellow classmates. Sometimes, they will discuss and critique the class predictions but more often students are just anticipating the experiment. In a sense, the prediction phase correlates with the traditional hypothesis formulation that is part of the so-called scientific method of investigation. Without realizing it, students have engaged in a first step of doing science.

After the prediction phase, the PRS instructs the students to perform the experiment in what we call the *observation phase*. This is perhaps the most interesting and exciting part of the activity because students witness what really happens and see if their predictions were correct. The instructor walks around and makes sure students perform the experiments and record their observations accurately in the PRS. It is very important that students record what actually happens and not what they expect to occur. In very real terms, the observation phase forms a critical component of scientific investigation where one carefully conducts experiments and tests their hypothesis.

The students cycle through the process of making predictions followed by observation and recording, testing the same phenomena over again in various configurations throughout the activity, after they enter the *discussion phase*. At this juncture, there are discussion questions on the PRS that allow students to consolidate their observations under one unifying physical theme. We encourage them to discuss the observations and debate answers to the questions with each other first, which is followed by a class-wide discussion. In this way, students are exposed to the various notions others have regarding the same observation. Through the discussion, the class often comes to a correct conclusion (or conclusions) about the phenomenon and agrees about the major governing concept. When there is agreement, the instructor restates the major conclusions in simple terms so all the students can record them on their PRS. In those rare occasions when students can not agree to a unified answer, the instructor makes observationally based remarks to guide the class toward the correct idea without forcing students to jump to it. This latter situation seldom arises because we have chosen the topics and experiments carefully to avoid ambiguous results.

Each activity has several *Prediction-Observation-Discussion* cycles. Since we designed the class time to be an hour long, several of the topics span two or more periods so students are able to assimilate the material and display an understanding commensurate with our goal. Interestingly, students in our class do not take notes similar to traditional classes; all the information they accumulate on the PRS serve as their class notes. Although the in-class work is very nontraditional, student testing and assessment are similar to most other courses. There are about ten homework assignments, each having an equal mixture of short-answer questions, numerical problem solving, and conceptual drawings. There are three short quizzes, three hour-long exams, and a comprehensive final. The exams and quizzes are structured similar to homework, and are tailored to probe their basic understanding of the subject, as well as their ability to apply what they have learned to situations not directly covered in class. Students in the FYS course also have to write a research paper on an optics-related topic of their choice by following a detailed rubric. Critical thinking and deductive reasoning abilities, as well as clear written communication are things we nurture in our students in *World of Light and Color*.

Examples of Activities

We developed a wide variety of activities in optics and gathered them under a few themes students can appreciate. This allows students to get the best possible exposure to the subject while seeing the main ideas that connects each activity. Table 1 shows the topics we cover in our class and how many class periods we spend on each activity. Those familiar with the subject will recognize most topics as part of a standard undergraduate optics course. The major themes covered are the basic properties of light, geometrical or ray optics, and physical or wave optics. The reader will also note that there are more activities dealing with geometrical optics than physical optics. The reason for this is that students are much more familiar with everyday geometrical optics, whether it is through the use of a camera or simply wearing prescription glasses. These concepts are also more intuitive and the experiments more tactile, which help students build confidence in their experimental skills. Towards the end of the semester, we cover sundry topics ranging from ophthalmology, geology, to relativity.

Table 1. The various topics in A *World of Light and Color* appear in the thematic blocks.

Activity	Number of classes
Basic Properties of Light	
Introduction to color and wavelength	2
What lies beyond the visible?	2
Reflection, absorption, and transmission of light	1
The inverse square law of radiation	1
The mixing of colors: addition and subtraction	2
Geometrical Optics	
Shadows and eclipses	2
Reflection of light and image formation from flat mirrors	2
Reflection of light and image formation from curved mirrors	4
Refraction of light and Snell’s law	2
Total internal reflection	1
Basics of fiber optics	1
Refraction of light and image formation by a lens	4
Telescopes and microscopes	2
The pinhole camera	1

Physical Optics and Polarization	
Introduction to waves: reflection and superposition	3
Waves in a ripple tank	1
Optical diffraction of lasers	2
Optical interference of lasers	2
Polarization of light	1
Other Topics	
Human eye, fluorescence of minerals, relativity.	3 or 4

Students enjoy the two-day activity on shadows where they learn about shadow formation and then apply that knowledge to understand solar and lunar eclipses. For this low-tech exercise, students use a strong lamp as the source of light, a small wooden cylinder as the object, and a piece of white cardboard as a screen. The PRS guides them to make predictions and observations about the nature of the shadow when the object is near the screen, and the lamp is first close to and then moved far away from the object. The students use the concept of light rays to develop models for these two and other configurations of the source and object. They discuss and record the types of shadows they observe, namely, the umbra and penumbra. Discussion questions follow where students are asked to explain the formation of solar and lunar eclipses. Then they study the differences between point sources of light, like stars, and extended sources of light, such as lamps in close proximity to the observer, and the effects these sources have on the nature of shadows. On the second day of the activity, they study the nature of shadows cast by multiple sources where the phenomenon of umbra and penumbra appear more distinct. The activity culminates with students combining their knowledge of shadows from this activity and color addition from a previous activity to predict and observe colored shadows. After these two days, students have a better understanding of shadows in general, eclipses in particular, and can grasp why some shadows look light bluish on a clear, sunny day.

As a second example, we present a novel pinhole camera activity in which students play the role of the film. In this low-tech exercise, students use a stand holding a piece of cardboard with solid objects printed on it (this serves as the object), a 10-gallon aquarium, an opaque piece of paper with a small hole (aperture), transparency sheet (screen), and markers. They fix the aperture on the outside of the aquarium, place the stand about half meter from the aperture, and attach the transparency sheet on the side of the aquarium that is opposite to the aperture. Students look from the back of the aquarium through the transparency sheet and through the hole directly on a tiny portion of the object. After they carefully line up their sight, students make a dot on the transparency sheet with a marker wherever they see the object boundary. This is illustrated in Figure 1. Students repeat this process many times until a pattern emerges. When they look at the transparency sheet from inside the aquarium, they discover the inverted nature of the image for a pinhole camera. The one-to-one relationship between points on the object to points on the image becomes clear immediately. By simply switching the location of the holed paper and transparency to the smaller dimension of the aquarium, students discover how the size of the image depends on the aperture-screen distance. When they enlarge the aperture and repeat the experiment, students find a much fuzzier image emphasizing the relationship between hole size and image clarity. Discussion questions in this activity relate to cameras and the human eye for which the pinhole camera serves as a basic model.

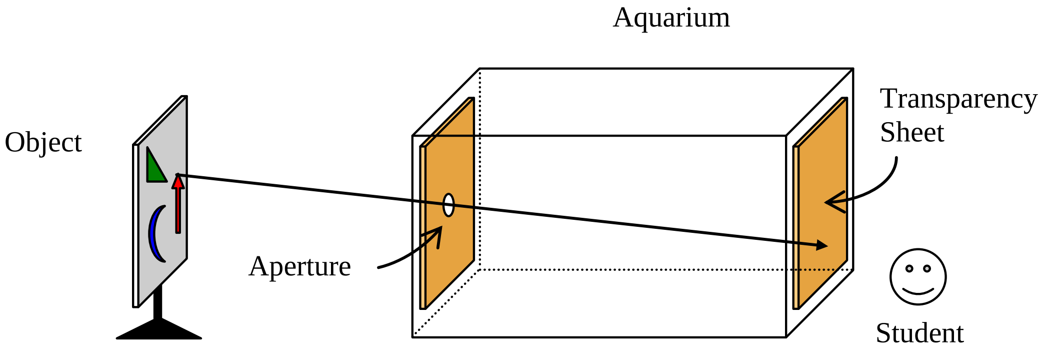

Figure 1. This picture represents the arrangement for the pinhole camera.

As a final example, we present a mixture of low and high-tech activities involving spectroscopy. Some of the key questions in the activity include whether the pattern of colors produced by a source can be related to its chemical composition. On the first day, students use a low-tech hand-held spectroscope to study the light emitted from an incandescent light bulb, a florescent light bulb, a mercury lamp, a sodium lamp, and two different kinds of red lasers whose subtle variations color cannot be picked up by the naked eye. Students are asked to predict the color spectrum first based on their observation of the sources. For example, all students predict the full visible spectrum for both the incandescent and florescent bulbs. They are shocked to discover that incandescent bulbs produce a continuous distribution of colors across the visible spectrum, whereas fluorescent bulbs produce light in specific bands in the visible, notably, red, green, and blue. This leads to a discussion of human eye physiology and color perception. They learn the light emitted form mercury and sodium lamps also occur in bands, and lasers produce bright single colors that can be distinguished even though they appear to be the same color by eye. On the second day, students use a high-tech USB computer interfaced spectrometer to repeat the activity and correlate their observations from the previous class. Students clearly observe that incandescent bulbs generate most of their light in the infrared, which apart from giving a sense of warmth, cannot be seen by people. Students are then asked why the lighting industry is moving from traditional incandescent lamps to fluorescent or halogen lamps. The advantage of using the USB spectrometer over the hand-held spectroscope is that it shows light in the ultraviolet and infrared region of the spectrum in addition to visible light. The spectrometer also shows the relative brightness of certain colors which is difficult to gauge using the hand-held spectroscope. Students gain an appreciation for the USB spectrometer after they have used the hand-held spectroscope since the former device is simply a more sophisticated version of the latter. At the end of the activity, students learn that the origin of light be related to fundamental excitations of atoms and molecules and can therefore be used as valuable fingerprint.

Our Experiences in Teaching a Learner-Centered Course

The active-learning environment we create in *A World of Light and Color* poses several challenges for the instructor, particularly in the area of involvement. The instructor must carefully choose their participation level because too much will ruin the value of the pedagogical method, and too little will frustrate the whole class. The activities we developed have explicit places for instructor involvement and student discussions, and still others indicating for the whole class to stop so all groups can catch up. In this manner, the instructor can assume an engaging position that preserves the pedagogical intent. In what follows, we reflect on our experiences and offer suggestions for those who may want to implement this form of learner-centered course.

It is critical to foster an open intellectual environment where students feel comfortable speaking. If students feel uneasy or fear ridicule, then they will most definitely not participate in class. Recall, offering and discussing predictions is a key element of the *prediction phase* and is vital to their learning. It is at this phase that students often face their deeply held beliefs or misconceptions. The instructor's role is to carefully referee the exchanges so there are civil and considerate evaluations of predictions and discussions. Many predictions will simply be wrong, but that is alright since the ideas generated through the discussions will benefit the entire class; even incorrect answers have a place in the classroom. The instructor must set the standard on how to evaluate various ideas politely and openly.

During the observation phase, students often ask what they should record because they have a certain model in mind when they make their observations. Every now and then their experimental data and expectations do not match and this tends to confuse them. It is very important to define and discuss the differences between *ideal* and *actual* results. A notorious example of this case occurs in the activities dealing with color addition and subtraction. In these experiments, the color students see is often not the color they predict because their expectations are based on a model that treats the filters as ideal or perfect. For example, an ideal blue filter will only allow blue color to pass but a real plastic filer will also allow some green and even some red to pass as well. We use this exercise as a learning opportunity by teaching students that models have limitations and once they know the range of its validity, they can make even more productive predictions. It is essential students record what they observe and not what they expect. Sometimes students will look at the same data but will record different information and so the instructor should visit each group and make sure they agree on what they are recording.

We cannot emphasize the importance of preparatory work enough; it is simply an indispensible part of the learning environment we aim to create. If students came to class unprepared, the dynamics of whole class would suffer. The PW forces students to think about the material before coming to class and allows them to spend class time more effectively. We found developing good preparatory problems to be quite challenging. On the one hand, we want students to be able to do the PW, and, on the other hand, we want them to really think about the topic. Ultimately, we decided to make the PW relatively easy to prevent frustrating them with material not yet covered in class, but, perhaps, a more thought-provoking PW is in order.

Another crucial strategy we employed was to focus each cycle of prediction, observation, and discussion focus on one concept. Too many concepts in a given cycle prevent students from drawing a coherent picture of the phenomenon. Also, each activity contained only one or two optical principles. Our goal is to instill in students that one or two broad ideas govern their observations rather than a mixture of disconnected specific examples. This approach plays into the tenet that scientists look for overarching principles that can explain multiple observations.

Finally, most of our activities do not require computer interfaces. We recognize the value of computer-based experiments, but for the kind of course we developed a less technology oriented track seemed appropriate. We felt that it is important for our students to have sense of ownership of their observations rather than rely on what the computer tells them. The non-science students to whom we cater the course are not experienced in using the computer for experimental data collection, and lack an understanding of physical phenomena. Trying to master computer interfacing and learning concepts at the same time is difficult and would perhaps damage the very nature of the course. After all, our goal is to educate non-science about science so they can make informed decisions that affect the public good.

Student Reactions to the Course

During the two-year NSF grant period, we solicited feedback from students from eight sections of the course by having them respond on written evaluations forms at the end of the semester. We also conducted focus-group interviews with three to four students at the midpoint of the semesters. Students were asked to comment on the overall format of the course, as well as indicate any problems with individual hands-on activities. We compiled the students' comments and considered them carefully while implementing improvements to the activities. The evaluation forms indicated students' enthusiasm for the course structure and content. Some excerpts from the course evaluations follow:

> "I was very anxious about taking a science course in college, but Dr. Marx made science fun."
>
> "Everything was planned really well"
>
> "Dr. Pagonis was a very helpful teacher. If anyone needed help, he did not hesitate. I felt comfortable asking questions in class."
>
> "Instructor's teaching allowed for highest level of learning"
>
> "I liked how Dr. Mian had us predict, do the experiment, then explain what was really going on."
>
> "Great course! Interesting and fun!"

Students were also asked the question: "Would you recommend this course to a fellow student?" on the evaluation form. Their answers were compiled and averaged on a scale of 1 to 5, with a "1" indicating an answer of "absolutely no" and a "5" indicating an answer of "absolutely yes". The results averaged 4.5, indicating an overall student satisfaction with the course. In subsequent years that we offered *A World of Light and Color*, we found it to be filled to capacity always with a long list of students waiting to enroll.

Assessment of Conceptual Understanding

The activities we developed build concepts and overarching principles that bind many optical phenomena together. As such, we closely monitored improvements in students' conceptual understanding of light and color during the two-year grant period. We designed an optics survey containing fifteen free-response items that we administered pre-instruction and post-instruction. Only those students who took the survey both pre-instruction and post-instruction were included in the study. There were a total of eight sections of the course (two a semester), yielding 131 matched data for students.

To be sure, students did not show improvement on all the items on the survey, but those items that did, consistently showed their conceptual understanding of light improved as a result of taking the course. For example, we asked "*Is red light different from blue light? If so, how are they different?"* The answer is related to the wavelength or frequency relationship between to red light and blue light. In the beginning of the semester, on 25% of the students could meaningfully answer the question. After taking the course, 86% gave a correct and appropriate answer.

In another question, we presented students with a list of 10 examples of “light” and asked them to highlight as many examples of light they thought were on the list. Some examples were obvious such as “*the brightness that comes from a flashlight*”, while others were more challenging like “*UV rays from the sun that tan your skin*”. Pre-instruction, student on average picked 6 out of 10 examples while post-instruction the average number rose to 8, indicating students had expanded their understanding of light.

As a final example of the kind of questions we posed on the conceptual survey, we presented students with a picture of a laser beam running in front of person but parallel to the person’s eye. We asked whether the person will see the laser beam and to explain their answer. This question probed their understanding of how one sees light. Most people do not realize (and popular science fiction movies are partly to blame) that in order for person to see light, it must enter the person’s eye. In this example, the laser beam passes in front of the person’s face but the person would be oblivious to it unless something, like dust particles, scatters or redirects the light into the person’s eye. Only 27% of students gave the correct answer pre-instruction, while the number increased to 61% post-instruction. In general, we feel students demonstrated a deeper conceptual understanding of light and color after taking our course.

Assessment of Epistemology

The physics education research community has long been concerned with developing curricular materials that positively impact students’ understanding of the basic natural phenomena that govern the cosmos. Until recently, confronting students’ attitudes and beliefs regarding the nature of science and scientific inquiry (often referred to as “students’ scientific epistemology”) went unaddressed. It is unclear why such a seemingly important aspect of students’ education was, at least, explicitly, overlooked. Moreover, it became clear from the few studies designed to investigate the influence of traditional-style or research-based curricula on students’ scientific epistemology that these instructional methods had no or even negative influences on students’ ideas about how scientists accrue and organize their knowledge, the role of science in society, and how scientific understanding evolves over time [See (Redish et al. 1998) and (Adams et al. 2006) for example]. So, instead of improving students’ attitudes and beliefs as a value-added part of a course, as one might hope, students’ attitudes and beliefs drifted away from more expert-like worldviews. A study by Elby showed realizing attitudinal gains was possible, but only if the students were exposed to curricular materials that were deliberately designed to have student explicitly tackle epistemological questions (Elby 2001).

Our Light and Color class provided us a unique opportunity to look at how an activities-centered physical science course would impact general science students’ scientific epistemology. Reports on the effectiveness of curricular interventions, of any kind, in the physical sciences for this group of students are essentially non-existent. Yet, as we mentioned earlier nearly all colleges and universities in the United States have some science requirement for all of their undergraduates.

To measure students’ epistemology we employed a survey instrument designed by Laura Lising and Andy Elby, with input from Priscilla Laws and David Jackson. They combined items from the Epistemological Beliefs Assessment for Physical Science (EBAPS) and the Maryland Physics Expectations Survey (MPEX). Both instruments have documented history [(Redish et al. 1998) and (Hammer and Elby 2000)]. We have previously discussed our administration of this instrument in a broader survey of general science students' scientific epistemology at McDaniel (Marx et al. 2005).

Briefly, all of the items on the survey are dichotomously scored. An examinee receives a point if his/her response matches the response typically offered by experts (read, "seasoned scientists"), zero otherwise. All but one item on the survey has two options that the test designers considered to be expert-like. For example, if experts generally strongly agree (or strongly disagree) with a particular statement, then the options "strongly agree" and "agree" (or "strongly disagree" and "disagree") are both worth one point. The total survey consists of twenty-two five-point, Likert-scale (strongly disagree – strongly agree) items; five multiple-choice items; and five "hypothetical dialogue-scenarios" where the student is asked to aligned his/her responses with one or both of the hypothetical participants in dialogue. Examples of three items on this survey instrument can be found in Figure 2.

Our data on students' attitudes from this survey spans the spring semester of 2002 through the Spring semester of 2004. This covered eight sections of *A World of Light and Color*. We were able to match pre-instructional/post-instructional data for 107 students. We approached the analysis of our data set in three ways. First, we simply looked to see if there was any measureable shift in students' attitudes from pre-instruction to post-instruction. The pre-instructional average for this group was 60 ± 1.0% and post-instructional average was 60 ± 1.5%. (The uncertainly in the percentage is simply the standard error of the mean.) Second we were interested to see if students with different initial attitudes we impacted differently by the course. Specifically, we created two groups of matched students, those whose score on the pre-instructional attitudinal survey fell in the bottom third of the data pool ("novices", N = 36) and those whose score was in the top third in the data pool ("experts", N = 36).

20. Understanding science is really important for people who design rockets, but not important for politicians.
A: Strongly disagree B: Somewhat disagree C: Neutral D: Somewhat agree E: Strongly agree

24. Scientists are having trouble predicting and explaining the behavior of thunderstorms. This could be because thunderstorms behave according to a very complicated set of rules. Or, that could be because some thunderstorms don't behave consistently according to *any* set of rules, no matter how complicated and complete that set of rules is.

In general, why do scientists sometimes have trouble explaining things? Please read all options before choosing one.

(a) The system simply doesn't obey definable rules.
(b) Most of the time it's because the system doesn't obey definable rules; but sometimes it's because the system follows rules that are very complex or difficult to figure out.
(c) About half the time it's because the system doesn't obey rules, and the other half it's because the rules are complex or difficult to figure out.
(d) Most of the time it's because rules are complex or difficult to figure out, but sometimes it's because the system doesn't follow definable rules.
(e) A natural system always follows definable rules but the rules can be very complex or difficult to figure out.

30.
Leticia: Some scientists think the dinosaurs died out because of volcanic eruptions, and others think they died out because an asteroid hit the Earth. Why can't the scientists agree?
Nisha: Maybe the evidence supports both theories. There's often more than one way to interpret the facts. So we have to figure out what the facts mean.
Leticia: I'm not so sure. In stuff like personal relationships or poetry, things can be ambiguous. But in science, the facts speak for themselves.

(a) I agree almost entirely with Leticia.
(b) I agree more with Leticia, but I think Nisha makes some good points.
(c) I agree (or disagree) equally with Nisha and Leticia.
(d) I agree more with Nisha, but I think Leticia makes some good points.
(e) I agree almost entirely with Nisha.

Most expert-like responses - #20: A & B; #24: D & E; #30: D & E.

Figure 2. Example items from the attitudinal survey. The options graded most "expert-like" are listed at the bottom.

The novice group's pre-instructional average was 49 ± 1.5%, while their post-instructional average rose to 56 ± 2.3%. The expert group's pre-instructional average was 71 ± 1.0% and their post-instructional average slipped to 65 ± 2.7%. Finally, we were interested to see if there was a discernable difference between the genders with regards to scientific attitudes and beliefs. The females in the data pool for whom we have matched data (N = 64) had a pre-instructional average of 61 ± 1.2% and a post-instructional average of 61 ± 1.9%. The males (N = 43) scores on the pre- instructional and post- instructional surveys were 60 ± 1.9% and 58 ± 2.2%, respectively.

Our results for this class were a bit surprising. In our activities-centered course, students were often grappling with epistemological issues. Certainly as part of the cycle of Prediction-Observation-Discussion, they were involved in thinking about their own learning; classroom discussions are often quite lively, with students citing *their own experimental evidence* to support their assertions and new knowledge was often built in knowledge they had gained earlier in the course. Likewise, the faculty member rarely needed to intervene to tell students “what to think”. As such, students continuously assessed the “origins” of their knowledge (internal origins versus and external, “authoritative” origins). Also, as part of our curricular design, we conscientiously included “bridges” between classroom materials and familiar “real-world” natural phenomena (e.g. rainbows) and human-engineered devices (e.g. cameras) so students would see that the content of their science course connected with their day-to-day existence. Despite all this, for all intents and purposes, there was no instructionally significant shift in students’ attitudes as a result of our course. True, our Light and Color students’ attitudes did not regress, but why did our students fail to realize more dramatic gains? It seems that, like Elby’s physics students, our Light and Color students need to overtly and, perhaps, repeatedly confront epistemological questions. Clearly, creating a physical and mental environment that is conducive to having students reflect on the source of their knowledge, the organization of the library of scientific knowledge, the role of science and society, et cetera is not enough. Students need to confront these issues very directly and overtly though specifically designed materials. For example, discussion questions along the lines of, “Reflect on and discuss with your partners the relevance of this material to you everyday life” might bring about the shifts in attitudes that we would hope for. In support of this notion, one of us [JM] has done just this in an Earth-science course designed for the same population of students. Specifically, JM designed materials and strategies that connect coursework to students’ everyday life. This work had a measurable and positive impact on students’ scientific epistemology. (Marx and Knouse 2005) Additionally, these eight classes that comprised our data pool had traditionally-graded assignments, including several homework sets, quizzes, tests, projects, and a final exam. None of the graded assignments were intended to foster or reinforce students’ epistemologies. Perhaps graded work would have more substantial impact on students.

We found it counterintuitive to find that our materials positively impacted students with the lowest initial attitudes. We hypothesized that students with modestly well-developed attitudes would be most easily moved in the expert-like direction. The evidence points to our faulty premise. We now suspect that the students with the more sophisticated epistemologies found our materials too easy, and so they were less likely to engage in the kinds of activities (discussion, reflection, and knowledge-building) that we hoped would bring about shifts we intended. If true, this interplay between under-challenged students and degraded attitudes presents it own obstacles for curriculum development. We could certainty intensify the content of the class, but that might negatively impact our novice students, as at least part of their success rests on the accessibility of the material. Again, the neutral solution seems to be having all students explicit reflect on epistemic issues and questions. As we move forward with our curricular development plans, we will need to carefully monitor impacts on the “expert” and “novice” students. We do not want to undermine the gains in one segment of our population while treating the other segment.

Finally, we were pleasantly surprised to see that the distinctions between male and female students’ attitudes were non-existent. On so many measures in the physical sciences, female students lag behind males. Evidence that their attitudes about science and scientific inquiry matched those of their male counterparts was refreshing. One wonders if the science community would focus more attention on developing scientific attitudes and beliefs, then what effect that might have on representation of women in the sciences.

Conclusions

In this paper, we presented a general science course designed for non-science students called *A World of Light and Color*, where students learn about light and basic light phenomena. After taking the course, students showed an increased appreciation for the science behind the beauty of the natural world. Most importantly, the veil that seemed to separate many of our students from science was lifted and they were more willing to engage.

In the process of creating this course, we developed a novel way to educate non-science students about the scientific endeavor. We did so by fusing and adapting techniques that have been established previously in the physics education research community, but specifically designed for physics students. We believe our approach can be adopted and implemented by educators in other scientific disciplines to help students come to a fuller understanding of basic physical concepts. It may even be possible to adapt portions of the technique for social sciences or humanities courses. In particular, the cycle of prediction, observation, and discussion to help students relate to fundamental ideas concerning light or any other topic has tremendous educational value.

Most students who enroll in general science courses typically do so to satisfy a general education requirement, while others may be prospective elementary school teachers. Many non-science students go on to a variety of careers as administrators, lawyers, and policy-makers. It is imperative that they are able to make informed decisions about science-related issues and, thus, need a firm understanding of the scientific endeavor. Future elementary school teachers must also have a positive experience in their general science courses. Not only do they require a confident understanding of the material to properly teach it to our children, but also learning science in an active-learning environment may inspire them to design a similar experience for their pupils. We are confident that our method has fostered our students' natural curiosity by exposing them to the scientific process through hands-on, collaborative activities.

The assessment of our educational approach and course materials developed occurred through several channels. We conducted internal evaluations through surveys, tests, and focus-group interviews that fed directly into improving the course and activities. An expert in the field of physics education research served as the external reviewer for the two-year NSF project and endorsed our work. We administered a fifteen free-response survey pre-instruction and post-instruction to measure the gains in students' conceptual understanding of light and basic light phenomena. It showed improvement in their understanding of fundamental ideas such as how light is identified, what constitutes light, and how one sees. The attitudinal survey probed changes in student's epistemological beliefs presented a mixture of results. On the one hand, we found no difference between male and female attitudes about science and scientific inquiry. On the other hand, we found students with weaker attitudes showed improvement while those with stronger attitudes declined, perhaps, because the expert students found the course material easy and did not engage in the pedagogical process as much as they should have. Having students explicitly reflect on epistemic issues and questions may help improve attitudes across the board. The fact that we did not see a slide in attitudes from pre-instruction to post-instruction for all students is still a positive finding since studies most often report a decline.

So, what lies ahead? We have already developed and implemented activities based on our learner-centered method in two other general-science courses called *Sound, Music, and Hearing* and *Observational Astronomy.* We are moving our attention now into creating interdisciplinary courses that are offered to sophomores (second-year students) as part of the Sophomore Interdisciplinary Series (SIS) at McDaniel College. One such course under development is simply called *Color*. In this course, four professors plan to teach a single theme not only from their own disciplinary perspectives, as they are best suited, but also will integrate viewpoints from other fields to show the interdependence of subjects and the value of crossing boundaries. Currently, the course will be staffed from a faculty member from Biology, Philosophy, Visual Art, and Physics [SM, one of the authors of this paper]. The course will focus on helping students develop an appreciation for the role of color, shading, and pigmentation in the visual arts; the philosophical perception of what we call color; the importance of color in biological systems; and basic physics behind light to understand coloration in the world and beyond. Such an effort has recently been reported by Natalie Angier in the May 27, 2008 issue of the New York Times where she spoke of a "Balkanization of knowledge" that seems to pervade higher education in the United States, and how some universities are developing fusion courses that "capitalize on differences." It seems a general education curriculum that demystifies disciplines and approaches subjects through a multitude of lenses is exactly the kind of educational system C. P. Snow had in mind.

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