Conceptual Underpinnings of Students' Ability to Understand Reflections from a Plane Mirror

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Abstract. In this paper we explore students' pre-instruction knowledge of several conceptual and procedural pieces of knowledge that we believe are prerequisite to one's ability to generate correct light ray diagrams and understand image formation by a plane mirror. The research population is an algebra-based, introductory physics class of about 50 students at a medium-sized, urban, public university. Both individual interviews and written free response questions were used to gather data.

PRIOR FINDINGS

In 1986, Fred M. Goldberg and Lillian C. McDermott published a careful study of the difficulties students have applying their knowledge of geometric optics to novel situations involving image formation by a plane mirror.[1] Goldberg and McDermott probed students' functional knowledge within this domain using four tasks. They asked students about these tasks either in interviews or with written questions. Three of the tasks involved a dowel placed in front of a plane mirror. The students were asked to predict if (and where) an image would be visible for various observer locations. They were also asked to explain their reasoning. The forth tasked involved a small mirror held in front of the student. The student is asked if there is anything that she or he can do in order to see more of their image in the mirror.

Goldberg and McDermott found that many students fail at these tasks, both pre- and post-instruction. That is, they found that most students could not determine the location of an image in a plane mirror for shifting observation points nor could they determine whether observers at different locations would be able to see the reflection at all. Goldberg and McDermott also identified a common, largely incorrect student conception, the "line of sight" conception, which is depicted in Figure 1.

Seminal to this study, Goldberg and McDermott also found that many students could not draw correct ray diagrams. Even more notable, they found that students often could self-correct initially incorrect predictions if they were encouraged to draw ray diagrams and could do so correctly. These last two findings, stated immediately above, were the motivation for this study.

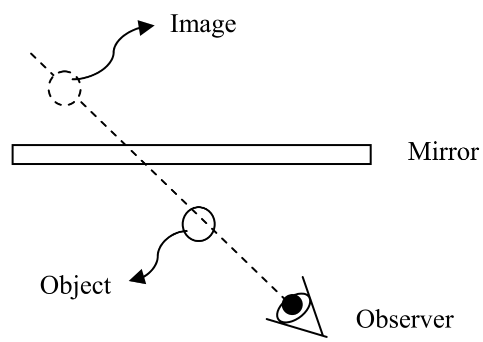


FIGURE 1. The "line of sight approach," depicted here, is a largely incorrect but common student approach to determining the location of the image formed by a plane mirror. The image is believed to lie somewhere along the observer-object line of sight. (This is correct if the observer-object line of sight happens to be perpendicular to the mirror.)

INTRODUCITON

The Goldberg-McDermott findings are helpful in that they clearly establish the difficulty students have applying physical principles from geometric optics in explanation of image formation by a plane mirror. In addition, their work supports our own theoretical belief that learning to draw correct ray diagrams is of fundamental importance if students are to develop functional knowledge of geometric optics. However, when we attempted to apply the Goldberg-McDermott findings to our own instructional practices we were left with several significant questions. Hence, this study was a preliminary attempt to answer a cluster of research questions related to students' inability to draw correct ray diagrams within the domain of reflections from a plane mirror.

Primarily, we wanted to know what piece or pieces of conceptual and/or procedural knowledge are missing or misunderstood when students fail to generate correct ray diagrams for the Goldberg-McDermott tasks. This is largely unaddressed by the Goldberg-McDermott paper. For example, do college-level, general-education students know that light is required for image formation? Do they realize that in general objects reflect light that falls on them from other sources? What are their intuitions about the reflection of light in a plane mirror?

STUDENT POPULATION

This study took place at Southern Connecticut State University, a public university with approximately 12,000 students in an urban setting. The student population studied was an algebra-based introductory physics class of approximately 50 students. The study took place during the spring of 2004. The course is a terminal one-semester course taken by computer science students and biology majors who are not pre-medical students. High school physics or a conceptual physics course is a prerequisite.

RESEARCH TOOLS AND METHODOLOGY

The data reported here were gathered as part of a study that employed four different sets of written, open-ended questions. The question sets were given to all students present during four fairly evenly spaced class periods. Individual student interviews were preformed periodically to clarify, verify and extend the information gained via the written responses. This approach is similar to the "hybrid" interview-written response approach used by Goldberg and McDermott in their earlier study. In each case the question sets were *not* returned to the students and the correct answers were *not* directly discussed. The first question set was given prior to any instruction in geometric optics. This "pre-instruction" assessment is the focus of this paper.

FINDINGS

With Good Eyes, You Can See Anywhere.

One of the most fundamental pieces of knowledge required for an understanding of image formation by a plane mirror is that at least some light must be present. We wondered if our population of students understood this. We probed it by asking Question #1, which is shown below along with student answers.

Question #1: *Suppose that you are in a totally closed room with only a light bulb and a mirror. There are no windows and no doors in the room. The light bulb is placed in front of the mirror but is NOT turned on. So, there is no light in the room. Will you see an image of the light bulb reflected by the mirror?*
Student Responses:
82 % No
18 % Yes

Among the small group who incorrectly answered "yes" there were often statements made that "one's eyes will adjust in time and then you will be able to see (even in a room with no light at all)".

Although the number of students using this line of reasoning was small in this study, some researchers believe that they see a higher prevalence of this type of faulty reasoning in other college level populations.[2]

Another preliminary conceptual piece required for understanding image formation in plane mirrors is knowledge that there are light rays reflected from nearly all objects and that this is required if an object is to be imaged. This idea interested us. We hypothesize that some students may have stumbled from the start of the Goldberg-McDermott tasks because they fail to see a dowel as a source of light rays. After all, it is wooden and so neither directly produces light nor is highly reflective. In order to probe student pre-instruction conceptions we asked Question #2 shown below with answers.

Wood Doesn't Reflect Light

There are two noteworthy results from our study of Question #2. First, a fairly large percentage of students (62%) did not recognize a wooden table as a source of reflected light. This is, of course, a fundamental problem in understanding image formation in most real situations.

Question #2: *An object can be a "source" of light in several ways. For example, an object might produce, reflect, scatter, or transmit light from an outside source. In each case, we will call the object a "source" of light. Suppose that you are in a closed room with only a light bulb, mirror and a wooden table present. The bulb is turned on, so there is light in the room.*

Student Responses are shown in bold.

Is the bulb a source of light? If so how?
100% Yes, it produces light

Is the mirror a source of light? If so how?
81 % Yes, it reflects light
11 % Yes, it reflects light and thereby produces more light or amplifies the existing light
8% Other

Is the table a source of light? If so how?
38% Yes, it reflects light
62% No

Reflection is a Light Production Process

The second noteworthy result was a student conception of the mirror as an "amplifier of light" or reflection as a light production process. For example, one student wrote in free response and confirmed verbally that she believed "*the mirror's reflection produces a light*". Another said "*The mirror reflects the light from the bulb and multiplies its intensity*." These students also drew (incorrect) ray diagrams in response to Question #3 (discussed on the following page) that were consistent with this belief. An example is shown in Figure #2.

Although the concept of reflection as a light production process was not commonly expressed in our pre-instruction study (11%), it did seem to exist in some form in the minds of many of the students at various points of time. For example, later in the instructional/assessment process, when students were asked to draw ray diagrams for a two-eyed observer located next to an object (as opposed to behind it), several students "developed" the idea of multiple reflective rays from a single incident ray in order to justify their predicted image location. An example diagram is shown in Figure #3.

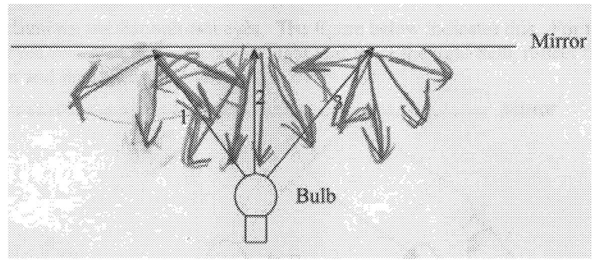


FIGURE 2. A student response to Question #3, discussed on the next page. This student's diagram is consistent with her assertion that reflection "produces light".

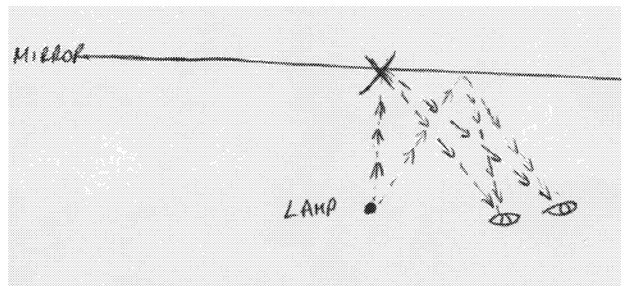


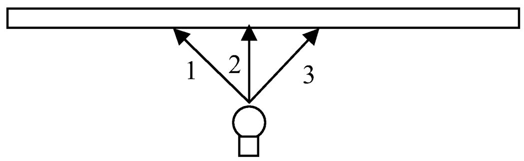
FIGURE 3. Another student diagram indicating that multiple reflective rays can be produced by a single incident ray. This student did not express that belief during pre-instruction questioning. Rather, he seemed to "develop" this conception in response to novel, more difficult tasks. The "X" in the diagram marks the location the student predicts for the image.

It Goes Out the Way It Came In…. Only Opposite

We had encouraging finding as well. Our students often appeared to have helpful, correct intuitions, preconceptions or remnants of knowledge from previous courses regarding the reflection of light by a plane mirror. The same is true for the path light travels in the process of image formation by a plane mirror. For example, 90% of the students questioned before instruction knew that light had to travel from the object to the mirror and then to the observer's eye in order for a reflective image to be seen.

Many students could draw correct diagrams indicating the reflection of light from a plane mirror, as probed with Question #3 shown below. In addition, 50% of students came up with a correct "law of reflection" although it was often stated in non-technical terms. For example, one student said "*Whatever angle the light hits the mirror is the angle it will reflect at*."

Question #3: *A light bulb emits rays of light in all directions. Consider the two dimensional situation shown in the figure below. A bulb is place in front of a mirror. Three rays of light coming from the bulb hit the mirror as shown. Draw appropriate rays of reflection for each of these three rays. Please label them R1, R2 and R3.*



Student Responses:
55% Correct Diagram
8% More than one reflected per incident ray
8% Reflected rays enter in the mirror (as in refraction)
5% Right angle between incident and reflected
24% Various Other Incorrect Diagrams

The Image Forms in Your Eye …and in Front of the Mirror

The simplest Goldberg-McDermott tasks involved an object placed in front of a mirror. The students were asked to identify where the image would be located. We asked the same question of our students. Table #1 shows the breakdown of responses for the two groups.

Stated Image Location	Goldberg Population	Cummings Population
Behind the Mirror	70%	16%
On the Mirror Surface	25%	8%
In front of the Mirror	---	21%
In the observer's eye	---	18%
"In" the Mirror	---	11%
In the observer's eye and in/on the mirror	---	18%
Other	5%	8%

TABLE 1. Percentage of students indicating various image locations for an object placed in front of a plane mirror

There are two obvious differences between the responses in this study and those in the Goldberg-McDermott study. First, far fewer of our students knew that the image was located behind the mirror. Second, 36% of our students wanted to discuss, or even focus on, the formation of the image in the observer's eye. This was not even mentioned in the Goldberg-McDermott study.

But That's Different

Evaluating students' answers to Question #3 in light of their ability to state a correct law of reflection, we found that many students simultaneously hold conflicting conceptual beliefs. For example, 25% of the students who stated the angle of incidence is equal to the angle of reflection drew diagrams that were inconsistent with this. Only 42% of the students gave clearly consistent answers to where an image is located (on the mirror, behind the mirror and so on) when asked to answer using words and then using diagrammatic representations. The idea that students might have "mixed-models" or context dependent beliefs is not surprising. It is consistent with what we know from the domain of mechanics.[3]

CONCLUSIONS

We have found that to varying degrees this population of students has conceptions regarding light and image formation by a plane mirror that include the idea that reflection is a light production or amplification process, light is not necessary for vision to occur (if you have good eyes), and "dull" objects like wood don't reflect light. In response to this last finding, we suggest that it might be prudent to start instruction with a lit light bulb as an object. This may help limit the "cognitive load" on students as they begin learning about image formation. In general, this study indicates that instruction for general education students likely needs to include clear demonstrations of the fact that nearly all objects reflect at least some light. Based on the results shown in Table #1, we also believe that many students need a chance to address their existing knowledge regarding image formation in the eye so that they can shift their attention to external images. In addition, Table #1 indicates that instructors should be careful not to reinforce a likely misunderstanding that the reflection is "in the mirror" through causal use of language.

REFERENCES

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3. L. Bao and E.F. Redish, AJP (PERS) 69, (7), S45-S53, 2001.