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## Invisible Misconceptions: Student Understanding of Ultraviolet and Infrared Radiation

**Julie C. Libarkin**

Geocognition Research Laboratory, Department of Geological Sciences, Michigan State University, East Lansing, Michigan 48824

**Anila Asghar**

Department of Integrated Studies in Education, McGill University, Montreal, Quebec, Canada H3A 1Y2

**C. Crockett**

Science Education Department, Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts 02138

**Philip Sadler**

Science Education Department, Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts 02138

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### Abstract

The importance of nonvisible wavelengths for the study of astronomy suggests that student understanding of nonvisible light is an important consideration in astronomy classrooms. Questionnaires, interviews, and panel discussions were used to investigate 6–12 student and teacher conceptions of ultraviolet (UV) and infrared (IR). Alternative conceptions about the characteristics and human sensual perception of visible light, UV and IR, were observed in many students and in a subset of teachers. Instruction involving electromagnetic radiation should first address preexisting alternative conceptions, and conceptual questionnaires such as the one used here can help teachers to identify student ideas prior to instruction.

## 1. INTRODUCTION

Conceptual understanding of visible light is a highly developed field of research in science education. Student ideas about vision, light propagation, optics, and light characteristics are well understood (Piaget 1974; Guesne 1985; Ramadas and Driver 1989; Feher and Meyer 1992; Shapiro 1994a; Shapiro 1994b; Galili and Hazan 2000). Additionally, researchers have explored the effects of both student preconceptions and instruction on learning (Fetherstonhaugh and Treagust 1992). Consequently, research into conceptions of visible light has moved far beyond the simple identification of commonsense beliefs and student ideas. Current research is actively documenting how and why beliefs about visible light develop and change. However, human interactions with light are not limited to the visible spectrum. Media exposure (e.g., Johnson 2001) focuses routinely on two types of invisible radiation: ultraviolet and infrared. Additionally, these radiations, particularly ultraviolet, are becoming an integral part of science curricula, especially those that focus on climate change. The science benchmarks developed by the American Association for the Advancement of Science (AAAS) include the following concepts related to the electromagnetic spectrum: electromagnetic waves, radio waves, microwaves, infrared waves, visible light, ultraviolet rays, X-rays, and gamma rays (AAAS 2009).

Our research question focuses on student ideas about ultraviolet (UV) and infrared (IR) radiation. Although several classroom experiment designs related to exploring UV have been published (e.g., Abney and Scalettar 1998), only a few studies addressing conceptual understanding of UV and no studies of IR have been published.

Boyes and Stanisstreet (1998) explored student perceptions of the links between UV, the ozone layer, and skin cancer. A questionnaire distributed to 647 students (ages 13–14) contained 11 statements, each of which suggested causal links between these and other phenomena such as heat flux. The researchers found that only 10% of the participants held a scientific view: that ozone depletion may cause increased UV, which may lead to increased skin cancer rates. Leighton and Bisanz (2003) and Boyes, Stanisstreet, and Papantoniou (1999) extended this work through interviews conducted with 117 K-5 students and adults and 115 high school students, respectively. Both studies confirmed the earlier finding that students hold nonscientific models about skin cancer and its relationship to UV. Suping (2004) studied Botswana students' understanding of UV and its effect on human health, identifying several key areas of knowledge about UV. In particular, students were very aware of diseases related to UV and ways in which people can protect themselves against UV. These studies do not systematically explore fundamental student understanding of UV, but rather embed the study of UV in a discussion of human health and/or the Sun's *harmful* effects. In this study, we are interested in documenting students' (grades 6–12), teachers', and scientists' models about visible and invisible radiation. Other studies have addressed student ideas about radiation in the context of climate change (Rye, Rubba, and Wiesenmayer 1997; Hansen 2010). Development of a concept inventory to measure student understanding of light and spectroscopy (Bardar *et al.* 2007) has provided some insight into entry-level college students' understanding of light. In particular, results suggest that college students enter classrooms understanding 25–30% of the basic light and spectroscopy concepts covered in entry-level astronomy courses (Bardar 2008). Overall, these studies have found that students rarely understand the difference between incoming solar radiation and the infrared energy emitted toward space by Earth.

Conceptions of visible light have been extensively studied among elementary and middle school students, especially with respect to mechanisms of light transmission (Ramadas and Driver 1989; Fetherstonhaugh and Treagust 1992), characteristics of light (Ramadas and Driver 1989; Feher and Meyer 1992), optics (Galili and Hazan 1985, 2000), and vision (Piaget 1972; Guesne 1985). The majority of earlier studies deal with K-6 students, with a few later studies focusing on high school students (i.e., Ramadas and Driver 1989). Shapiro (1994b) gives a useful overview of key areas of the relevant research. In general, these studies focus on two aspects of conceptions research, pervasive ideas and effects of instruction.

Researchers in all areas of science education have noted that students (and adults) often hold commonsense beliefs that derive from their perceptual experiences (e.g., Halloun and Hestenes 1985). A variety of perceptions related to vision have been reported. Early on, Piaget (1972) documented one of the most widely held ideas in a study of children, the concept of “eye-centered” vision. When probed, students described vision as a process that begins in the eye, with transmission (sometimes of light) from the eye toward the observed object. This pervasive idea has been redocumented in a number of studies of similar aged and older children (Fetherstonhaugh and Treagust 1992, and references therein), including this one. Additionally, a number of participants fail to mention the eye or the eye's role in detecting light (Guesne 1985).

Ideas firmly held by students will directly impact the ability of instructors to help their students to reconstruct their existing knowledge and gain new scientific insights. A variety of anthropological studies have attempted to develop an understanding of student viewpoints (Brook, Briggs, and Driver 1984), as well as a clear picture of the intersection between preconceptions and instruction (Solomon 1984). Fetherstonhaugh and Treagust (1992) suggest that science teachers must understand the student perspective before attempting to teach new scientific ideas. It is important to diagnose students' thinking through formal diagnostic testing or open-ended verbal and pictorial student descriptions. It is particularly important for students to examine their own and the teachers' models during instruction. Scientific paradigms must be introduced carefully especially in those instances where commonsense beliefs are at odds with the scientific perspective (Driver 1985; Driver and Russel 1982; Harlen 1987). As a consequence, it is vital that we provide teachers and curriculum developers with evidence of commonly held ideas.

## 1.1. Objectives of the Present Study

In the present study, the extensive research on visible light has been extended to include other familiar forms of electromagnetic radiation, namely UV and IR. In particular, this research (a) determines common ideas held by students and adults about UV; (b) reveals the extent of student and adult exposure to ideas about UV and IR; (c) demonstrates the links between understanding of visible light and other forms of electromagnetic radiation; and (d) suggests implications for curriculum, especially content that requires understanding of radiation, light, and UV. In particular, we address the implications that this research has for astronomy and climate change education, including the development of efficient questionnaire tools.

## 2. METHODS

Research was conducted using two primary modes of investigation: questionnaires and open-ended interviews. Questionnaires were designed to uncover participant ideas about UV and IR. To allow for a connection with the existing literature, most of which focuses solely on visible light, several questions related to visible light were also included (Appendix). 283 grade 6–12 US students, 33 teachers and 8 scientists, an expert control, completed the questionnaire; nine teachers and all scientists completed the questionnaire online. Semistructured interviews of students and scientists and a panel discussion with eight teachers were conducted as a follow-up to the questionnaire. Eleven 7th–8th grade students participated in in-depth interviews that probed visible light, UV and IR in detail, using the questionnaire as a basis for discussion, and three scientists were interviewed to document the expert framework.

Eight teachers were recruited to take and discuss a pilot version of this survey; an additional nine teachers completed the pilot version online. This pilot was modified to the current version of the questionnaire (Appendix) through: (1) substitution of “apple” for “white paper” in question 4, since some paper dyes absorb UV and emit in the visible spectrum and (2) modification of question 5. This question originally asked participants to choose the complete pathway that light takes during vision, which required a large number of possible choices. The current version asks participants to identify the subpathways that light takes, such as “Light from her eye must reach the tree.” Participants are then asked to identify which subpath occurs first. These modifications were based upon written and oral comments made by teachers during the panel discussion. The remaining questions are related to IR. In initial conversations with students, we found that very few had heard of infrared radiation. Therefore, we explored student understanding of IR through a simple question asking students what they would like to know about IR (Appendix). Teachers and scientists were asked to describe the relationship between visible light, UV, and IR, and to explain the term “electromagnetic radiation.”

In all, 283 students from the northeastern USA and five different grade 7–12 classes, 16 additional teachers, and 8 scientists were recruited to complete the modified questionnaire (Table 1). The 33 participating science teachers had 2–33 years of teaching experience, were teaching in 11 USA states, and were teaching grades 6–12 at the time of the study. Eight scientists also completed the survey as an expert group to allow us to compare student and teacher ideas to an accepted norm. Six of the scientists were actively engaged in scientific research, one scientist was working as a community college science professor, and one scientist self-described as an administrator. Interviewees were pulled from these teacher and scientist participants; an additional scientist (male, 31) participated in an interview but did not complete the survey.

### 2.1. Data Analysis

Questionnaire responses were analyzed via thematic content analysis (e.g., Patton 1990), wherein themes are allowed to emerge naturally from the data, with coding supported by probing during interviews. Participants’ responses to multiple-choice questions and explanations of their responses were tabulated electronically. Open-ended responses were coded thematically to capture important ideas and misconceptions expressed by the participants in relation to visible light, UV, and IR. Codes were grouped into broader categories and general themes as shown in Figure 2 and described in the results text. Two of the authors analyzed student open-ended responses collaboratively to ensure agreement in coding and establishing inter reliability for open-ended questions.

**Table 1. Study population completing survey.**

Cohort	Number of Participants	Mean Age (years)	Females <sup>a</sup>	Males <sup>a</sup>
7th grade	106	12.8 ± 0.56	51	43
8th grade	57	13.5 ± 0.64	37	18
9th grade	58	15.0 ± 0.72	30	28
11th/12th grade	62	17.3 ± 0.70	26	36
Teachers	33	41.5 ± 0.10.5	12	18
Scientists	8	Over 50	0	8

<sup>a</sup>Gender was not identified by all participants.

## 2.2. Validity and Reliability

The questions related to visible light included in this questionnaire (Appendix) were generated from review of the extensive literature on children’s understanding of visible light and vision. We view this grounding in the research literature as a significant measure of the usability of these tasks for eliciting light concepts. In addition, piloting of these questions allowed revision of the instrument as described above. Responses to the pilot questionnaire indicated that teachers were able to understand and respond to the tasks and questions, and did not feel that these tasks were too simplistic or difficult for 7th–12th grade students.

Additional aspects of qualitative validity and reliability were addressed during this study. In particular, the credibility and dependability (e.g., Lincoln and Guba 1985) of the research findings are supported by the study population and prior work. Credibility, the level to which the study participants agree with the research findings and interpretations, was evaluated through consideration of interviews conducted with students. Probing interviews with a small subset of students indicated that our interpretations of written responses were consistent with the intent of the interviewed students. Dependability, which in part is the level to which study findings are repeatable and stable over time, can be investigated through comparison with findings of other studies. Although investigation of student understanding of UV is limited, our findings with relation to vision and visible light are very consistent with thirty years of similar research.

## 3. ANALYSIS AND RESULTS

### 3.1. Visible Light

Analysis of questionnaire data suggests that a significant number of students believe that it is possible to see objects in the absence of visible light (Table 2). As students get older, the proportion of students that believe light is necessary for vision increases, from 22–25% in 7th–9th grades to 52% in 11/12th grade. Students were comfortable answering and explaining this question, with only one 7th grade student failing to respond. The range of objects that students believe are visible in complete darkness also narrows as students get older. Almost one-third of 7th–9th graders believed paper would be visible in complete darkness; by 11/12th grade only one student believed paper would be visible. Similarly, 71% of 7th–9th graders believe cats’ eyes would be visible in the dark, while only 47% of 11/12th graders holds a similar belief. These effects may be related to the fact that the 11/12th grade students in this study were enrolled in physics courses, which should result in a self-selection toward the more knowledgeable students. The fact that almost half of the high school physics students polled believe that cat’s eyes are visible in complete darkness has serious implications for how and what we teach students prior to their enrollment in high school physics, as well as how we approach these subjects in physics.

The explanations given by students for the visibility of objects in darkness indicates a heavy reliance on personal experiences, as would be expected. The most prominent responses reflected personal interactions with cats, such as “I can see my cat’s eyes at night” (7th grade, female), “I have seen my cats eyes in a completley [sic] dark

**Table 2. Student and adult ideas about visibility in complete darkness and in the presence of ultraviolet (UV) radiation.**

	Nothing		Cat’s eyes		Paper	Apple	Dime		No Response		Cat’s can see in dark
	V	UV	V	UV			V	UV	V	UV	
<b>7th</b> (n = 106)	25	19	75	47	32	31	4	52	1	9	81 (76%)
<b>8th</b> (n = 57)	14	11	40	36	15	22	3	17	0	2	42 (74%)
<b>9th</b> (n = 58)	13	11	41	29	18	20	0	20	0	4	47 (81%)
<b>11/12th</b> (n = 62)	32	17	29	31	1	13	1	6	0	3	37 (60%)
<b>All students</b> (n = 283)	84	58	185	174	66	86	8	125	1	18	207 (73%)
<b>Teachers</b> (n = 33)	29	28	3	4	2	1	1	3	0	1	4 (12%)
<b>Scientists</b> (n = 8) <sup>a</sup>	8	7	0	1	0	1	0	0	0	0	0

Note: Some participants chose more than one object.

<sup>a</sup>The scientist claiming that cat’s eyes and apples would be visible in the presence of UV described himself as a “bureaucrat.”

basement” (9th grade, female), and “I have seen cats eyes in the dark” (11/12th grade, male). In addition, many students claimed that cat’s eyes “glow,” “light up,” “emit light,” or have their own “internal light source.” The idea that cats’ eyes simply reflect ambient light was present in only a small fraction of student questionnaire responses. In interviews, participants called upon physical or vicarious experience to reinforce the idea of visible cat’s eyes, pointing out that in “darkness,” the eyes of cats are often visible and appear to be glowing. Students had either experienced this themselves or had seen a movie or read a book depicting this event. When probed during interviews, some students explained that cats must have an internal source of light that causes their eyes to glow.

Explanations provided on questionnaires for the visibility of white paper relied most heavily on the color of paper, rather than internal sources of light, for instance: “White is not a color, so you don’t need light to see it” (7th grade, female), “white paper stands out in the dark because it’s white” (8th grade, male), “the paper because it reflects all colors” (9th grade, male), and “After your eyes adjust to the dark its easier to see bright things” (11/12th grade, female). The nine students who believed a dime would be visible stressed the fact that dimes are shiny.

Among teachers and scientists, the idea that light is necessary for vision dominated. Those few adults who believed that objects could be visible in darkness provided no explanation or used the same arguments as their students. Of the 33 teachers, 29 correctly responded that it would be impossible to see in a completely dark room, explaining with comments such as: “If there is no light at all then there is nothing to reflect off an object into your eyes.” Three teachers believed, like most students, that cat’s eyes are visible in complete darkness, and the remaining teacher believed that paper would be visible, stating, “Eyes always see white first” (7th–8th grade science teacher, male, 26 years experience). One middle school science teacher (male, 6 years experience) provided a sophisticated, albeit incorrect, reason for the visibility of cat’s eyes, stating, “There are specific chemicals that certain animals genetically have, the species cats are one of those animals whose eyes provide a specific fluorescence [sic] stimulus that allows us to see [their] eyes in the dark.” One 7th–8th grade science teacher (female, 13 years experience) believed that all objects in the room would be visible. Finally, one teacher with 2 years of experience indicated that vision in a dark room is impossible, although he expressed an internal conflict between the scientific perspective and his instincts: “There is no light to detect. But I want to say the paper.” All eight of the scientists agreed that it would be impossible to see any object in a completely dark room.

## 3.2. Vision

Understanding of vision and the pathways taken by light as vision occurs increases as students get older. Only 0.9% of 7th graders were able to accurately identify the pathways taken by light during vision (Appendix, question 5). This percentage increases slightly to 3.5% in 8th grade, 5% in 9th grade, and 8% in 11/12th grade. 55% of teachers correctly identified the pathways taken by light during vision. Participants were also asked to indicate which path light must take first before vision can occur (Appendix, question 6). Students were more aware of the necessary first step, with similar improvements across grades. In 7th grade, 17% of students were aware that light must first travel from the Sun or other source of light; this number increases to 35% in 11/12th grade. 79% of teachers were aware of the first step on the road to vision. Although this improvement, albeit small, suggests that students are improving their understanding as education progresses, these numbers may be indicative of the teaching of an incorrect idea, namely “eye-centered” vision.

As with [Piaget’s \(1972\)](#) study, a significant number of students exhibited an eye-centered perspective of vision. Surprisingly, the incidence of this idea actually increases as students get older. 24% of 7th grade students, 37% of 8th grade students, and 50% of 9th grade students believed that the eye projects light to an object; it is this passage that allows an individual to see. Similar to 9th graders, 48% of 11/12th grade students, enrolled in a high school physics course, believed that vision requires projection of light from the eye. 42% of teachers believed that vision is eye-centered. Two of eight scientists also agreed with this “eye-centered” perspective; one described himself as an administrator and the other holds only a Master’s degree in astronomy. Given the facts that the prevalence of eye-centered ideas actually increases as students move through school, from 24% of students in 7th grade to 50% in 9th–12th grade, and that teachers themselves have a high prevalence of this common alternative conception, it seems likely that teachers may actually be teaching incorrect ideas to students.

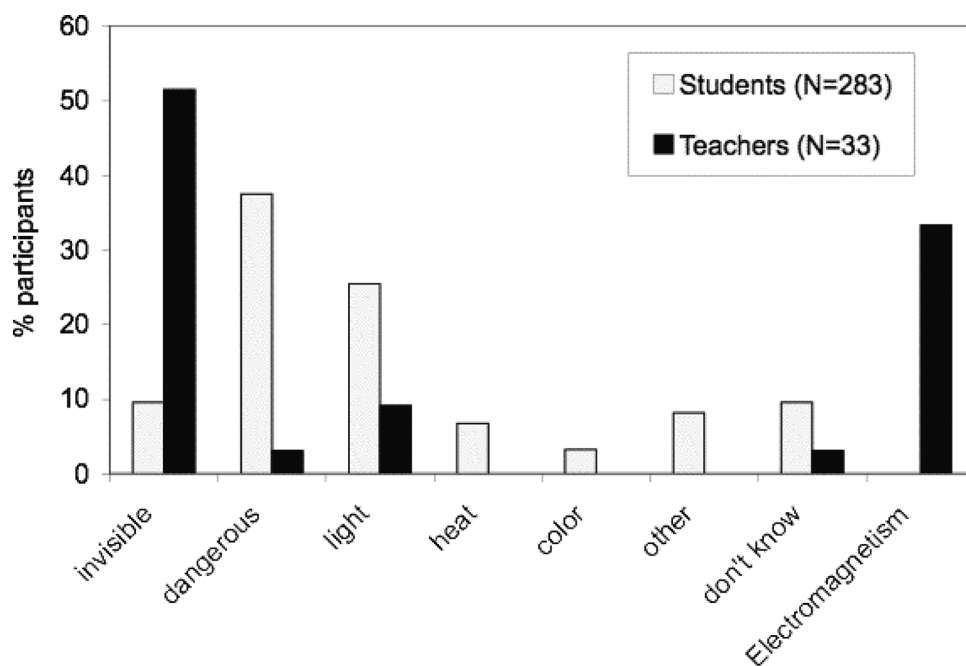
## 3.3. Ultraviolet Radiation (UV)

Students had a variety of ideas about the meaning of the term “ultraviolet radiation” (Figure 1). Approximately 80% of students believed that UV originates from the Sun. This common response may be the result of the wording used in the questionnaire to scaffold students from common experiences to a discussion of UV, “People often wear sunscreen when they go out on a sunny day. People wear sunscreen because of ultraviolet radiation”

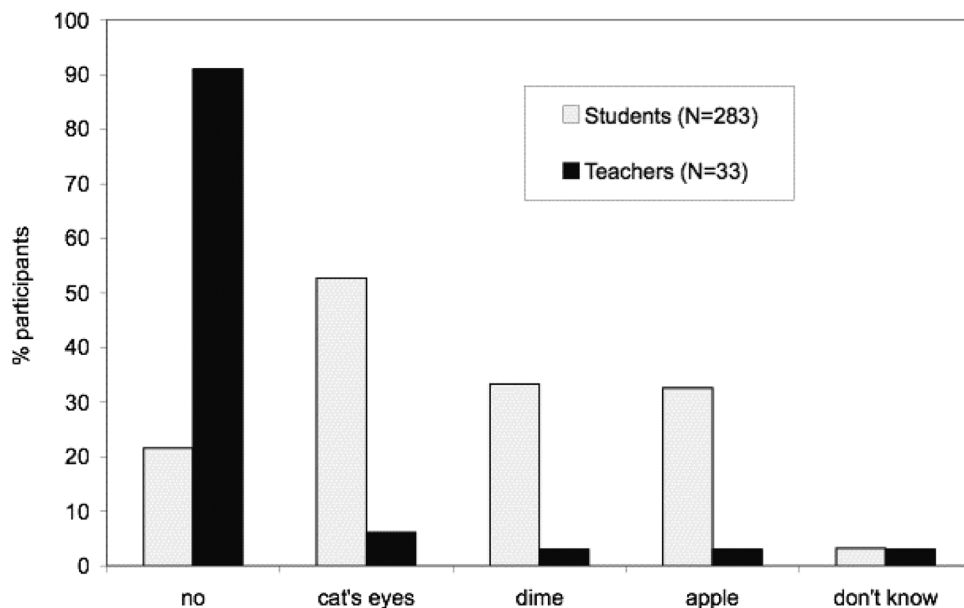
(Appendix). However, in interviews, all 11 students were aware that ultraviolet radiation can originate from the Sun, with most students believing that the Sun is the only source of UV, or that all solar light is UV in nature. Alternative responses included: “certain lights,” “chemicals,” “when your skin is not protected it will happen,” “a plant called a violet,” “heat,” “objects that are used for tanning,” “visible light,” and “hole in the ozone layer.” Approximately 7% of students did not respond to this question. Although most students were aware of the primary source of UV on Earth, the Sun, very few students understood that UV is a form of electromagnetic radiation. Most students described UV as “light,” “bright light,” “strong rays,” “very violet,” “a color like red, blue, purple light,” or “harmful rays.” Additionally, 30% of the students freely associated UV with “sunburn” and “skin cancer.” Probing during interviews indicated that although students had been exposed to the term “ultraviolet” through the media, personal, or classroom experiences, very few had a clear conception of its meaning and impact on their lives. In all, only 9.5% of all students described ultraviolet light as “invisible” light.

Teachers were generally more aware of the origin and explanation of UV, although a significant number of our teacher participants expressed some uncertainties. 88% of teachers, like their students, were aware that ultraviolet radiation can originate from the Sun. Only 55%, however, provide scientifically accurate and complete definitions for ultraviolet radiation. Alternative teacher responses generally incorporated scientific terminology, and included ideas that ultraviolet light is “Gamma rays in the light?,” “sun burn or a particular range on the electromagnetic,” “Rays of the sun that the eye cannot picture” and “Rays from the sun.” A small number, about 12%, of teachers freely associated UV with sunburn or skin damage when providing an explanation for the term “ultraviolet,” in contrast with 30% of students. Only one teacher mentioned the many positive uses for UV, “[UV] can create either a positive or negative effect to surfaces such as the skin of animals as well as plants. It also has many other positive medical effects.” All scientist participants related a correct understanding of the invisible nature of UV, and none described UV as dangerous in any way while defining the term “ultraviolet.”

Analysis of questionnaire data (Appendix, question 4) indicates that a significant number of students, almost 80%, believe that it is possible to see objects in the presence of ultraviolet light alone (Table 1; Figure 1). Indeed, even those students who believed that light was necessary for vision believed that UV, since it was a type of “light,” would allow vision to occur. Unlike the connection observed between maturation and changes in ideas about visible light, this idea does not change as students get older. In addition, students were more uncomfortable discussing UV than visible light; eighteen students failed to respond to question 4 and during interview discussions were more hesitant. As with visible light, over half of the students believed that cats’ eyes would be visible under UV. Interestingly, 125 students believed that a dime would be visible under UV light, as opposed to nine with visible light. Explanations for this included “a dime is shiny” (7th grade, male), “because the



**Figure 1.** Terms used by students and teachers in their explanations of “ultraviolet radiation.” Notice that over half of teachers used the term “invisible,” and over 30% used the concept of “electromagnetism.” Almost 30% of students thought of UV as dangerous in addition to a wide array of other ideas described in the text.



**Figure 2.** Prevalence of alternative conceptions of the visibility of objects in UV. The majority of teachers in this study recognized that objects would not be visible in UV, while 80% of students believed a wide array of objects would be visible.

ultraviolet [sic] radiation will make it shine better” (8th grade, female), and “a dime is a metal and the dime will shine due to the UV radiation” (11/12th grade, male, Figure 2).

Finally, explanations given for the belief that objects are visible in ultraviolet light can be placed in four categories: (1) *Only cat's eyes would be visible*. It is not possible to see in UV, but cat's eyes have an internal light source. (2) *All objects are visible*. UV is a type of light therefore everything would be visible. These two categories dominate the discussion. (3) *Responses related to personal experiences or previous education*. Most of these seem to be related to experiences or education revolving around black or fluorescent light: “Ultraviolet lights reflect their ‘rays’...off of something light colored like white (especially). You can see this @ the aquarium [sic] on that spiral walkway” (7th grade, female); “because Germs are on apples and money so you could be able to see the germs on the objects” (8th grade, female); “UV light tends to travel or attack living organisms” (11/12th grade, male); and “Because it is what helps the apple grow” (9th grade, female). These latter comments may also be related to formal educational experiences. Similar to findings with visible light, teachers, and scientists were fairly well versed in the functioning of vision in the presence of UV (Table 1).

### 3.4. Infrared Radiation (IR)

In initial conversations with students, we found that very few had heard of infrared radiation. Therefore, we explored student understanding of IR through a simple question: “You probably have heard about another kind of radiation called infrared. What would you like to ask your teacher about infrared radiation?” Most students simply wanted to know what IR is, what it does, and where it comes from. Other students asked: *How dangerous is IR?*; *How can IR affect your skin?*; *Why is IR red?*; *Can we experiment with IR?*; and *How is IR used?* Although preliminary, we view this data as an important first step in revealing preconceptions, or lack of exposure, that are important when discussing IR in the classroom.

Teachers expressed a range of familiarity with the relationships between IR, UV, and electromagnetic radiation. Twenty three teachers used concepts of waves, electromagnetic radiation, and/or energy spectra to explain the relationships between these phenomena; three teachers simply described a common source for these radiations, the Sun. Remaining teachers expressed uncertainty about these concepts, either not answering the question or providing ambiguous responses, such as “people see things and feel things through these” (7th–8th grade science teacher, male, 26 years experience; this teacher also believed white paper would be visible in complete darkness). Four teachers provided sophisticated explanations about these relationships, invoking electric and magnetic fields to tie the phenomena together; for example, “Light is a form of electromagnetic radiation. This is energy produced by vibrating electrons affecting electric and magnetic fields that travels through ‘SPACE’ at the speed of light. Visible light is a small portion of this energy” (5th–8th grade science teacher, male, 3.5 years experience, 51 years old). A fifth teacher provided a similar explanation with a much lower level of

understanding: “[There] is an energy that [is] produced between electricity and magnet that produces light in the form of radiation” (middle school science teacher, male, 6–10 years experience). Overall, teachers are familiar with electromagnetic radiation of all types, with varying levels of conceptual understanding.

During an interview, one physicist (male, 31 years old) explained both the common notions about types of electromagnetic radiation as well as the scientific ambiguity that surrounds this idea:

[electromagnetic radiation is an] oscillation of the electromagnetic field generated by movement of charged particles...it’s unknown what it is except that it is detectable by the force that it exerts on other charged particles. [What is] interesting is people studied the forces of charged particles that they could make in the lab, they could make currents...this didn’t lead to electromagnetic radiation and...they had light, but initially the subject of the study of forces on charged particles was separate from the study of light. Eventually they found the right equations that described in detail the electromagnetic field and found it supported wave solutions and found waves propagated all at the same speed and this was [the] speed of light...it dawned on them light itself was just an oscillation of the electromagnetic field. This tied everything together into one electromagnetic phenomenon.

## 4. SUMMARY AND CONCLUSIONS

### 4.1. Conclusions

Students exhibited a variety of conceptions about visible light, UV, and IR. As expected, many ideas about visible light were quite similar to those documented in previous studies. Although only 283 students were tested in this study, the commonality with the literature vis-à-vis visible light allows us to generalize our findings about UV and infrared. Specifically, most middle school students do not have a clear understanding of the terms “ultraviolet” and “infrared.” Additionally, almost half of the high school physics students and some teachers had alternative conceptions that were similar to those held by middle school students. Nearly 80% of all students in the study were unclear that humans cannot see in the presence of UV light alone, supporting the idea that “light” to most students is a singular concept. The lack of understanding of visible light, even among advanced students enrolled in honors physics courses, may explain the finding that student understanding of UV does not change significantly with age.

### 4.2. Implications

This research has significant implications for instruction at all levels. Certainly, the finding that high school students do not differ significantly from middle school students in their understanding of UV suggests that this concept needs more attention. Experience with visible light and vision is a daily occurrence for students, and understanding of these is a prerequisite to understanding other types of light. Yet, nearly 50% of high school students enrolled in honors physics still believe that vision is possible in complete darkness, and 45% of teachers were unable to identify the pathway taken by light during vision.

This study suggests that certain naive ideas may remain unchanged with exposure to current instructional approaches. Certainly, this has implications for instruction in astronomy on such diverse topics as observation (Beare 2006), greenhouse effect (Francis 2005), and astrobiology (Tang 2005). Discussion on UV and IR is prevalent in both the media and classroom curriculum (e.g., Abney and Scalettar 1998), and The Center for Astronomy Education (<http://astronomy101.jpl.nasa.gov/>) highlights the importance of multiwavelength astronomy to the discipline.

Students, both K-12 and preservice teachers at the college level, need to have their alternative conceptions about all forms of light challenged directly. We suggest that teachers and university faculty address visible light conceptions prior to instruction about other forms of light. A conceptual change approach, such as that proposed by Posner and others (1982), would challenge alternative conceptions directly. Faculty and teachers can use the findings reported here as a springboard for discussion, demonstration, and direct experimentation with visible light, IR, and UV. Hopefully, hands-on experience with these phenomena will help students comprehend the true nature of electromagnetism.

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### Appendix: Questionnaire

Please answer the following questions using complete sentences

1. You are in a completely dark room without lights or windows. Which object(s) do you think you will be able to see?
  - a. A cat's eyes
  - b. A dime
  - c. White paper
  - d. A cat's eyes and white paper
  - e. None of the above

Please explain your answer.

2. Can the cat in the completely dark room from question 1 see you? Why or why not?
3. People often wear sunscreen when they go out on a sunny day. People wear sunscreen because of ultraviolet radiation.
  - a. What does the term 'ultraviolet' mean to you?
  - b. Where does ultraviolet radiation come from?
4. You are in a completely dark room without lights or windows. However, you have an ultraviolet lamp that only emits ultraviolet radiation. When you turn on the lamp, which object(s) do you think you will be able to see?
  - a. A cat's eyes
  - b. A dime
  - c. An apple
  - d. A cat's eyes and an apple
  - e. None of the above

Please explain your answer.

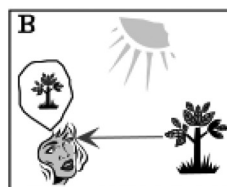
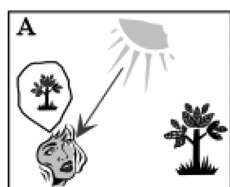
5. Fatimah is sitting in her backyard, looking at a tree. Which of the following statements about how she is able to see a tree do you agree with? Circle T for TRUE or F for FALSE for each statement.

**A.** Light from the Sun must enter her eye before her mind can create an image of the tree.

T F

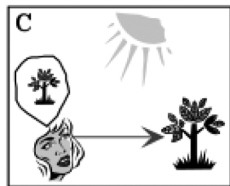
**B.** Light from the tree must enter her eye before her mind can create an image of the tree.

T F



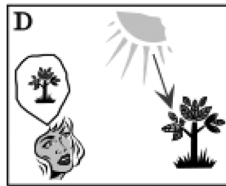
C. Light from her eye must reach the tree before her mind can create an image of the tree.

T F



D. Light from the Sun must reach the tree before her mind can create an image of the tree.

T F



6. Which of A, B, C, and D do you believe must occur **first**?
7. *It is a sunny day. Sean sits by the window and enjoys the sunshine. His mother tells him not to sit there for too long because she thinks he could get skin cancer from the ultraviolet radiation. Sean says it's ok, because ultraviolet radiation can't get through the glass of the window. Who do you agree with, and why?*

[responses to this question were not used in this study]

**Students:** 8. You probably have heard about another kind of radiation called infrared. What would you like to ask your teacher about infrared radiation?

**Teachers and Scientists:**

8. Do you think visible light has anything in common with:
- ultraviolet radiation?** Please explain your answer
  - infrared radiation?** Please explain your answer.
9. How would you explain the meaning of **electromagnetic radiation** to another teacher?

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