Optics in the Great Exploration in Math and Science (GEMS) Program: A Summary of Effective Pedagogical Approaches

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ABSTRACT

This paper examines how optics is treated in instructional materials developed for the Great Explorations in Math and Science (GEMS) Program at the Lawrence Hall of Science, University of California, Berkeley. The GEMS program is a prominent resource for teachers in the United States and in many other countries. It represents a widely acknowledged, innovative approach to science and mathematics education. GEMS teacher's guides and handbooks offer a wide range of supplementary learning experiences for preschool through 8th grade (about age 13). Two guides already developed (*Color Analyzers* and *More than Magnifiers*) and one under development (working title: *Invisible Universe*) have a strong emphasis on fundamentals of optics. The organization and approaches of the guides will be described, with particular emphasis on the pedagogical approach represented. GEMS activities engage students in direct experience and experimentation to order to introduce essential, standards-based principles and concepts. Overwhelming educational evidence that students learn best by doing is the basis for the GEMS approach.

Keywords: optics education, professional development, inquiry, color

1. INTRODUCTION

GEMS, recently lauded by the US Department of Education's Expert Panel on Mathematics and Science Education, is a growing resource for the advancement of inquiry-based science and mathematics education. The GEMS program at the Lawrence Hall of Science at the University of California, Berkeley has published a number of science teaching guides for teachers. To support the introduction and use of these guides, the program runs specialized workshops, and maintains an international network of teacher-training sites and centers, including a Singapore GEMS Center. The GEMS guides are developed by science education experts well-versed in both science content and science education pedagogy. The guides are extensively tested in a variety of classroom situations. A first draft of the GEMS guide is tested locally, and then revised. The next draft is tested more extensively in different schools across the country and the results of this testing are used to create the next version. This version is also tested nationally, in a variety of classrooms. A further revision takes place after this last round of testing and the guide is expanded and then later published.

GEMS Teacher's Guides are standards-based, clearly organized, easy to use, and do not require special background in math or science. Each classroom session is outlined with an overview, materials list, and preparation requirements, followed by clear, step-by-step directions. Complete background information is provided for the teacher, along with photographs, illustrations, and often examples of student work. Throughout each guide there are comments on presentation strategies and practical advice to help the teacher, many of them suggested by teachers who tested the units.

Two teacher s guides already developed, *Color Analyzers*[1] and *More than Magnifiers*[2], and one under development with a working title of *Invisible Universe*[3] have a strong emphasis on optics. These three guides provide a basic approach to

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the treatment of light for grades 5-9 (ages 10-14). All of these guides use a guided inquiry approach. This approach has proven to be most effective, as described below.

2. VALUE OF INQUIRY-ORIENTED MATERIALS

Inquiry instruction is prominent in the teaching of science and in the national science education standards (National Research Council[4] (NRC), 1996; Science for All Americans[5], 1990). Inquiry has been described by the NRC as a pedagogical method combining intellectual questioning with student-centered discussion and discovery of pivotal concepts through laboratory activities . Inquiry instruction allows students to experience the processes of science such as questioning their own observations, dealing with experimental data, and disproving theories made by past researchers (Collins[6], 1998; Uno[7], 1990; Bybee[8], 1993; Moore[9], 1993)

Research shows that both teachers and students benefit from inquiry instruction. The use of inquiry activities has been shown to enhance student interest in science, their motivation to continue studying science, their attitudes toward science, and their view of themselves as practitioners of science (Damnjanovic[10], 1998; Jones, Mullis, Raizen, Weiss, & Weston[11], 1992; Kahle[12], 1985; Kahle & Damnjanovic[13], 1994; Levin, Sabar, & Libman[14], 1991; Huber & Burton[15], 1995; Smith, Juber, & Shotsberger[16], in press).

Our experience with the GEMS guides reinforces these research findings. The guides are highly motivational to students and teachers, and continually reinforce student excitement in questioning and experimentation. Student and teacher confidence in doing science is significantly enhanced. Science becomes a highly interpersonal contact sport rather than an intimidating exercise.

3. KEY FEATURES OF GEMS GUIDES

A. Skills Emphasized

These guides emphasize certain fundamental scientific and mathematical skills. Some of the skills that are emphasized in the guides are:

Observing	Comparing	Describing	Classifying
Inferring	Predicting	Recording Data	Drawing Conclusions

B. Optics Concepts

Key concepts in optics that are covered by these guides are given below. Concepts are not presented in isolation. The guides emphasize concept building through observation, experimentation, and inquiry.

Properties of light and color	Color Filters	Diffraction Gratings
Lenses Images	Images	Focal Length
Magnifiers	Cameras	Telescopes
Projectors	Field of View	

C. General Themes

The word themes is used in GEMS context to describe key recurring ideas that cut across all scientific disciplines. Themes are large, and connect different areas of the curriculum. For example, one theme is Patterns of Change and represents the ways in which change can take place. The 10 themes of the GEMS series are given below. Many of them are present in the GEMS guides dealing with light and color.

Systems and Interactions	Scale
Models and Simulations	Structure
Stability	Energy
Patterns of Change	Matter
Evolution	Diversity and Unity

D. Nature of Science and Mathematics

GEMS guides also address the process of science. The students work as scientist by asking questions, conducting investigations, evaluating data, and making predictions. Some of the key areas communicated in the GEMS guides on the nature of science and mathematics are:

Scientific Community	Interdisciplinary	Cooperative Efforts
Creativity and Constraints	Theory-Based and Testable	Real-Life Applications
Science and Technology	Changing Nature of Facts and Theories	Real Life Applications

E. Importance of Sequencing

The GEMS guides present a sequence of activities. These sequences are chosen for their educational effectiveness. The testing process of each guide often leads to a rearrangement of the sequence based on the test results. Sequence is critical in teaching about optics concepts. For example, a student may be exposed briefly to how the colors from different light sources combine (additive color mixing). Then they are exposed briefly to combining different color paints (color mixing by subtraction). The result might be very confusing for the student. The two ways of mixing may be best presented in a particular context or sequence.

4. MISCONCEPTIONS: LIGHT AND COLOR

Programs such as GEMS must take into account the common misconceptions that students (and teachers) have about light and color. The research suggests that a number of misconceptions are prevalent. Most elementary (years 1-5 in school) and some middle-school (years 6-8 in school) students who have not received systematic instruction about light tend to identify it with its source. They do not understand light as something that travels from one place to another, but thing of it only in terms of the Sun, a light bulb, or a laser where they can see the source directly. As a result, they have difficulties explaining how shadows form. In fact, the direction and formation of shadows and the reflection of light by objects are extremely confusing concepts. Middle-school students accept that mirrors reflect light but often reject the idea that ordinary objects reflect light, according to Guesne (1985)[17] and Ramadas & Driver (1989)[18]. Many elementary and middle school students do not believe that their eyes receive light when they look at an object. They therefore have wildly varying conceptions about how their vision works. Some 5th-graders, though, can understand seeing as "detecting" reflected light after specially designed instruction (Anderson & Smith, 1983)[19]. For more details see: *Atlas of Science Literacy*)[20] and Driver *et al.*[21] Stepans (1996)[22] and Comins (2001)[23] also have excellent discussions of misconceptions in this area.

Ideally, the essential features of professional development materials such as the GEMS guides include:

- **Discussion of common preconceptions.** Discussion and summary of major research-based student preconceptions in optics. It also includes selected additional resources on cognitive science, developmental studies, standards, and inquiry. These will include descriptions of the logical constructs behind student preconceptions and an attempt to explain their persistence.
- **Pre-post assessment instruments.** A collection of pre-post assessment instruments related to the selected learning outcomes that teachers can use to assess change.

5. CONCEPTUAL CHANGE MODELS

Student conceptual change is the desired result of many instructional units including these GEMS guides. Teachers who use inquiry-oriented materials need to be aware of how conceptual change takes place. Stepans (1996) provides a Conceptual Change Model (CCM) that consists of six stages:

1) Students become aware of their own preconceptions about a concept by thinking about it and making predictions (*committing to an outcome*) before any activity begins.

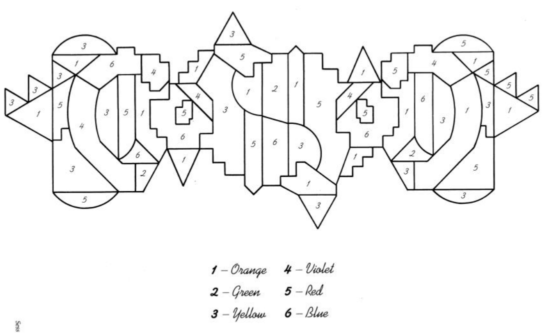
2) Students *expose their beliefs* by sharing them, initially in small groups and then with the entire class.
3) Students *confront their beliefs* by testing and discussing them, initially in small groups and then with the entire class.
4) Students work toward resolving conflicts (if any) between their ideas (based on the revealed preconceptions and class discussion) and their observations, thereby *accommodating the new concept*.
5) Students *extend the concept* by trying to make connections between the concept learned in the classroom and other situations, including their daily lives.
6) Students are encouraged to *go beyond*, pursuing additional questions and problems of their choice related to the concept.

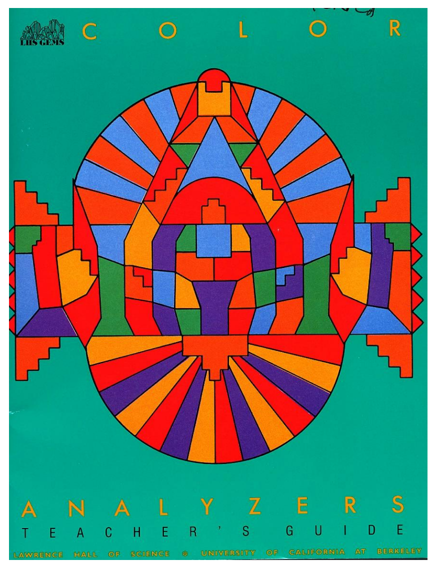
This model should be kept in mind while using the GEMS materials.

6. APPROACH OF *COLOR ANALYZERS*

The GEMS book Color Analyzers has 4 activities:

1. Decoding Secret Messages
Using colored light filters to decode secret messages





2. Inventing Secret Messages
Applying what they have learned to create their own secret messages.

3. The Colors in Light
An introduction to diffraction gratings.
Discovery that light sources give off many colors.

4. Why Does an Apple Look Red?
A synthesis of what the students have learned to expand their understanding of how people perceive color.

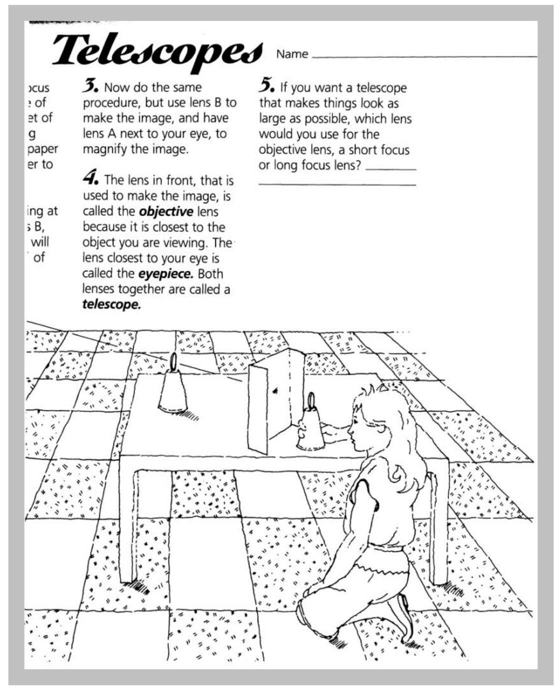
7. APPROACH OF *MORE THAN MAGNIFIERS*

In this book students do experiments with simple lenses. They learn how lenses are used in magnifiers, simple cameras, telescopes, and slide projectors. The activities headings are:

1. Magnifiers 2.Cameras 3.Telescopes 4. Projectors 5. Behind the Scenes
Students:

- Learn that lenses have properties that can be measured.
- Learn that some lenses are better for specific purposes than others.
- Develop scientific skills of manipulating laboratory materials, observing, comparing, measuring, and solving problems creatively.

The Behind the Scenes session give background information on the properties and functions of the lenses in the four devices constructed in this unit.



8. APPROACHES OF *INVISIBLE UNIVERSE*

A key area of emphasis for the guide Invisible Universe is an understanding of light sources, detectors, and shields. Students do experiments with fluorescence as well and begin to understand that many items, such as money, can appear very differently under ultraviolet illumination. Students conduct experiments with sources of electromagnetic radiation and materials that can block these different forms.

Sources include:

- TV remote control (IR source)
- Ultraviolet light source (Mercury UVA light)
- AM Radio
- FM Radio

Shields include:

- Aluminum foil
- Window screen

- Plastic
- Paper

Detectors include:

- Eye
- Radio
- CCD Camera
- Ultraviolet sensitive and color changing beads

Other parts of the guide explore the wave nature of light and the different uses for light of different wavelengths. Students also order the different parts of the electromagnetic spectrum by wavelength and gain an understanding of how light waves can be reflected.

9. CONCLUSION

The GEMS program has three teacher s guides that address fundamental issues in light, color, and the electromagnetic spectrum. These guides attempt to address these concepts in a guided inquiry format. They emphasize science process and the characteristic skills of scientists. These guides also address misconceptions in detail and the conceptual change process. This combination of features has made GEMS guides very well accepted by teachers and much enjoyed by students.

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