# Stimulating Future Color Imaging Scientists and Engineers

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## Abstract
*The future of science is in the hands of our school children and it is becoming increasingly difficult to encourage them to choose the "difficult" science majors when they move on to college. This is despite the expanding needs and opportunities for scientists and the importance of scientific research in solving national and global economic and environmental problems. The opportunities for scientists in imaging and color science are endless. This paper describes an effort to stimulate scientific thinking in students of all ages, introduce them to science in a friendly, practical way, and perhaps inspire a few more to join our field or other areas of science and technology. This effort revolves around a website, <whyiscolor.org>, and printed workbook that aim to answer student questions about color in a way that gently introduces them to the science of color through their natural curiosity.*

## Introduction
As summarized by the U.S. National Science Foundation in 2002:

> *Key challenges for undergraduate education in science and engineering include preparing teachers for K–12 and college levels, preparing scientists and engineers to fill needed workforce requirements and provide the capacity for long-term innovation, providing understanding of basic science and mathematics concepts for all students, and measuring what students learn. These challenges relate to the nation's ability to retain its innovation capacity and international position in science and technology.*
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> *The need for undergraduate teaching that could attract and retain students in science and engineering fields has been widely noted and discussed. Professional associations, private foundations, public officials, and universities themselves have each expressed concern regarding the delivery of undergraduate education.*[1]

More recent data from UCLA's Higher Education Research Institute,[2] shows that the rate of aspiration into STEM (Science , Technology, Engineering, Mathematics) college majors has been relatively stable at about 30% of college-bound students for the past decade after declining almost as low as 20% in the 1980s. Of interest is that the distribution is even across race in contrast to the significant lack of minority STEM students in the 1970s. However, such data masks the internal distribution of students' aspirations and while there remains significant interest in technology programs, the interest in college education and ultimate careers in the basic sciences, engineering, and mathematics remains depressed. Colleges and Universities have begun to take it upon themselves to more actively recruit students into science and engineering programs through significant outreach to K-12 constituencies.

This paper provides an overview of one such activity, based upon the science and engineering of color and imaging, aimed at building on the natural curiosity of school children on topics related to color to foster a greater interest in science as a possible career path. The effort is focussed on an interactive website, built upon color imaging research and education, along with an inexpensive hard-copy publication for teachers and students, to reach out to students of all ages to answer some of their questions and encourage further explorations. The project is entitled *The Color Curiosity Shop* to evoke the concept of wandering about a curios shop with no particular objective, but enjoying with a curious inquisition that which is found. It resides at <*whyiscolor.org*>. The following sections outline the structure of this resource, its objectives, and future directions for the project. The color imaging community is encouraged to explore this resource, make suggestions on its future improvement, and most importantly spread the word to teachers and students.

## The Color Curiosity Shop
*The Color Curiosity Shop* is an interactive, multiple-medium, resource illuminating the relationships between scientific endeavors and everyday experiences. The project theme is color — a topic of near-universal experience and fascination. Descriptions of color and imaging in scientific terms are made in a way that eliminates the potential intimidation of scientific and technical discourse. Once viewers work through an exploration series on color topics, they might discover they were learning about science without having to overcome any science anxiety. Innate curiosity is the driving force behind this mode of learning. Viewers greatly increase knowledge about color, gain an appreciation of how science enriches everyday life, and perhaps become motivated to engage in additional exploration and education.

The main resource is a public website with 64 modules addressing actual student questions about color at eight levels spanning eight traditional disciplines. As viewers navigate the modules they can discover that science is ultimately about satisfying our natural curiosity. Further dissemination takes place through a downloadable, navigable, electronic book, a free printable book, and an at-cost printed book. Information on all modes of viewing can be found at <*whyiscolor.org*>.

The website is populated with common questions about color, their answers, and explanatory photographic and video illustrations. The modules are arranged in a color-coded, two-dimensional array where one dimension represents increasing level (pre-school to post-graduate) and the other represents scientific discipline (mathematics to psychology). Eight disciplines, each represented at eight levels, results in 64 modules, each addressing a different question. Viewers can optionally navigate at a constant level while exploring different disciplines, within a given discipline while increasing level, or through random topical selections and suggestions. Design is simple and uncluttered allowing exploration without distraction. Topics were derived from surveys of schools and students assuring the questions are of general interest and placed at appropriate levels. Disciplines are designated with common terms (*e.g.*, light instead of physics, objects instead of chemistry, numbers instead of mathematics) until viewers reach the highest levels where the scientific disciplines are revealed with resources for ongoing exploration. Likewise, levels are notated simply, not defined by age or grade level. It is possible for anyone to enjoy the content at any level. Furthermore electronic and printed book versions arranged for the different methods of navigation have been created.

A major project goal is to allay some fears of science. The problem addressed is one of motivation and interest. Science is widely held as one of the most respected career areas and the drive to understand the world is fundamental to our basic human needs. Scientists are also among the most satisfied with their personal careers. However, students at all levels can become discouraged from pursuing science because it is perceived to be difficult, boring, or impractical for their daily lives. The end result is that the United States has an unparalleled system of scientific research and education at the university level, but a lack of interested and motivated students to take advantage of those opportunities. This project aims to help bridge that disparity by encouraging a life-long interest in science among students of all ages by satisfying some of their natural curiosity about the world, specifically their color perceptions, through sound scientific explanations of phenomena illustrated with interesting and pleasing photographs and video segments. The burdensome overhead of science classes and textbooks is absent. Only after viewers enjoy themselves and satisfy their curiosity will they discover that they have been learning some science and perhaps retain that connection.

Figure 1 shows the project icon that has been designed as both a symbol of the project and the navigational map of the content. It is an 8x8 matrix with a square for each planned module. Each column (a different hue) represents a different scientific discipline and each row represents a level (starting with saturated primaries for the pre-school level and moving to more subdued colors for the higher, more "serious" levels). The disciplines are Light (Physics), Objects (Chemistry), Eyes (Biology), Numbers (Mathematics), Seeing (Psychology), Photography (Technology), Challenge (Interactive Q&A), and Explorations (References). The eight levels are not labeled by age or grade level, but very approximately represent (1) pre-school, (2) grades K-2, (3) grades 3-4, (4) grades 5-6, (5) grades 7-8, (6) high school, (7) undergraduate, (8) post-graduate. The material has been prepared and presented in such a way that even the pre-school level is of interest to adult learners while the higher levels are available for those wishing to challenge themselves further. Everyone can move through the resource at whatever level they feel comfortable with no labels attached. Each module has a modified icon showing its spatial location in the resource by highlighting the appropriate block and projecting a shadow of that color. The icon for level 3 of the Numbers discipline is shown in the bottom part of Fig. 1. Navigation with this map is, itself, a lesson in color science that makes a nice animation in both the website and printed forms (as a flip-book when printed).

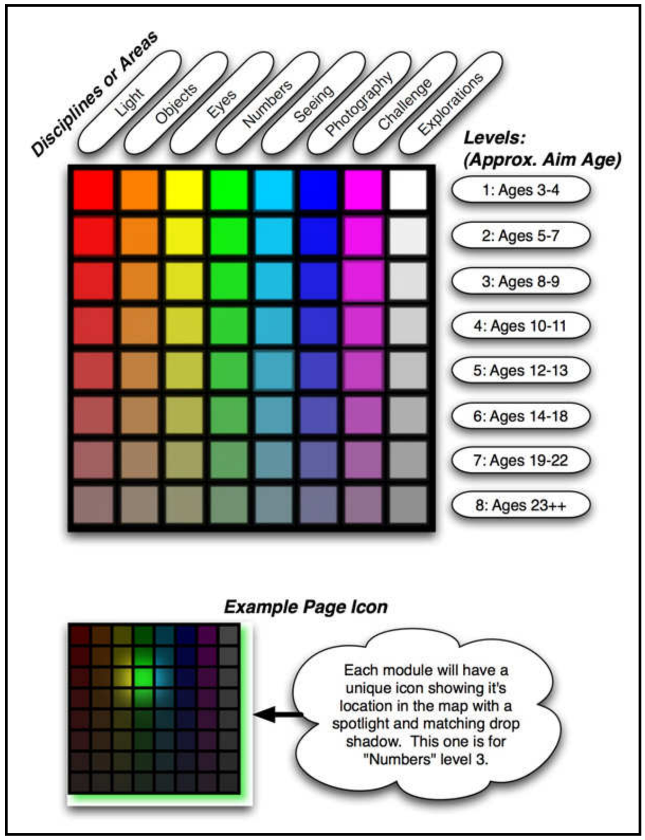


*Figure 1. The project icon and navigation map for The Color Curiosity Shop. The 8x8 array covers a range of scientific disciplines (the columns) at a range of levels (the rows). The bottom image shows the rendered icon/map for a given module in the resource.*

## Development Procedures

Appropriate questions were obtained through teacher/student surveys completed using a variety of means. Some were submitted by teachers who directly requested questions from their students while others were obtained through online submission over the course of about one year. Over 300 viable questions were submitted. The final questions included in the main resource were selected through review by a high-school summer intern who studied the submissions along with exhibits at several science museums to come up with recommendations. The remaining questions were also answered in a more abridged, short answers, format that is available on the website and has proven quite popular at attracting visitors to the website through search-engine results.

Answers were prepared by the author in consultation with teachers and students at various levels and will be subject to ongoing revision as appropriate. The author has created, and/or obtained permissions for, high-quality photographic and video images illustrating the concepts of the modules. A related project, *The HDR Photographic Survey*,[3] was undertaken with several objectives, one of which was to provide photographic content for this resource. Content was also built upon previous experiences with on-line course development/teaching and the creation/maintenance of a successful *Ask-a-Color-Scientist* feature on the <*mcsl.rit.edu*> website. Students and teachers have been involved in reviewing the material for comprehension, appropriateness of level, and to assure modules hold the intended audience's interest. There is also an online feedback form with a link on each module page for continuous improvement and revision of the resources. Publication beyond the electronic format has also been completed with the hope of preserving the free access goals of this project. Initially the electronic book will be a free download and a bound book will be available on demand for the cost of printing and shipping.

Each module consists of a question submitted by a student at the appropriate level, a written answer for that student, and at least two visual illustrations with captions describing related phenomena. When appropriate, other interactive web resources are included or linked. In the printed version, each module becomes a two-page spread. Some examples of questions that have been submitted include the following. How many colors are there in the world? Why do leaves change color in the fall? How does color-changing silly-putty work? Why are some people color blind? Why can't I see colors at night? How do glow sticks work? Why do they last longer if put in a freezer? How do color printers work? How are the colors in fireworks made? What is brown? Clearly the possibilities for good questions are endless. An example of the content of one module is given in the next section.

## Example Content

Figure 2 illustrates a screen capture of one online module, the question for the *Numbers* topical area at level 3. The submitted question for this module is *"Why is three an important number in color?"* The main text of the answer is as follows.

> *We see color the way we do because there are three types of light sensitive cells (called photoreceptors) in our eyes that produce our perceptions of light in the daytime (there is a fourth type that works at night when there is very little light to see). These cells are called cones because some of the scientists who first saw them thought they had shapes very much like the shape of an ice cream cone. The three types of cones each respond to different types of light and can be thought of as roughly sensitive to red, green, and blue light. Different colors have different amounts of red, green, and blue light coming from them and our three types of cones can help us figure out how much of each and therefore see beautiful colors. It is the fact that there are three types of cones that makes the number three so important in color.*
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> *Those three cones result in color perceptions that can be described with three types of descriptions. These are called lightness (how light or dark a color is), chroma (how different a color is from white, gray, or black) and hue (the color names we give objects like red, green, yellow, and blue). A bright red sports car might have a medium lightness, a very high chroma, and a red hue.*
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> *Also because of the three types of cones, we can mix colored lights or materials together to make many other colors. It just takes three distinct colors (or primaries) in the mixtures to make a very wide variety of colors. As you can see, three is an important number in color for many reasons.*

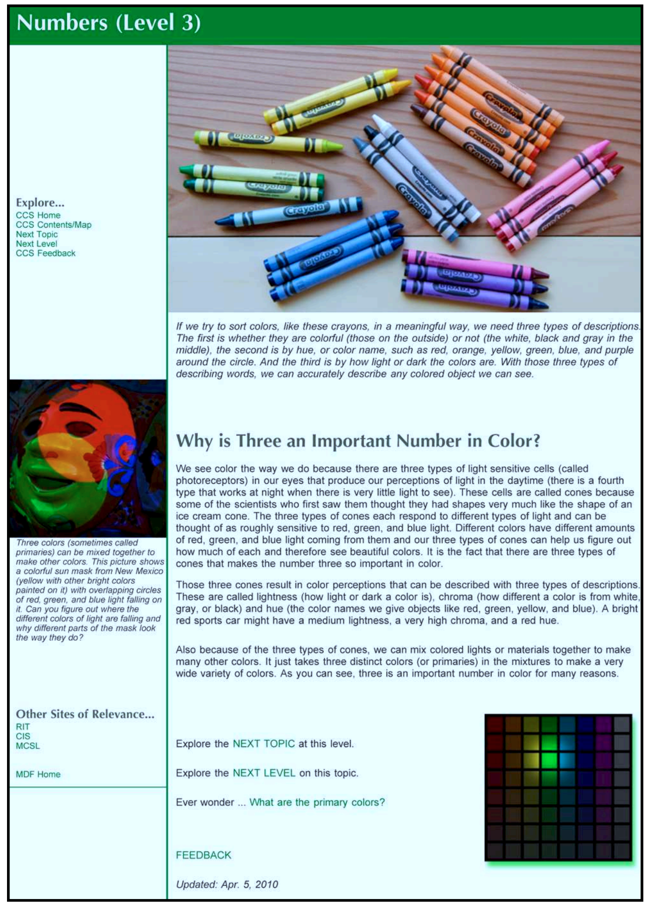


*Figure 2. A screen capture of an example module page. This one is from topical area 4, Numbers, and level 3.*

The modified icon at the bottom of the page indicates the overall location in the resource. In addition there are links to move to the next topic at the same level, the next level on the same topic, and to a "randomly" connected module with some relationship. In this case, there is a link to the question *"What are the primary colors?"*

Each module also incorporates two related images (as well as general navigation links), a large main image at the top of the page and a smaller, and perhaps slightly more exploratory, image to the middle-left. These images, along with their online captions are presented in Figs. 3 and 4 respectively.

As mentioned previously, approximately 200 student-submitted questions and short answers are included on a separate, but linked from each module, page called *Short Answers*. The final topic, *Explorations*, consists of a large number of books and website links for further research and learning at each level. This page is also linked through each of the modules along with the ever-present link to the feedback page.


*Figure 3. "If we try to sort colors, like these crayons, in a meaningful way, we need three types of descriptions. The first is whether they are colorful (those on the outside) or not (the white, black and gray in the middle), the second is by hue, or color name, such as red, orange, yellow, green, blue, and purple around the circle. And the third is by how light or dark the colors are. With those three types of describing words, we can accurately describe any colored object we can see."*

*Figure 4. "Three colors (sometimes called primaries) can be mixed together to make other colors. This picture shows a colorful sun mask from New Mexico (yellow with other bright colors painted on it) with overlapping circles of red, green, and blue light falling on it. Can you figure out where the different colors of light are falling and why different parts of the mask look the way they do?"*

## Feedback

Parts of the online resource have been in place for over two years, for example the *Short Answers* and *Books/Links* sections, and subject to significant scrutiny and feedback. Several of the modules have also been online and received some review and feedback. Submitted feedback ranges from simple suggestions for typo corrections, to critical review of the questions and/or answers. Such feedback is consistently addressed and those submitting feedback are personally answered. It is expected that this informal feedback will continue indefinitely serving to improve the resource on an ongoing basis. (Experience from other publications bears this out.) Additionally feedback from teachers will be directly solicited once the full resource has been put in place for awhile (later in 2010).

Most rewarding of the feedback have been numerous expressions of gratitude from young students and their parents, both to finding answers to their curious inquiries on the internet and to the personal interaction prompted by their feedback. While it might never be known for sure, it is hoped that some of these interactions will lead to new color imaging scientists in the next generation.

## Future Directions and Conclusions

This paper describes a long-term effort to create and publish a resource to help entertain and enlighten curious students through the use of color and imaging science. It exists with the simple hope of perhaps inspiring just one student to pursue a career in science who might otherwise have not been interested. There are several future directions in the planning and early implementation stages for this project. The first is a complete translation into Spanish to bring this material to a wider audience in the U.S. and internationally. Assuming the Spanish edition is successful, other potential collaborators will be sought to create translations into additional languages. Initial plans for this project also contemplated interactive exhibits for each module that could be installed in science museums (or other locations) to allow a hands-on exercise to accompany each module in the workbook and website.

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## Author Biography

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