Interdisciplinary Connections

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The Art and Science of Light

An Interdisciplinary Teaching and Learning Experience

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Light fascinates us. We study it, use it, and in the absence of natural light (sunlight), spend time and money to generate artificial light. When humans first looked at the heavens, they were in awe of the power of light. They wondered where it came from and about its properties. In time, they found ways to investigate light and in turn found answers to some of their questions. The day we learned to generate artificial light our world changed forever. Without artificial light our current way of life comes to a standstill. Clever as we have become with our advanced technologies, without natural light, life on Earth would not be possible. It is not by accident, then, that light is one of the most studied phenomena and one of the most desired resources. Light is investigated by scientists, pondered over by philosophers, sung about by musicians, and depicted on canvas by artists. Light obviously had to precede life on Earth.

Light, therefore, is an excellent topic for an interdisciplinary course. I was fortunate to have the opportunity to design and teach such a course with a visual artist at The Evergreen State College (TESC). Our goal was to explore how artists and scientists use and study light with a group of 50 junior- and senior-level students. Almost all the students who enrolled in this course were art majors, providing me with an excellent opportunity to teach them some science (chemistry in particular), while learning how artists use and study light.

Although seemingly disparate, art and science have much in common. Both disciplines require careful observation, contemplation, record keeping, attention to detail and, in the 21st century, use of advanced technology. Artists and scientists use different tools for probing nature and nature provides fascinating challenges for all. The connection between art and chemistry in particular, has been explored in this *Journal (1–4).* Mary Virginia Orna has written extensively on this topic *(5–9).* The National Chemistry Week (NCW) theme for the year 2001, "Celebrating Chemistry and Art", included several *Journal* articles on this topic as well *(10–17).*

Academic Setting for the "Light Program"

Judging by the publications in this *Journal* alone, there is a significant increase in the interdisciplinary academic offerings at the undergraduate level *(18–24).* From its inception, interdisciplinary study has been the norm rather than the exception at TESC, a liberal arts college located in Olympia, WA. Articles describing the context in which TESC operates, the nature of an interdisciplinary science course *(25)* and a freshman course *(26)* were published in this *Journal.*

Most of these interdisciplinary academic "programs" (as we call them) are taught by teams of faculty, each bringing expertise in his or her discipline to their team. The student-to-faculty ratio is 25:1; for freshman programs this ratio is 23:1. These interdisciplinary programs could be one, two, or three quarters in duration and provide a full-time course load for both faculty and students; the instructors teach and students enroll in only one academic program at a time, enabling the instructors to organize the program activities without scheduling conflicts. Faculty and students are immersed in the topic they are studying for a significant period of time. This is essential for the success of any interdisciplinary program. The students remain in the program for its duration providing opportunities for them to work together on long-term projects. The instructors get to know their students well which is vital for our evaluation process.

At TESC students in *all academic programs* are given narrative evaluations instead of letter grades. These describe students' academic accomplishments as well as their process of learning, engagement with fellow students and instructors, and academic growth. Suggestions for future development are discussed in an evaluation conference where each individual student meets with the faculty team. Students' academic transcripts consist of these narrative evaluations written by faculty and the students' own self evaluations.

Designing the Light Program

Both Susan Aurand, a visual artist at TESC, and the author, a chemistry instructor, developed the Light Program based on a mutual interest in studying light from scientific and artistic perspectives. Our goal was to help students use their scientific understanding of light to create artistic images and objects. The focus of the first quarter was on skill building in lab sciences, art studio, and library research methods. These activities continued into the second quarter, increasing in sophistication as the students gained experience.

Starting with short projects in the first quarter and moving to more extensive projects in the second, students were directed to use the tools they learned to pursue independent investigations on an aspect of light of their choosing. The instructors determined that students should be able to:

- Make meaningful connections between art and science disciplines in investigations of light
- Present work appropriately, using scientific and artistic methods
- Accurately record data from lab work
- Critique art work productively
- Display art using aesthetic standards
- Create science posters that adequately communicate scientific findings

Both instructors were present at all class meetings and became students of the other's discipline. This faculty role of being a model student was an important part of the program design. Students who had little or no exposure to the sciences were far more willing to venture into challenging (sometimes unnerving) tasks such as graphing, mathematical manipulation of data, and working with scientific instrumentation when a faculty co-learner provided leadership by example. On the other hand, in the art studio the students had the upper hand compared to the science instructor. This provided an environment of close interaction and trust building between students and instructors, one that encouraged academic risk taking leading to intellectual growth. It was also an excellent faculty development opportunity for both instructors.

Program Activities

Each week students participated in lectures, workshops, seminars, science labs, art studio work, and discussion sessions where students' work from the week were displayed and critiqued. We used *Seeing the Light (27)* as our primary textbook. This excellent book covers the properties of light, optics, photography, color, vision, and holography. It uses images and diagrams extensively to explain the scientific concepts to aid more artistically inclined students.

Table 1. Skill Development through Art Workshops and Science Labs in the Light Program

Art Workshops	Science Laboratory
Drawing with pencil and charcoal with a focus on line, value, texture, and light	Classification of electromagnetic radiation, exploring relationships between color, wavelength, frequency, energy, wave number and speed of light
Understanding the color wheel, composition, color theory, and color mixing	Understanding light sensors, band pass filters, various light sources including lasers, introduction to monochromatic light, understanding absorbance and transmittance, Beer–Lambert Law, learning to use a diode array spectrophotometer
Painting with oils and acrylics	Exploring the composition of primary and secondary colors using paper and thin layer chromatography, T-shirt chromatography *(28)*
Working with neon lights and light as an art medium	Emission spectroscopy using flame tests, making sparklers *(29)*, emission spectrum of atomic hydrogen and the analysis of the Balmer series
Creating 3-D art with fabrics, ceramics, wood, and metal	Chemistry of tie-dyeing, natural dyes, and vat dyeing
Using mirrors, lenses, prisms, different light sources, and lasers to create art	Investigating mirrors, lenses and prisms, reflection, interference and diffraction

In the Light Program, the work done in the laboratory and the art studio were central to students' learning. The lectures and workshops were used to help students acquire the necessary skills for laboratory and studio investigations. In workshops, students in small groups worked through predesigned worksheets with help from the faculty as needed.

Each week one concept on the theme of light was explored from science and art perspectives. Students were directed to make connections between these artistic explorations and scientific investigations. Table 1 lists the art studio workshops and science labs undertaken in the program. Recognizing that technology plays a key role in the lives of artists and scientists, computers were used as a tool in every possible assignment.

Students learned the techniques of drawing, painting, critiquing, and displaying art in the studios. In the laboratory, record keeping, the scientific method, use of instrumentation for data collection, proper lab techniques, lab safety, graphical representation of data, scientific analysis of data, and the use of the science library were emphasized. The level of expectation for lab and art studio work was well defined and equivalent to those in other science–visual arts courses.

Seminar Discussions

In addition to the main text, students read several articles and books that explored the history of light in art, science, and the use of light in healing *(28–30).* The life and works of Albert Einstein was explored by viewing the video *Einstein Revealed* (made by NOVA) and the history of light in art was surveyed by viewing slides from various times in history. Students wrote papers in response to these readings and viewings and participated in seminar discussions. The goal of the seminar was to help students further their knowledge by articulating their understanding of the readings. Each instructor worked with a group of 25 students in seminar. The role of the instructor was to facilitate the discussions and provide clarifications when needed, rather than to be the authority on the material. TESC students are familiar with this seminar format since most academic programs include a seminar component *(25, 26).* Light Program students, being juniors and seniors, generated enlightening seminar discussions. The seminar book *Health and Light* by John Ott was selected because of students' desire to learn more about the healing properties of light. Some of these discussions continued along the corridors after the seminar sessions ended!

Art and Science Connections

Artist materials provided an excellent avenue for studying chemistry. In response to the pigments used in painting, we studied the chemicals in pigments, the periodic table, ionic and covalent bonds, and the chemistry of the elements. The use of neon lights as an art medium led to studying emission spectroscopy and the structure of the atom. Students tie-dyed T-shirts and learned about the chemistry of tie-dyeing and the structure of cellulose. Many Light Program students initially had difficulty understanding the structure of cellulose using the chemist's ball and stick notation when written on paper. To overcome this problem, each student was directed to assemble a monomeric unit of β-D-glucose with molecular model kits. These were then combined to form the cellulose polymer (poly-1,4,D-glucopyranose). This exercise was very effective in helping students comprehend how bonds break and form. We extended this activity to incorporate dye molecules (using models) to the cellulose structure. After completing this hands-on activity students were better able to comprehend the ball-and-stick model notation chemists use.

In the lab we used paper chromatography to explore the composition of pigments in washable markers. In response students created chromatography T-shirts *(31)* and chromatography art by painting images on paper with water soluble paint and allowing the solvent (water) to wick up the paper.

We studied the structure of the atom and analyzed the Balmer series of atomic hydrogen. Students made sparklers in response to this lab, experimenting with different chemicals for desired color effects *(32).* During the winter solstice, students lit these sparklers attired in lab coats and goggles!

Many students in the Light Program had used pigments without a clear understanding of the toxicity of some of them. Often toxic and environmentally harmful solvents are used to clean paintbrushes and paint-covered fingers and then disposed down the drain! Perhaps one of the most useful things students learned in the Light Program is the true nature of these toxic materials.

Scientific Diagrams and Artistic Drawings

To show that science and art are complementary tools for studying light, students made three diptychs on “light through a prism”, “the human eye” and “the light of a candle flame”. A diptych is a side-by-side illustration of an artistic drawing and a scientific diagram of a given subject. Scientific diagrams required that each important component be appropriately labeled and often included a visit to the library to gather information. Artistic drawings included three-dimensional art using a student’s choice of medium (charcoal, pastel, paint, wood, metal, geometric optics, etc.). Students were fascinated to discover that while the artistic drawings varied greatly from person to person, the scientific diagrams were very similar to the point of being identical.

Cross-Cultural Celebrations of Light

To provide an avenue to bring cultural studies into the program, students in small groups (4–5 students) were directed to investigate how light has been used in the context of a number of cultural celebrations. Students chose to study a wide variety of cultures including those of Native Americans, Australian Aborigines, ancient Egyptians, Mayans, ancient Europeans, Jews, Indonesians, Buddhists, Caribbean and ancient Chinese. Each group made a 30-minute presentation summarizing their research, which included audience participation. These “celebrations of light” coincided with the northern hemisphere winter solstice.

Independent Student Projects

During the second quarter students spent a considerable amount of time on individual projects exploring the science and art of an aspect of light of their choice. They were required to keep a project notebook, which was reviewed by peers and faculty regularly. At the end of the quarter, students made an oral presentation of their projects. Titles of some of these projects are provided in List 1. The breadth and depth of the projects was a clear indication of the investment students made in this academic adventure.

A Sample Laboratory from the Light Program

The first laboratory experience in the Light Program was a collection of “mini-labs” where students conducted short experiments to understand the properties of light. The first of these mini-labs explored the relationships between wavelength, color and frequency of light. In the general chemistry courses, this is often accomplished by solving several problems using the following three mathematical relationships,

$$E = h\nu \tag{1}$$

$$c = \nu\lambda \tag{2}$$

$$\tilde{\nu} = \frac{1}{\lambda} \tag{3}$$

where E is energy, h is Planck’s constant, ν is frequency, c is the speed of light, $\tilde{\nu}$ is wave number, and λ is wavelength.

For students who had avoided science most of their lives, this approach was not appropriate. Instead they needed to be able to visualize the relationships. First, students worked on a guided activity to help them understand the definitions of wavelength, wavenumber, and frequency of light.[W] Then they were directed to construct light waves of the same amplitude for different colors of visible light using knitting yarn. For this purpose students used the data in Table 2 with a scale of 100 nm = 1 inch.

List 1. Example Independent Project Topics on the Theme of Light

- Art and science of holography
- Long-exposure photography
- Amorphic art
- Photosynthesis
- Luminous tubes
- Microscopy
- Pinhole photography
- Light and shadow using metal sculptures
- Stellar evolution
- Solar power
- Bioluminescence
- Kirlian photography
- Effect of light on plants

Table 2. Approximate Wavelengths of the Colors in the Visible Spectrum

Color of Light	Approximate Wavelength/nm
Violet	420
Blue	470
Green	530
Yellow	580
Orange	620
Red	700

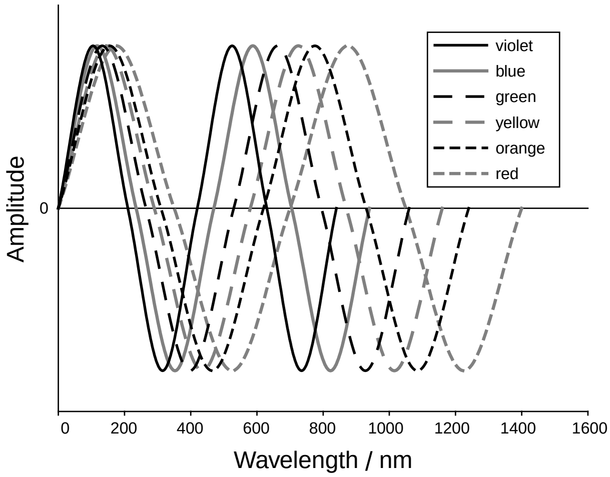

Figure 1. Constructing light waves with yarn to understand the relationship between wavelength, color and frequency of light. Please note that this figure was created using Microsoft Excel for ease of publication. In class this was done on graph paper using yarn, glue, rulers and scissors.

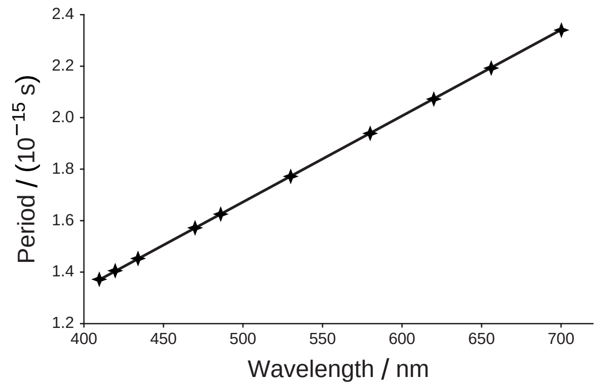

Figure 3. The relationship between 1/frequency and wavelength for light waves

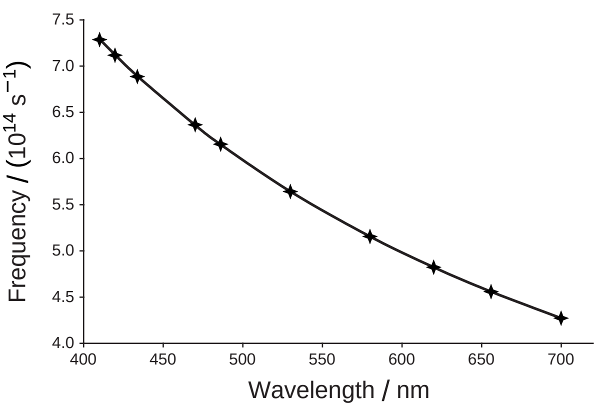

Figure 2. The relationship between frequency and wavelength for light waves.

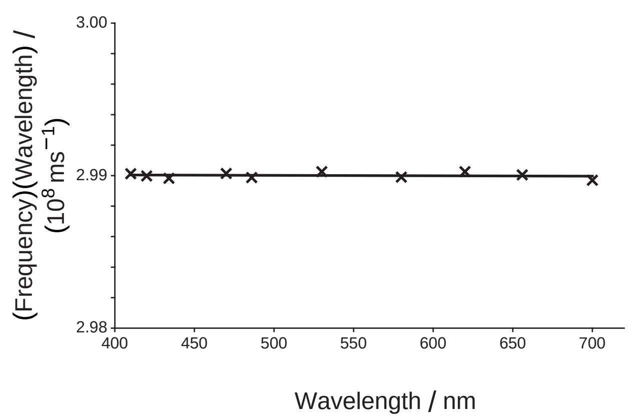

Figure 4. The relationship between speed and wavelength for light waves.

Table 3. Data Showing Inter-Relationships for Values of the Physical Properties of Light

Wavelength/nm	Wavelength/(10^{-7} m)	Frequency/(10^{14} s^{-1})	Frequency^{-1}/(10^{-15} s^{-1})	Speed[a]/(10^{8} m s^{-1})
410	4.10	7.29	1.37	2.99
420	4.20	7.12	1.41	2.99
434	4.34	6.89	1.45	2.99
470	4.70	6.36	1.57	2.99
486	4.86	6.15	1.63	2.99
530	5.30	5.64	1.77	2.99
580	5.80	5.16	1.94	2.99
620	6.20	4.82	2.07	2.99
656	6.56	4.56	2.19	2.99
700	7.00	4.27	2.34	2.99

[a]Speed = frequency × wavelength.

Students glued yarn on graph paper (with the color of the yarn matching the color of the visible light), and discovered that violet light with a short wavelength has a higher frequency compared to red light with a longer wavelength. This visual image was embedded in student's minds and was easy to recall during the course of the program. The results of this mini-lab are shown in Figure 1.

Based on this exercise, students answered questions such as which color of light has the longest or shortest wavelength and which has the highest or lowest frequency. This visual experience aided students in understanding the mathematical relationships given in equations 1–3. In the second mini-lab[W] students were asked to predict the shapes of the graphs shown in Figures 2–4 with the help of equations 1–3: frequency versus wavelength; wavenumber versus wavelength; and speed versus wavelength, with speed = frequency × wavelength. Students were then provided with the data in Table 3 and asked to plot that data using Microsoft Excel.

Students compared their predictions with the graphs they plotted. This was an effective way to help students learn the relationships among frequency, wavelength, and the speed of light. The fact that the speed of light is a constant becomes visually apparent from Figure 4. This was the first time many of the students had used graphing software.

Conclusion

Through the experience of teaching this program, I learned that the use of visual exercises could aid students in grasping complex mathematical relationships. Now I often use these two mini-labs in my general chemistry classes. Chemistry majors, just like Light Program students, find the equations easy to work with once the visual images are firm in their minds. Teaching the Light Program convinced me that using interdisciplinary themes is an effective ways of teaching science to non-science students, thereby "hooking" them into the sciences. As a spectroscopist, I had always been interested in light. This teaching and learning experience enhanced my own understanding of light and provided me with more tools and reasons for studying this fascinating topic.

Acknowledgments

The Light Program would not have been possible without the dedication and resourcefulness of Susan Aurand of the visual art faculty at The Evergreen State College. Technical staff at The Evergreen State College provided the science laboratory and art studio technical support. Their commitment was vital for the success of the Light Program.

[W]Supplemental Material

A worksheet for students on the properties of light, instructions for five minilabs, and notes for the instructor are available in this issue of *JCE Online*.

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