PROJECT SPECTRA: BUILDING A COGNITIVE MODEL OF REMOTE SENSING INTERPRETATION

AN UNFUNDED PROPOSAL

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1. Project Spectra Abstract

In complex physical science domains such as astronomy and Earth System Science, remote sensing is one of the most commonly-used tools for investigating large-scale phenomena. Some examples include combating forest fires, warning people of deadly storms, monitoring the health of Earth, and searching for life in our solar system. When remote sensing is used in the classroom to investigate similar problems, however, cognitive science research indicates that students' naive conceptions of properties of light interfere with their ability to interpret remotely sensed data. Since the national science education standards emphasize student use of scientific inquiry to investigate problems and since remote sensing interpretation is a form of scientific inquiry, it is essential that students understand the properties of light upon which remote sensing is based.

Project Spectra will develop and test a cognitive model of remote-sensing interpretation that describes the relationship between conceptions of light and conceptions of remote sensing. The final model will propose an optimal developmental sequence by which 7- to 18-year-olds can acquire an understanding of three properties of light that are necessary for proper interpretations of remotely sensed data. These properties are emission of light from a source, propagation of light through space, and interaction of light with other objects.

Using the cognitive model as a guide, project staff will work with middle school teachers to generate instructional prototypes for their students. Students will use a standard computer image processing program to analyze images of astronomical and earth system science phenomena. The image processing activities will help students make connections between their intuitive understanding of

light and the formal concepts involved in processing and interpreting remotely sensed data. In accordance with the developmental model, the exercises will also prepare students to engage in more complex image processing activities at the high school level.

Two types of learning outcomes will be used to compare students in the experimental curriculum with students learning by more conventional methods: (a) Students will be assessed on their understanding of properties of light; and (b) they will be assessed on their ability to use remote sensing to solve problems in astronomy and earth system science.

2. Instructional Problem

Does life exist on other planets?

How do galaxies form?

Basic science questions such as these capture the imagination and interest of scientists and nonscientists alike. It is largely through technological advances in remote sensing and image processing that scientists have been able to make progress on answering them. For example, images from the *Galileo* spacecraft have provided evidence of a potential ocean of liquid water underneath the ice surface of Europa, one of Jupiter's moons. Where there is liquid water, there is the potential of extraterrestrial life (Svitil, 1997). In the debate over the effects of rising CO_2 levels in the Earth's atmosphere, satellite images have served an important function in studies of the role that clouds play in exacerbating or mollifying the greenhouse effect (Karl, Nicholls, & Gregory, 1997). On the question of how galaxies form, the Hubble Space Telescope has recently provided dramatic images that will allow for cross-sectional investigations of galaxy formation (Macchetto & Dickinson, 1997). All three of these investigations use measurements of light as a means to draw inferences about basic phenomena.

The media have been tracking the progress of the scientific community on answering these questions. The number of articles in popular science magazines such as *Scientific American* and *Discover*, and the number of stories in newspapers and on television provide evidence that the general public shares the scientific community's interest in these questions. However, to what extent are high school graduates capable of evaluating the scientific explanations reported in the media and to what extent are these graduates capable of investigating these questions themselves? The overwhelming evidence indicates that in general most students are not very capable. Results from the science component of the National Assessment of Educational Progress (NAEP) have consistently shown that high school students are not able to "analyze scientific procedures, explain how data support a theory, or understand the design of a scientific experiment" (Bruer, 1993, p. 5). In other words, students are capable of reading about the results of scientific research but are not capable of thinking scientifically about important problems (Kuhn, Amsel, & O'Loughlin, 1988).

Currently, there are a variety of efforts underway to reform science education in a way that will help students become capable of thinking scientifically. One of the more prominent efforts in science education reform has been the development of the National Science Education Standards (National Research Council, 1996). The Standards indicates that students will best learn science by engaging in scientific inquiry. This recommendation is consistent with cognitive science principles for teaching complex problem solving. Cognitive science research and development efforts have made great strides in developing activities that engage students in scientific inquiry across a variety of physical science domains (Bruer, 1993).

Much of this work in conceptual change has focused on physical science domains in which students can directly manipulate the phenomena in fields such as electronics (Magnusson, Templin, & Boyle, 1997), mechanics (White & Horwitz, 1988), optics (Reiner, Pea, & Shulman, 1995), and thermodynamics (Linn & Songer, 1991). Very little work has been done on conceptual change in physical science domains in which students cannot manipulate the phenomena such fields as astronomy or Earth System Science. Phenomena in those domains can only be experienced through remote sensing. Our research efforts at the Center for Educational Technologies have begun to uncover ways in which students' underdeveloped conceptions of light interfere with interpretations of remote sensing. For example, research on the *Astronomy Village* multimedia program, developed at the NASA Classroom of the Future, indicates that high school students have difficulty understanding the rate at which light dims as an observer moves away from the source (McGee, Howard, and Hong, 1998). This property of light is fundamental for many of the calculations about remotely sensed data of astronomical phenomena. After engaging in *Astronomy Village*, students took a post-test, which revealed that while they were able to identify the particular class of variable star that was used to determine distance in this investigation, they were not able to use the more general techniques for identifying star types to determine distances. In other words, the process of engaging in the investigation did not prepare students to investigate other similar questions such as the three presented at the beginning of the proposal: Does life exist outside of Earth's atmosphere? What will be the impact of rising levels of CO2 within Earth's atmosphere? How do galaxies form?

In order to think scientifically about these questions, students need to be able to use concepts of emitted and reflected light to draw inferences about the nature of the light source (e.g., Europa's surface, Earth's atmosphere, distant galaxies). The proposed educational intervention will help students develop conceptions of light that can be used to investigate a variety of physical science questions using measurements of light.

COTF is in position to scale up the prototype that will result from Project Spectra. The resulting prototype will be incorporated into future enhancements of *Astronomy Village* and other COTF products. In addition, we will work with representatives of the publishing industry to help textbook publishers learn from the results of this project in order to enhance the design of commercial textbook programs.

3. Relevant Cognitive Science Research

Cognitive science will inform Project Spectra in two ways. First, we will use cognitive science research techniques to inform the development of the educational intervention. Second, the cognitive literature on student conceptions of will light serve as a starting point for investigating students' abilities to draw inferences from measurements of light.

3.1 Task Analysis

There are four basic features of light that are important to an understanding of all applications of remote sensing: (1) A light source **emits** photons at specific wavelengths; (2) Photons are objects that **propagate** through space at a finite speed; (3) Photons **interact** with other objects and are absorbed, refracted, or reflected; (4) An absorbent material can be used to **detect** the number of photons. These four features comprise what we are calling a cognitive model of remote sensing interpretation. For example, astronomers examine the light that is *emitted* by a particular star to determine its type. One of the properties that is determined by the class of stars is the total amount of light that is *emitted,* which can be compared to the total amount of light *detected*. As light *propagates,* it disperses at a measurable rate; therefore, the ratio of the total amount of light *emitted* to the total amount *detected* can be used to determine distance.

In the study of *Astronomy Village*, students were capable of replicating the specific techniques used to determine the distance to a nearby galaxy (McGee, Howard, & Hong, 1998). However, they did not develop the more general conceptions related to the cognitive model of remote sensing interpretation. Therefore, it would be difficult for these students to transfer the specific techniques they replicated into a new domain such as earth system science. The Project Spectra educational intervention will help students develop conceptions related to the cognitive model for remote sensing interpretation through the process of engaging in specific investigations in astronomy and earth system science.

3.2 Student Conceptions of Light

In this section we discuss what the cognitive science community has already uncovered about students' conceptions of light and how these conceptions relate to each of the elements of the cognitive model of remote-sensing interpretation (see Table 1 for a summary).

	Emission	Propagation	Interaction	Detection
Student Conceptions	view light sources as qualitatively different	static illumination or dynamic-directed illumination	view color as a stable trait of the object	visual ray model
Remote Sensing Implications	can determine composition of stars	speed of light, can determine astronomical distances	can determine composition of planets	limitations of the detection device

Table 1: Summary of Cognitive Model of Remote Sensing Interpretation

1. **Emission.** Light occurs when an object emits energy in the form of photons. Individual photons exhibit both a specific wavelength and energy. The nature of the light source determines the number and the range of wavelengths of the emitted photons. The human eye perceives differences in the number of photons as differences in brightness, and differences in the wavelengths as differences in color.

Common Student Conceptions. Before the age of about 13, most students define light in terms of the light source (Guesne, 1985). Students categorize light based on the type of light source: electric light vs. sunlight (Guesne, 1985); white light vs. colored light (Feher & Meyer, 1992). The term *dark* is used to describe the gradations of colored light. The "gradation in darkness goes from black to purple, through green and red to yellow and then to white" (Feher & Meyer, 1992, pp. 516-517).

Implications for Remote Sensing. Scientists determine the composition of a light source based on the spectra of light that is detected. This technique has been used to infer that stars are composed of mostly hydrogen and helium. The students' propensity to categorize the light source depending on the qualities of the perceived light can form the basis for understanding how spectroscopy is used to analyze the composition of a light source. Students could conduct investigations that would determine that the perceived color of light depends on the amount of light at each visible wavelength that is detected.

2. **Propagation.** Photons emanate from a light source in all directions at a finite speed and continue until they are absorbed. As photons propagate away from the light source, they disperse at a measurable rate.

Common Student Conceptions. Students who characterize light based on the light source do not conceive of light as an entity in space propagates away from a light source (Guesne, 1985). Bendall, Goldberg, and Gallili (1993) describe this conception of light as the "static general illumination" model. Students using this model perceive of light as being everywhere. There is no source or detection; light simply exists. This model is commonly used to explain why it is possible to see daylight even when the sun is not in view. Bendall, Goldberg, and Gallili (1993) describe another model that is commonly used to characterize electric light—"dynamic directed illumination." Students using this model perceive that light emanates directly from a light source to an object. They also refer to this as the flashlight model of propagation. Students perceive that light travels in a preferential way from the source to the object. Students who reason with these incomplete models of light propagation have a difficult time explaining why light appears to dim with distance from the source. To explain the dimming of light, students often explain that light loses its energy as it travels from the light source (Bell & Linn, 1997).

Implications for Remote Sensing. Developing and using the conception that light is composed of object (photons) that travel away from the light source is fundamental to the use of remote sensing. The fact that photons travel at a finite speed and disperse at a measurable rate is used in astronomy to determine distances to stellar objects. Students could conduct experiments to measure the speed of light and to measure the rate of dispersion. Without a conception of photons as objects, it is hypothesized that students will find it difficult to understand the next two elements, Interactions and Detection.

3. **Interactions.** As light at a particular wavelength encounters other objects, it can be absorbed, refracted, or reflected. When an object absorbs light, the energy of the light is transferred to other forms of energy such as heat. Light passes through transparent objects; however, as it

passes through its speed is lowered, and thus the path of the light appears to bend. Light bounces off reflective objects.

Common Student Conceptions. Students have a difficult time understanding the interaction of light with objects until they develop a conception of light as photons that propagate in space. There has been quite a bit of work done on students' conceptions related to optics (Reiner, Pea, & Shulman, 1995). In order to accurately predict where an image will appear through various lenses, students need to develop a representation of light as parallel rays. The rays converge or diverge through refraction with the lens (Reiner, Pea, & Shulman, 1995). When trying to explain how light interacts with objects, students tend to view the color of an object as a stable trait of that object as opposed to a perception of the light that is reflected by the object. Therefore, students believe that white light helps us to see the object's inherent color. They believe that colored light interacts with the color of an object. In addition, they believe the object's color is active and can change the color of the light (Feher & Meyer, 1992).

Implications for Remote Sensing. The concept of interactions serves two important purposes in remote sensing. First, scientists design technology to control the light that will be detected. In a telescope, for example, there are lenses to focus the light, filters to block out certain wavelengths, and mirrors to guide the light to the detection device. Second, scientists study the objects that interact with the light (e.g., Earth's atmosphere, planet surface). It will be important to help students to understand that the color of an object is dependent upon the manner in which light interacts with that object.

4. **Detection.** A device is used to record the number of photons received from an object as a function of wavelength and/or configuration.

   Common Student Conceptions. Most studies of student conceptions of light ask students to explain light with reference to their eyes. Students will agree that light enters their eyes, allowing them to see a light bulb when the light bulb is on. However, when the light bulb is off, they do not believe that there is light entering their eyes. Instead, students believe that there are visual rays that are projected from the eye, enabling them to see an object (Fetherstonhaugh & Treagust, 1992).

Implications for Remote Sensing. To our knowledge, there have been no studies of students' conceptions of exposure time. There are several characteristics of image processing that can only be explained through tradeoffs in the exposure time. In order to see remote galaxies, it is necessary to have long exposure times. However, if there are any nearby stars in the field of view, the stars will become over-exposed and a cross-spike will appear over the star. If students do not understand the limitations of the detection device and maintain the dynamic-directed illumination model, they might perceive this cross-spike as a feature of starlight.

Current research literature on students' conceptions of light serves as a starting point for Project Spectra. We propose to contribute to this body of literature by focusing on how the conceptions revealed by these studies impact students' abilities to interpret remotely sensed data. Project Spectra will also investigate how these conceptions interact with each other as students try to manage all four elements of the cognitive model of remote-sensing interpretation.

	Year 1	**Year 2**	**Year 3**	**Year 4**
Develop/Refine Cognitive Model	•	•	•	•
Design Remote Sensing Activities	•	•	•	•
Design Hands On Light Activities		•	•	•
Design Lesson Units			•	•
Evaluation				•

Table 2: Summary of Tasks and Timeline

4. Proposed Educational Intervention

Project Spectra will develop and test a cognitive model of remote-sensing interpretation that describes the relationship between conceptions of light and conceptions of remote sensing (see Table 2 for a summary of tasks and timeline). The resulting model will propose an optimal developmental sequence by which 7- to 18-year-olds can acquire an understanding of three of the four properties of light that are necessary for proper interpretations of remotely sensed data: emission, propagation, and interaction. Project investigators have begun discussions with three middle school teachers, who have participated in past COTF activities, to become Project Spectra teachers. They will use the cognitive model of remote sensing interpretation to design and implement activities in their classrooms. The teachers will be paid $1000 stipend each year for participating in the project.

4.1 Initial Remote Sensing Activities

Through a task analysis, we have identified two remote-sensing activities that together require an understanding of emission, propagation, and interaction. The first remote-sensing activity is measuring the distance to galaxies. Before studying how galaxies form, it is important to determine the distance to and thus the age of the galaxy. As indicated above, this activity will require that students understand that the spectra of light emitted from a source can be used to categorize that source. The activity will also require students to understand that light disperses as it propagates such that the distance can be determined by knowing the actual brightness and the apparent brightness of a light source.

The second remote-sensing activity is searching for chlorophyll in remotely-sensed images. This is a technique that astronomers have used to search for life on other planets. In addition, earth system scientists use this technique to investigate life on earth. Chlorophyll has a unique property that allows it to reflect infrared radiation. This property helps a plant regulate its body temperature. Thus, green, inanimate objects are indistinguishable from chlorophyll when measured in the visible spectrum. However, in images taken at the infrared spectrum, chlorophyll will appear as a bright object relative to inanimate objects. This activity will require students to understand how light interacts with different objects.

4.2 Develop and Refine Cognitive Model

During the summer of Year 1, project investigators will conduct a cross-sectional study of conceptions of light and remote sensing. The cross sectional study will encompass students in elementary school (N=20), middle school (N=20), and high school (N=20). Existing protocols for assessing student conceptions of light will be identified from the literature and administered. In addition, students will engage in the galaxy distance and chlorophyll activities. Given the variety of ages that will be engaging in the study, the protocols will be tailored to the appropriate age level. The study will use think-aloud protocols and question prompts to elicit student conceptions of light and remote sensing. Analysis of student responses will focus on understanding how students' understanding of the three properties of light develops in relationship to their understanding of the remote-sensing activities. By December of Year 1, project investigators will propose a developmental sequence that will describe how the understanding of light influences the kinds of remote-sensing activities that students can engage in.

During winter and spring of Year 1, these teachers will collaborate with project investigators to use the cognitive model of remote sensing interpretation in developing remote-sensing activities that middle schools would be likely to accomplish successfully. In addition, the teachers will develop remote sensing activities that the cognitive model of remote sensing interpretation predicts will be too difficult for middle school students. Prior to engaging in the remote sensing activities, students will be assessed for their conceptions of light using protocols refined from the summer study. The teachers will conduct both the middle-school- appropriate- and the complex-remote-sensing activities at their schools. Based on the cognitive model, students should be able to accomplish the middle-school-appropriate-remote-sensing activities, but they should not be able to accomplish the complex-remote-sensing activities. This study will serve to verify the cognitive model though the process of making predictions and testing them. This process of testing and refining the model will continue through the life of the project.

4.3 Develop Hands-On Light Activities

In the second year the project investigators will begin collaborating on the design of hands-on activities intended to increase students' understanding of the properties of light that the cognitive model has identified as critical for understanding remote sensing. Using the cognitive model as a guide, project staff will work with middle school teachers to generate instructional prototypes for their students.

Based on the task analysis of remote sensing, we have identified several potential hands-on activities that might facilitate students remote-sensing abilities. Students can explore some of the basic properties of light emission, propagation of light through space, and the interaction of light with matter by doing the following activities.

Viewing Typical Spectra. Students view light from several different sources using a simple, hand-held diffraction-grating spectroscope. The objects viewed can include fluorescent lights in the classroom, different types of street lights, ordinary incandescent light bulbs, brightly illuminated solid surfaces, and a series of low-pressure fluorescent light tubes, each filled with a different pure gas or mixture of gases. The objectives are to have students see that there are different types of light sources; recognize the basic types of light spectra (sharp emission line spectra from the light tubes and some street lights, broad emission line spectra from most street lights and ordinary fluorescent lights, and continuous spectra from incandescent light bulbs); and, perceive that each type of material displays a distinct spectrum.

Viewing the Solar Spectrum. Students will examine the spectrum of the Sun with a simple spectroscope made from a large prism. The spectrum will be sufficiently dispersed to show the dark spectral lines in the otherwise bright solar spectrum. This is an absorption spectrum, the last important type of spectrum. Students should compare the patterns and positions of the dark lines in the solar spectrum with the lines in the spectrum of the low-pressure fluorescent lights. The objectives are to illustrate an absorption spectrum and help students understand that the dark lines in the solar spectrum correspond to the bright lines in the emission spectra of gases in low-pressure fluorescent lights, which have the same composition as the solar atmosphere.

Multispectral Digital Photography. The students will photograph several familiar objects (cars, buildings, each other, etc.) in different colors using a set of color filters mounted on a digital camera. Specific objects should include at least one image including both green vegetation and another green object like a green car or a green rock. The students will then use computer software such as NIH or PC Image to combine the single-color images in different ways to form true and false color composites. The objectives are to help students recognize different reflective properties of objects familiar to them and to see how particular types of color composites are used to recognize different types of materials, even from great distances. In particular, students will see the distinct spectral response of green vegetation.

Inverse Square Law of Light Propagation. Students will use a light meter to measure the energy per unit area from a point light source at different distances away from the source. The light meter will be mounted on an optical bench for precise distance measurements. The measured energy will then be graphed as a function of distance from the source to illustrate that the energy decreases as the square of the distance from the source. The objective is to let students explore an aspect of light propagation important in astronomical applications.

During the summer of Year 2, investigators will conduct an experimental study focusing on middle school students. The students will be assessed on their understanding of the conceptions of light. They will engage in the hands-on activities designed by the teachers and researchers. After engaging in the hands-on activities, the students will be assessed again on their understanding of the properties of light to determine if their understanding has increased. Then students will engage in the middle-school-appropriate- and the complex-remote-sensing activities. If the hands-on activities were successful at increasing students' understanding of the properties of light, it should increase their ability to successfully complete the complex-remote-sensing activities. The treatment group will be compared to a control group that will study the properties of light using multimedia presentation materials. During the school year of Year 2, the teachers and researchers will refine the hands-on and remote-sensing activities based on the summer experiment. These refined activities will be tested in the middle school classrooms in an attempt to improve upon the results received during the summer.

4.4 Developing Lesson Units

During Year 3, the teachers will create lesson units that combine hands-on light activities with remote-sensing activities to help students learn about a phenomena. For example, if one of the teachers is teaching astronomy and wants students to investigate how galaxies form, she can begin with hands-on light activities that increase students' understanding of relevant properties of light. These would be activities related to identifying light sources from their spectra and deriving the inverse square law. The next part of the unit would focus on applying that knowledge of light to remote sensing. The students would now be able to classify stars of known distances to determine their absolute brightness and would be able to determine distances to more distant objects. Finally, students would now be ready to use remote sensing to investigate how galaxies form. Using the cognitive model as a guide, the teacher could arrange activities so that they led into future activities. This strategy is usually referred to as the vertical curriculum (Tanner, 1997). With this modular approach, teachers do not have to teach units in a continuous fashion. The investigations of light could be taught at one grade level, and then the applications of remote sensing could be taught at a subsequent grade level, provided that the hands-on activities could support actual movement along the developmental sequence as opposed to short-term retention.

5. Experimental Design to Assess the Intervention

One of the main findings within cognitive science is that students learn best by solving problems. In order to test whether the lesson units that the teachers design will indeed support greater learning through problem-solving, the researchers will conduct a classroom-based evaluation of select units during the Year 4. These problem-solving units will be compared to units that present the same topics through a more conventional approach. Students in the conventional group will use textbooks and multimedia resources to study the same topics. The treatment group will consist of 2 to 3 units that will demonstrate links between each of the critical properties of light and their application in remote sensing. The three Project Spectra teachers will serve as treatment group teachers. A variety of quasi-experimental designs will be explored to maximize the power compare treatment and control groups within the constraints of curriculum scheduling.

Two types of learning outcomes will be used to compare students in the experimental curriculum with students learning by more conventional methods: (a) Students will be assessed on their understanding of properties of light; and (b), they will be assessed on their ability to use remote sensing to solve problems in astronomy and earth system science.

6. Conclusion

During the final six months of the project (January 2002–May 2002), we will engage in a variety of activities in preparation to sustaining and scaling up the results of this project once funding is completed. During the entire course of the project, we will share our results with product development teams at the NASA Classroom of the Future program, which is also a program at the Center for Educational Technologies. This sharing will enable COTF to incorporate the remote-sensing units into their product development.

We recognize that textbooks remain the most prominent source for classroom activities (Matti, Soar, Hudson, and Weiss, 1995). The evaluation of Project Spectra is designed to provide results that will be informative to textbook publishers. While the purpose of Project Spectra is to develop a prototype and not a publishable product, we feel it is important for us to work with representatives of the publishing industry so that they will understand the results of Project Spectra and will be able to recognize how the cognitive science techniques can be applied to the development of curriculum programs. We will actively seek partnerships with publishers to participate in Project Spectra at the publishers' expense. Through these partnerships we will encourage them to apply the cognitive science results of Project Spectra to the design of their curriculum programs.

If funded, Project Spectra, through the application of cognitive science, has the potential to significantly impact science education reform. The design and evaluation of the instructional prototype will contribute to our understanding of students' conceptions of light and how those conceptions of light impact their ability to use remote sensing in complex physical science domains such as astronomy and Earth System Science. Through its partnerships with K-12 schools, with NASA Classroom of the Future, and with members of the publishing industry, Project Spectra will germinate the seed money provided by the McDonnell Foundation and will thus nurture reform efforts for many years to come.

7. References

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