ELEMENTARY TEACHERS' UNDERSTANDING OF STANDARDS-BASED LIGHT CONCEPTS BEFORE AND AFTER INSTRUCTION

Abstract: A descriptive study conducted to investigate how the pre-instruction and post-instruction conceptual understanding of inservice elementary teachers compare on: 1) light travels in a straight line until it strikes an object; 2) light is reflected in a predictable manner by a plane mirror; and, 3) refraction changes the straight line path of light in predictable ways. Because interviews were impossible, ten multiple choice tasks with alternative conceptions embedded in distracter options were utilized to assess the conceptual understanding of 72 teachers from rural school districts in three Mid-Atlantic States. Results are discussed by task in the paper. Pretest performance ranged from 8.3% to 75.0% correct responses on the ten tasks and 49.3% to 90.1% on posttest. The strong improvement across all tasks is attributed to the utilization of evidence-based instructional materials (McDermott, 1996) that promote intentional learning. While the results suggest most teachers made substantial progress in constructing a logically consistent and scientific model of the targeted light phenomena, further improvement is desirable and should be possible by using the data for formative purposes.

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Rational

The research literature on precollege students' conceptions of light reveals major deficiencies in conceptual understanding. Piaget's ground-breaking investigations (1974a, 1974b) have been followed by other important work, including studies by Guesne (1985), Crookes and Goldby (1984), Feher (1990), Feher and Rice (1988), Fetherstonhaugh and Treagust (1992), Ramadas and Driver (1989), and Shapiro (1994). Conceptual difficulties related to light also have been documented in college-level students (Goldberg & McDermott, 1986; Huang & Hwang, 1992). A few studies have focused on the conceptual understanding of light-related phenomena held by preservice elementary teachers (Feher & Rice, 1987; Bendall, Goldberg, & Galili, 1993). However, related studies of inservice elementary teachers' conceptions of light phenomena are scant (Greenwood and Scribner-MacLean, 1997) and remain a largely unfilled need, probably due to the reluctance of practicing teachers to agree to the assessment of their conceptual understanding.

Lack of a scientific understanding of standards-based concepts elementary teachers may reasonably be expected to teach is likely to be problematic for efforts to help their students construct a rich understanding of light concepts. The majority of practicing elementary classroom teachers completed their collegiate content preparation before the national science education standards (National Research Council, 1996) and AAAS benchmarks (American Associations for the Advancement of Science, 1993) impacted the science curricula of local school districts. Further, science courses that preservice elementary teachers have taken too often have been, and continue to be, superficial surveys of a large body of information delivered in large lecture sessions (Atwood & Christopher, 2005). Thus, important light concepts included in the standards probably have not been adequately addressed in the teacher preparation programs of the majority of practicing elementary teachers.

Any model aimed at producing effective teachers should include the construction of appropriate academic content knowledge (Barnett & Hodson, 2001). Without a rich scientific understanding of concepts to be addressed instructionally, teachers with superior pedagogical knowledge may emphasize the memorization of statements of the standards, or worse, simply be more effective at teaching non-scientific conceptions. To begin to grasp the magnitude of the problem at the middle school level, Christopher, Atwood and Trundle (2002) completed a pilot investigation of the understanding of standards-based light concepts held by a group of experienced middle school teachers. Using a multiple choice instrument modeled after the Force Concept Inventory (Hestenes, Wells & Swackhammer, 1992), in that alternative conceptions were embedded in the distracter options, the content preparation of the sample was found to be seriously deficient. Subsequently, Atwood and Christopher (2004) reported that a sample of inservice elementary teachers also showed serious conceptual deficiencies for light concepts. In order to extend that work, the understanding of standards-based light concepts held by a group of practicing elementary school teachers was investigated before and after instruction targeting selected standards-based light concepts. That descriptive study is the focus of this paper.

Research Question

The three-part research question the study sought to answer follows. How do the pretest and posttest performance of inservice elementary teachers compare on tasks that assess the conceptual understanding of: 1) light travels in a straight line until it strikes an object; 2) light is reflected in a predictable manner by a plane mirror; and 3) refraction changes the straight line path of light in predictable ways?

Procedure

The sample consisted of 72 elementary teachers from rural school districts in three Mid - Atlantic States. During the summer, 2003, each teacher was enrolled in one of three two-week physical science institutes offered through a funded project. The use of multiple-choice tasks that included commonly held non-scientific conceptions in the distracter options to assess teachers' conceptual understanding of standards-based light phenomena was well suited to the testing time limitation that existed. Ideas for test items discussed in the paper benefited from previous work (Goldberg & McDermott, 1986; McDermott, 1996; Osborne & Freyberg, 1985). To relieve teachers' anxiety about potential negative effects of poor assessment results, the tests were completed anonymously at the beginning and end of the institutes. Ten light tasks were included in a 31-item test that also assessed three other topics addressed in the institute.

Light Instruction

In order to provide background information necessary to interpret the results, a brief description of the instruction on light is provided. Participants learned about light during intensive, two-week summer institutes in which light was one of four topics addressed. During the five-hour work days, small groups of three teachers engaged in investigations accompanied and followed by interpretive discussions and interpretive writing. Written responses to questions and prompts were routinely defended in conference with an instructor, producing an active learning culture among the instructor, participants, and the curriculum (Duschl & Gitomer, 1991). A whole-class review of light was conducted at the end of the light studies. The source of investigative activities, questions, and other prompts for interpretive discussion and writing was Physics by Inquiry (McDermott, 1996). An examination of these materials reveals that the developers were aware of the most frequently held non-scientific conceptions for each major topic addressed. Further, the developers utilized activities that lead to observations at odds with popular non-scientific conceptions. During study in the institute, participants were pushed repeatedly to construct conceptual models consistent with their observations and to modify a model, when new observations were determined to be inconsistent with it. Using this strategy, some popular non-scientific conceptions were intentionally confronted.

Highlights of the instructional activities follow. Each group was given a small Minimaglite® (2AA battery size) that can be made into an electric "candle" by removing the cap containing the lens and reflector. The advantage of this feature is that the very small exposed bulb approximates a point source of light. Observations of the light bulb were made by participants with and without a special cap, which was a black ping-pong ball with a few small holes. The ping pong ball cap was placed over the top of the Minimaglite® with the bulb located in the center of the ball. Teachers determined where the eye must be placed to see the bulb when the bulb is on and the room lights are off, as well as when the bulb is off and the room lights are on. In a darkened room, with the special cap attached, participants determined that an invisible light beam could be made observable by placing chalk dust in it. From these investigations the teachers concluded that light travels in a straight line from a source or from an object after being reflected from another source, and that light must enter the eye to be observed. They also were able to predict circumstances in which a light beam could be observed. These principles were subsequently applied in activities that involved light passing through a mask and onto a screen. The hole shapes in the mask, number of point sources, line and surface sources (frosted light bulb) were varied. A few investigations with shadows also were completed.

The study of reflection of light began with basic exploratory experiments using a narrow light beam directed across a piece of butcher paper to strike a plane mirror and reflect back onto the butcher paper. The participants were able to observe and trace the path of light and ultimately conclude that the angle of the incoming beam of light and the mirror form an angle which is equal to the angle of the outgoing beam of light and the mirror (angles are measured as those that are less than 90 degrees.) The diffuse reflection of light from construction paper was also observed, as well as light reflecting from a glossy book cover. The latter shows traits of both the specular reflection of mirrors and the diffuse reflection of construction paper. Ray tracing and observations were used to determine the range of positions and directions one must look for viewing the image of an object in a plane mirror. The parallax phenomena was introduced and used to locate a second nail behind a mirror at the image of a first nail located in front of the mirror. Ray tracing was used to confirm the image location. Ray tracing was also used to explore the path of light traveling from a source to the mirror and ultimately to an observer's eye in image formation.

The study of refraction of light began with basic exploratory experiments. A narrow light beam was directed across a piece of butcher paper to strike a round beaker and later a cubic container. These activities were repeated sequentially with plain water, water containing a little coffee creamer, and finally corn syrup. Participants also observed light beams striking thin and thick plates of glass at different angles, noting the displacement of the light beam that resulted from the two refractions. The term "normal" was introduced and the results of experiments were described in terms of bending toward or away from the normal. Finally, participants performed brief, qualitative studies of the images formed by concave and convex lenses.

In summary, this inquiry-oriented instruction engaged participants in systematic observations and sense-making, interpretive discussions of their observations. This constructivist design encouraged participants to maintain a high degree of awareness of their own thinking and understanding as they mentally processed a steady inflow of observations and made conjectures. Instruction with these characteristics has good potential to facilitate intentional learning (Bereiter & Scardamalia, 1989; Hennessey, 2003) thought to be crucial for deep conceptual understanding. The total amount of in-class instructional time devoted to the study of light was in the range of 15 to 20 hours.

Results and Discussion

In this section, the light content assessed by a small cluster of assessment tasks is identified, followed by pre and post results for each task. The number of teachers selecting each option, A – E, is expressed as a frequency and a percent. Hopefully, this format for data presentation will facilitate readers' understanding of pre and post performance. A discussion of results for each cluster is inserted near the tasks.

Assessment tasks 1 – 5 provide opportunities for applying the concept, light travels in a straight line until it strikes an object. Tasks 1 and 2 are modest variations of assessments reported by Osborne & Freyberg (1985) and tasks 3 – 5 were inspired by McDermott (1996).

Task 1

Suppose you are watching a candle burn during the day. The light from the candle flame will:

A) stay on the candle flame.
B) stay in a small "halo" very near the candle flame.
C) come out about halfway towards you.
D) come out as far as you and no further.
E) come out until it hits something.

PRE				**POST**		
A	13	18.1%		A	7	9.9%
B	24	33.3%		B	11	15.5%
C	1	1.4%		C	0	0.0%
D	0	0.0%		D	1	1.4%
E	**34**	**47.2%**	**Correct**	**E**	**52**	**73.2%**
omit	0	0.0%		omit	0	0.0%

Task 2

Suppose you are watching a candle burn one night during a power outage. The light from the candle flame will:

A) stay on the candle flame.
B) stay in a small "halo" very near the candle flame.
C) come out about halfway towards you.
D) come out as far as you and no further.
E) come out until it hits something.

PRE				POST		
A	1	1.4%		A	0	0.0%
B	18	25.0%		B	3	4.2%
C	2	2.8%		C	2	2.8%
D	0	0.0%		D	2	2.8%
E	**50**	**69.4%**	**Correct**	**E**	**64**	**90.1%**
omit	1	1.4%		omit	0	0.0%

Perhaps the most striking result for Tasks 1 and 2 is the difference in correct responses for night compared to day on both the pretest and posttest. One probably would be more likely to focus attention on a candle flame at night, especially from longer distances, when far less ambient light is reaching the eye. B was the most popular distracter for both tasks on pre and post. More light may be seen near the edge of the flame, which may make B more appealing. And, Bendall, Goldberg and Galili (1993) have documented that preservice elementary teachers tend to have difficulty with the notion that light travels. Clearly, because of its speed no one sees light travel, as we think of travel in our everyday activities. The selection of distracters A, B or C for either task likely indicates a lack of understanding that light has to enter the eye in order to be seen (Atwood & Christopher, 2004). This understanding is an extension of the concept of primary interest, light travels in a straight line until it hits something. Returning to distracters A and B, the fact that intense, persistent light can be observed at the edge of the candle flame, might explain why B was a more attractive option than A. Following this line of reasoning, C could be expected to be less attractive than A or B, and it was, because no light is observed halfway toward you. Collectively, the pretest results indicate too few inservice teachers made the desired application of the targeted standards-based light concepts. The context of the desired application was quite different from any included in the instruction. Post results for these two tasks were encouraging.

It would have been informative to obtain interview data to complement data from all multiple choice tasks. In addition to learning why particular options were selected, data on the number of false positives included in the correct responses could have been collected. However, it was not possible to obtain additional data from the sample of inservice elementary teachers due to time and opportunity constraints.

Task 3

A light bulb is attached to the left wall of a small, bare room with no windows, as illustrated in Figure 3, and a clock is attached to the right wall. The bulb attached to the wall is on and is glowing brightly. There are no other lights in the enclosed room. If you were to move about the room looking first toward the left wall and then toward the right wall, which of the following statements would be most accurate?

A. You could see only the bulb and see it only from near the right wall.
B. You could see only the bulb, but see it from most places in the room.
C. You could see the bulb and some of the clock but only while standing near the right wall.
D. You could see the bulb and some of the clock from most places in the room.
E. You could see neither object.

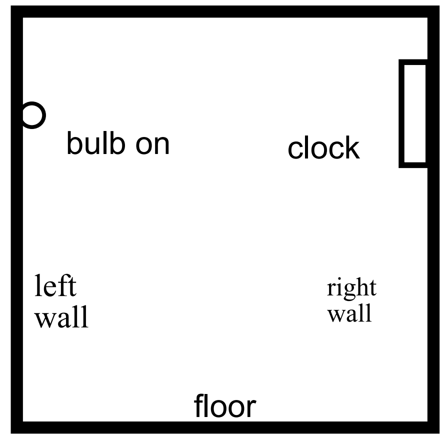


Figure 1

PRE				POST		
A	0	0.0%		A	2	2.8%
B	11	15.3%		B	3	4.2%
C	9	12.5%		C	5	7.0%
D	**51**	**70.8%**	**Correct**	**D**	**60**	**84.5%**
E	1	1.4%		E	1	1.4%
omit	0	0.0%		omit	0	0.0%

The setup described in Task 3 and illustrated in Figure 1 probably does not differ greatly from situations commonly experienced. Thus, the 70.8% of correct responses on the pretest is not surprising. That is, the teachers may have just recalled everyday experiences in responding correctly rather than applying an understanding of light traveling in a straight line from a source to the eye or light traveling from a source to a non-luminous object and then being reflected to the eye. It was somewhat disappointing that the post results were not higher. Assumptions teachers made about the size of the room and the intensity of the bulb could have been factors in selecting B or C. However, anticipating this possibility, the stem of the item revealed the room was small and the bulb was glowing brightly.

Task 4

Room A and Room B are adjacent to each other as shown from a side view in Figure 2. Suppose you are sitting near the floor in the center of Room B so that you can clearly see the right wall of Room B. Two very small bulbs (smaller than illustrated) are attached near the center of the left wall of Room A as shown; both are lit and are equally bright. Further, suppose there is a small hole as shown in the center of the very thin wall that separates the two rooms. On the right wall of Room B you would see:

A. A single bright spot about the size of the hole.
B. A single bright spot larger than the size of the hole.
C. A single bright spot smaller than the size of the hole.
D. Two bright spots; the spot caused by bulb 1 would be above the spot caused by bulb 2.
E. Two bright spots; the spot caused by bulb 2 would be above the spot caused by bulb 1.

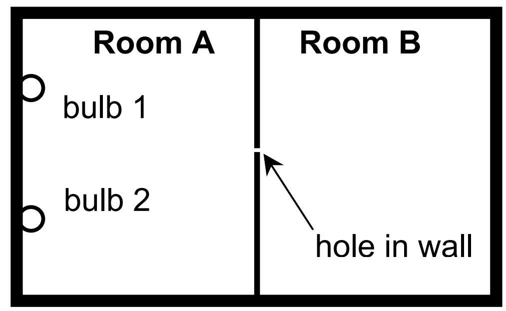


Figure 2

PRE				POST		
A	26	36.1%		A	9	12.7%
B	30	41.7%		B	15	21.1%
C	7	9.7%		C	2	2.8%
D	3	4.2%		D	6	8.5%
E	**6**	**8.3%**	**Correct**	**E**	**39**	**54.9%**
omit	0	0.0%		omit	0	0.0%

The setup described and illustrated for Task 4 probably is unlike anything in the teachers' everyday environment. This may partially explain why only 8.3% selected the option that represented an application of "light travels in a straight line until it hits something." It can also be inferred that the teachers lacked a deep conceptual understanding of this standards-based concept. Again, interviews could have been helpful in determining why options A and B were so attractive on the pretest but were not possible.

In one small-group institute activity, teachers held two small illuminated light bulbs several centimeters apart behind a mask with a small hole in it. Light from the two bulbs passed through the small hole, and onto a screen. Participants seemed surprised as they determined the higher held bulb was making the lower of two spots on the screen. After interpretive discussions in the small groups and further manipulation of the materials, a scientific interpretation of the phenomena was made. Based on the posttest results of 54.9% correct responses, the conceptual understanding developed in at least 45.1% of the teachers' explanatory frameworks was inadequate to make the desired application for a very similar setup. On the other hand, the posttest performance compared to the pretest performance is impressive.

Task 5

Room A and Room B are adjacent to each other as shown from a side view in Figure 5. Suppose you are sitting on the floor in the center of Room B and looking upward so that you can clearly see the whole space between the left wall and the right wall of Room B. Now, suppose that in room A, one brightly lit bulb is mounted near the center of the wall as shown. There is a small hole in the center of the wall separating the two rooms. From your position in room B, what would **you see *in the space*** (not on any surfaces) between the left wall and the right wall?

A. No light beam unless there is dust, smoke, or fog in the air.
B. A light beam that gets smaller from the left wall to the right wall.
C. A light beam that stays the same size from the left wall to the right wall.
D. A light beam that curves towards the ceiling.
E. No light beam under any circumstances.

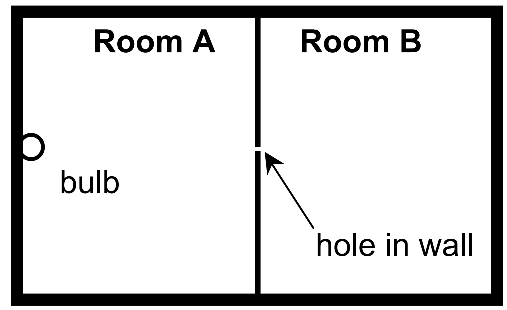


Figure 3

PRE				POST		
A	**9**	**12.5%**	**correct**	**A**	**51**	**71.8%**
B	23	31.9%		B	6	8.5%
C	34	47.2%		C	12	16.9%
D	2	2.8%		D	1	1.4%
E	4	5.6%		E	1	1.4%
omit	0	0.0%		omit	0	0.0%

The setup for Task 5 was likely unfamiliar on the pretest. The results support that inference. The teachers probably had observed a beam of light scattered by fog or snow. This kind of previous experience may have been inappropriately applied in responding to Task 5. During the institute, instruction included trying to determine when a laser light was turned on by observing a space between the laser pen and the end wall the laser beam would hit. Most teachers seemed surprised that they were unable to see the beam. Posttest results indicate this experience may have been helpful to teachers among the 71.8% who selected the scientific application response.

Task 6

A person who is represented by the circle in Figure 6 below is looking into the mirror. Which of the cards, represented by small rectangles numbered 1, 2, 3, and 4, can she see

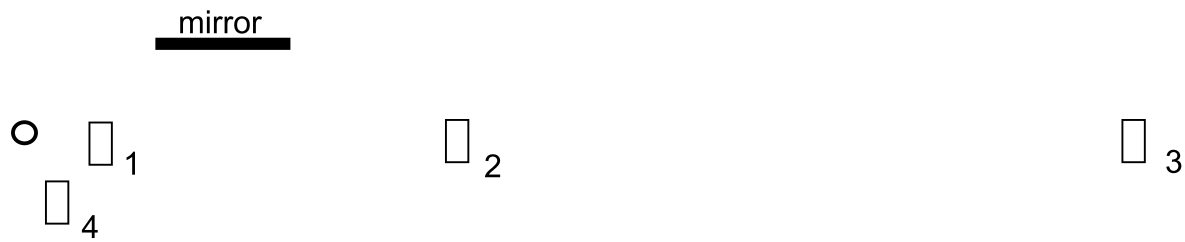


Figure 4

reflected in the mirror?

A) 1 and 2 **B) only 4** **C) 1 and 4** **D) 2 and 3** **E) only 2**

PRE				**POST**		
A	16	22.2%		A	8	11.3%
B	2	2.8%		B	1	1.4%
C	25	34.7%		C	23	32.4%
D	5	6.9%		D	1	1.4%
E	**24**	**33.3%**	**correct**	**E**	**38**	**53.5%**
omit	0	0.0%		omit	0	0.0%

Task 7

A student, a professor, an unlighted candle, and a plane mirror are arranged in a well-lit room as shown in a top view in Figure 7. The size of the mirror is typical of a bathroom mirror. The professor and the student can tilt their heads. As they look into the mirror.

A. both the professor and the student will be able to see an image of the candle in the mirror.
B. the professor will be able to see an image of the candle, but the student will not.
C. the student will be able to see an image of the candle, but the professor will not.
D. neither the student nor the professor will be able to see an image of the candle in the mirror.
E. there will be no image of the candle in the mirror for anyone to see.

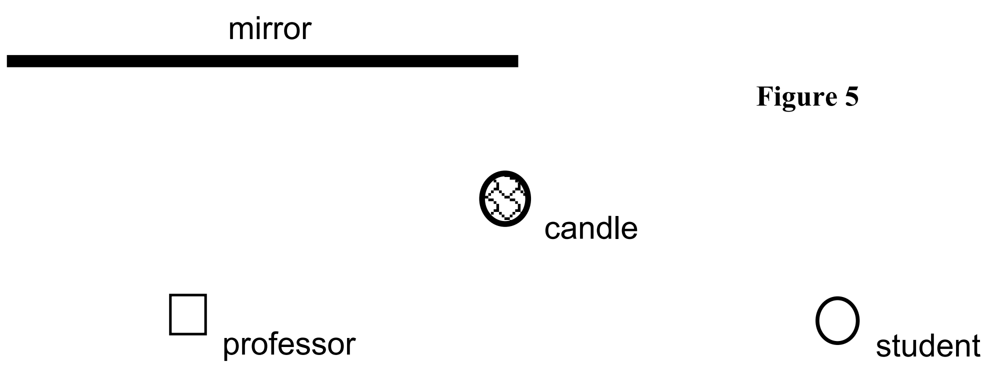
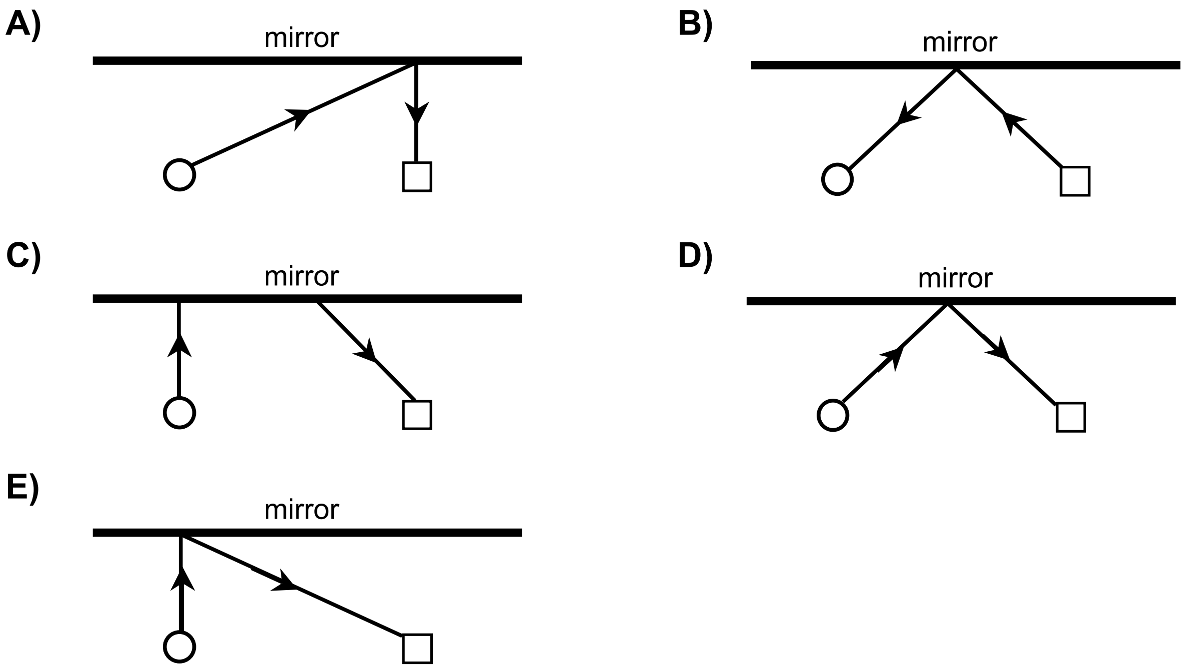


Figure 5

PRE				POST		
A	34	47.2%		A	19	26.8%
B	**31**	**43.1%**	**correct**	**B**	**49**	**69.0%**
C	3	4.2%		C	2	2.8%
D	3	4.2%		D	1	1.4%
E	1	1.4%		E	0	0.0%
omit	0	0.0%		omit	0	0.0%

Task 8

Light from a small light bulb, represented by a circle on the left in the diagrams below, encounters a mirror. Light from the mirror is observed to illuminate a small screen, represented by a small square on the right in the figures below. Which of the following diagrams best represents the path the light takes in reaching the screen via the mirror?



PRE				POST		
A	2	2.8%		A	4	5.6%
B	8	11.1%		B	5	7.0%
C	5	6.9%		C	0	0.0%
D	**43**	**59.7%**	**correct**	**D**	**52**	**73.2%**
E	14	19.4%		E	9	12.7%
omit	0	0.0%		omit	1	1.4%

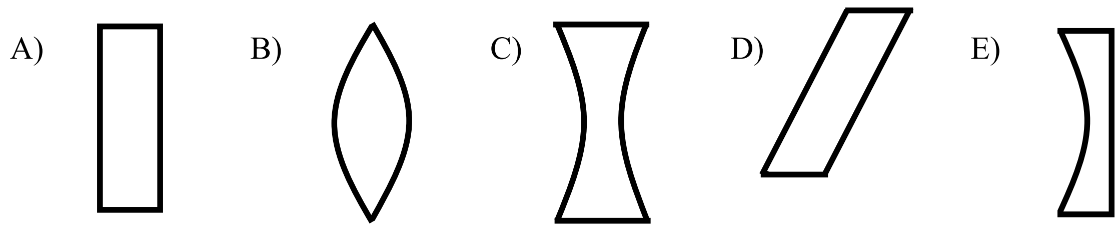
Tasks 6 – 8 provide opportunities for teachers to demonstrate their understanding of the predictable manner in which light is reflected by a plane mirror. Whether an image of an object can be seen from a particular location is a logical extension of the law of reflection included in this cluster of tasks. More specifically, Tasks 6 and 7 provide an opportunity to apply the law of reflection in determining whether one or more objects can be seen in a mirror from one or more locations. The pretest results for Task 7, which appears to be less complicated than Task 6, are disappointing, with 43.1% correct responses, but are better than the 33.3% of correct responses for Task 6. Following the instruction with plane mirrors described earlier, the percentages of correct responses were 69.0% and 53.5% for Tasks 7 and 6, respectively.

It is inferred one would need to understand the direction a light ray travels from a source to a mirror and then to an object, as well as the law of reflection, in reasoning that

D is the correct answer for Task 8. Post results showing 73.2% correct responses reflect a modest improvement over the 59.7% on the pretest.

Task 9

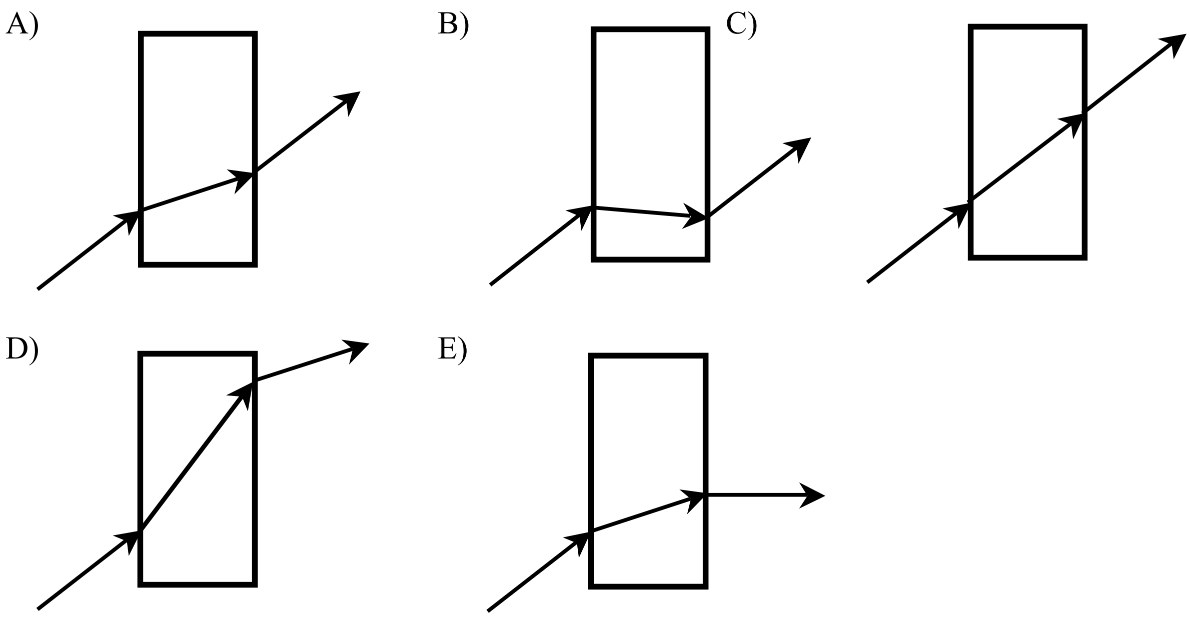
Drawings of five glass objects are shown below. Which of the objects can act as a magnifier?



PRE				POST		
A	4	5.6%		A	1	1.4%
B	**54**	**75.0%**	**correct**	**B**	**60**	**84.5%**
C	7	9.7%		C	6	8.5%
D	1	1.4%		D	1	1.4%
E	5	6.9%		E	3	4.2%
omit	1	1.4%		omit	0	0.0%

Task 10

A light ray encounters the left side of a flat plate of glass as shown in the diagrams below. In each drawing the ray initially hits the glass at the same spot and at the same angle. Which of the drawings best indicates the path that the light ray would follow as it travels through and exits the glass?



PRE				POST		
A	**21**	**29.2%**	**correct**	**A**	**35**	**49.3%**
B	7	9.7%		B	6	8.5%
C	30	41.7%		C	23	32.4%
D	7	9.7%		D	5	7.0%
E	6	8.3%		E	2	2.8%
omit	1	1.4%		omit	0	0.0%

Tasks 9 and 10 were intended to provide opportunities for teachers to apply their understanding of how transparent objects can refract light in predictable ways. Pretest results for Task 9 reveal 75.0% selected the correct response, suggesting the task was not very challenging. Perhaps selecting the correct responses for some was only a matter of associating a hand lens with shape B. The modestly improved performance on the post assessment, when 84.5% of the teachers selected the correct response, was accompanied by a puzzling result. Specifically, nine teachers selected a concave lens as a magnifier, compared to 12 teachers on the pretest. Further, a teacher selected each of the remaining two distracter shapes as a magnifer instead of the convex lens. Although the teachers seemed uniformly interested in the brief qualitative study of images formed by concave and convex lenses during the institutes, the connection between the size of images and shapes of the lenses apparently was not adequately made for 15.5% of the sample.

Task 10 utilizes a diagram of a set up unlikely to be encountered outside of school-based instruction. In fact, the institute instruction included the study of narrow light beams striking thin and thick plates of glass at different angles. The displacement of the beam was noted as part of the study. However, the path of the beam frequently was not easy to see. The most popular distracter option provides an opportunity to misapply the "light travels in a straight line until it strikes an object" concept. Rather, selection of option C likely reflects the conception that light travels in a straight line regardless. Option C was selected by 41.7% of teachers on the pretest and 32.4% on the posttest. For comparison, 29.2% chose the correct response before instruction and 49.3% afterward.

Conclusions and Implications

The results suggest that before instruction this sample of inservice elementary teachers was inadequately prepared to help students construct an understanding of the K-4 standards-based light concepts of interest here. It seems likely they had been instructed that: light travels in a straight line until it hits something; on the law of reflection, when light strikes a plane mirror; and that light can be refracted. However, on pretest many teachers were unable to apply these concepts in responding to the ten multiple choice tasks which featured alternative conceptions embedded in the distracter options. Posttest results showed stronger performance across all tasks but fell short of reflecting the rich level of understanding required for most teachers to consistently do applications of the concepts. Since multiple choice tasks are thought to generate more false positives than tasks requiring the teachers to generate responses (Trundle, Atwood & Christopher, 2002), the level of understanding of this sample may have been overstated on both the pretest and the posttest. Teachers showed less evidence on posttest of utilizing a synthetic model of light phenomena, which includes an inappropriate "mixing" of both scientific and non-scientific views (Vosniadou, 2002). The results for Task 10, option C, seem to provide the most striking example of responses reflecting a synthetic framework. Many teachers made substantial progress from pretest to posttest in constructing a logically consistent scientific model of the targeted light phenomena.

The results of this study support the view that evidence-based, investigative instruction (McDermott, 1996) can have a major positive impact on conceptual understanding of standards-based light phenomena with a modest investment of time. In a three-credit course for inservice or preservice teachers, more applications in different contexts could be completed than were included in the two-week institute. Physics By Inquiry includes many more applications than were utilized in the institutes. Further, the data obtained in this study could be used for formative purposes with potential to improve the instruction for similar samples of teachers. Attention should be given to strategies that encourage teachers to go beyond interpreting the results of investigations based on their own observations to becoming more metacognitively aware of how results fit with their existing explanatory frameworks. That is, teachers should be led to engage in more intentional learning (Vosnaidou, 2003).

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