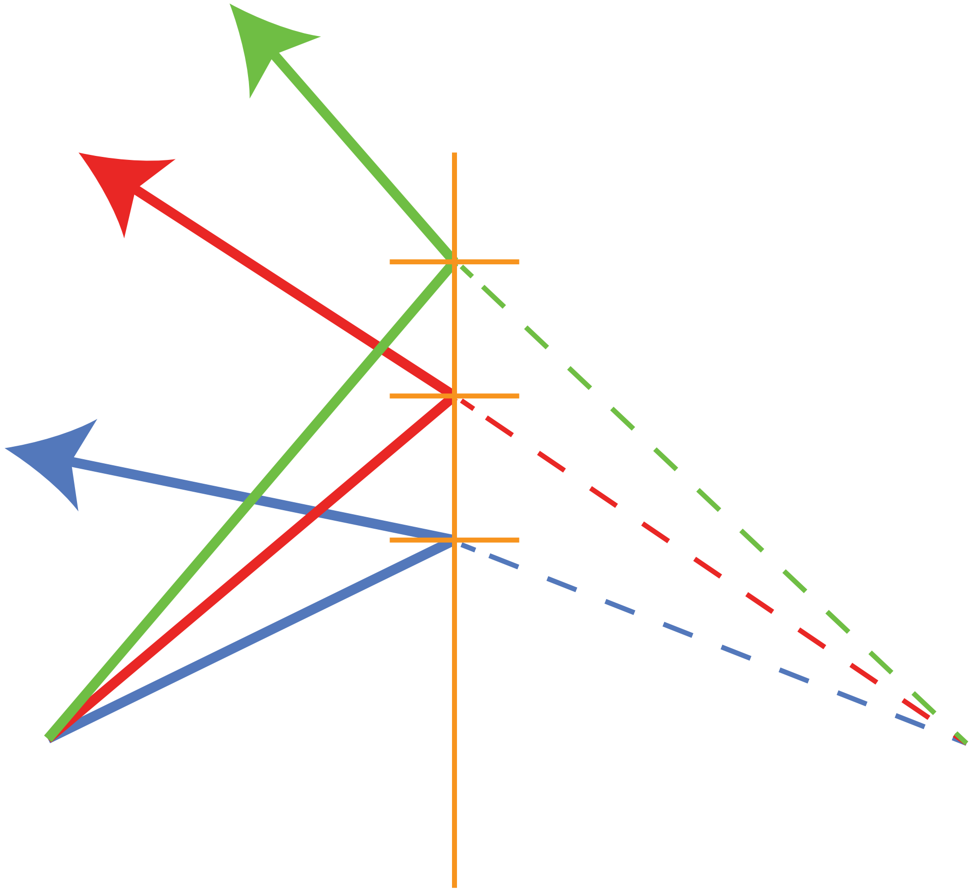
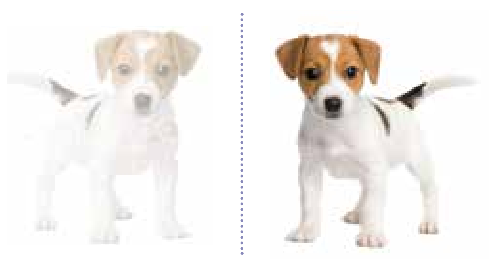


REFLECTING UNDERSTANDING

USING LAB STATIONS TO TEACH IMAGE FORMATION

by Ana Rita Lopes Mota and João Lopes dos Santos



When we began teaching eighth graders about plane mirrors, we quickly realized the task was harder than anticipated. During class, students showed no apparent difficulties, but when asked questions that elicited solid understanding of image formation, their answers were disappointing and somewhat discouraging—students not only failed to understand the concepts, they conveyed "strange" notions that had not crossed our minds. But it is these very kinds of difficulties that provide the opportunity for teachers to rethink their practice and design new pedagogical strategies.

Student difficulties

A little research showed that our problems teaching plane mirrors are actually shared by teachers all over the world. Previous studies have established specific student difficulties in dealing with image formation in plane mirrors (Galili and Goldberg 1993; Galili, Goldberg, and Bendall 1991; Goldberg and McDermott 1986). They also show that these difficulties often remain after instruction, especially if teachers fail to adopt teaching strategies devised with explicit knowledge of these difficulties. Some of the most common empirical ideas among students are as follows (Operation Physics; Galili, Goldberg, and Bendall 1991; Goldberg and McDermott 1986):

a. An image in a plane mirror is on/inside/in front of the mirror.

b. Objects' images appear when we look into the mirror. There is no image in the mirror when we are not looking at it.

c. Plane mirrors exchange left and right.

d. An image is formed along the line of sight between an observer and an object.

e. If the observer facing a plane mirror moves, the position/size of the objects' images in the mirror changes.

f. Images become smaller as objects move away from a mirror.

g. The larger a plane mirror, the larger the image in it.

h. Visual field does not depend on an observer's distance from a plane mirror or its size.

i. The position of an observer is not important in determining whether a mirror image can be seen.

All of these ideas are related in some way to one of two fundamental aspects of image formation: (1) the position of the image and its characteristics (empirical ideas a, c, f, and g); (2) the visual field: the relationship among the observer's position, the object, and the image (empirical ideas b, d, e, h, and i). Surprisingly, despite such difficulties being very well documented in research, there are few teaching suggestions to overcome them.

Of course, teachers should be aware that these subjects, like so many others in science teaching, are also fraught with linguistic difficulties associated with the use of common words that here have a context-specific meaning, such as *reversed image* or *inversion*, which can be different from their meaning in everyday language.

FIGURE 1 The reflect-view mirror

PHOTOS COURTESY OF THE AUTHORS

The reflect-view mirror

We have addressed some of these issues in middle school with a reflect-view mirror (see Figure 1), a partially transparent mirror made of semi-reflective plexiglass. It can be acquired from many suppliers of didactic equipment for as little as $5—just search the web for "reflect-view mirror"—but any sheet of semitransparent material will do. With this inexpensive device, students are able to see, simultaneously, real objects

FIGURE 2 Lab station 1

Materials

- Candle
- Safety glasses
- Matches
- Reflect-view mirror
- Ruler
- 2 balls of equal size
- 1 sheet of ruled paper
- Plane mirror
- Camera

In this station, the reflect-view mirror is used for activities leading to a more detailed understanding of image location. Image characteristics are also explored.

Procedure

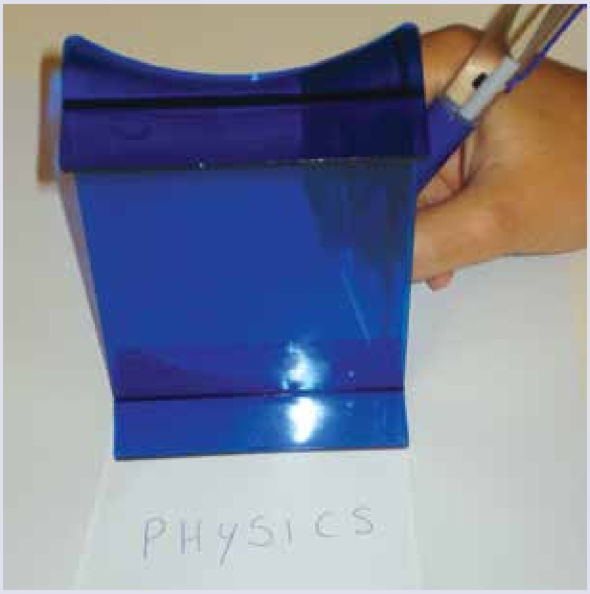
Wear safety glasses. Tie hair back and get any loose clothing out of the way of the flame. Clear all surfaces of flammable materials. Dispose of the match in the designated container.

1. Light the candle and place it in front of the reflect-view mirror. Stow away the matchbox safely; blow out the candle as soon as you have finished using it; remember that the flame and candle wax may be hot.
2. Try to move your finger behind the mirror to touch the image. How do you know that this is an image and not the real object?
3. Will the object image remain when you are not looking at the mirror?
4. Will a camera register the image, even when nobody is looking?
5. Take a picture and see what happens.
6. Where is the image formed?
   a. In front of the mirror.
   b. Behind the mirror.
   c. Inside the mirror.
   d. There is no image.
7. When compared with its object, the image size is
   a. bigger.
   b. smaller.
   c. the same size.
8. Measure the distance between the candle and its image.
9. Measure the distance between the mirror and the image.
10. The distance from the object to the mirror is
    a. bigger than the distance of its image to the mirror.
    b. equal to the distance of its image to the mirror.
    c. smaller than the distance of its image to the mirror.
11. On your table, you have a “real” plane mirror. Put it on top of the ruled sheet of paper. Put a ball in front of this mirror and a second one in the place where you think the image is formed.

Stop: Call your teacher to evaluate the placement of the balls.

12. Replace the plane mirror with the reflect-view mirror and confirm your prediction.

FIGURE 3 The plane-mirror reflection



and their virtual images behind the mirror. Using this device, we designed and implemented some useful teaching approaches, initially as class demonstrations performed with the help of one or two students, and later developed as hands-on lab activities. We found the latter more efficacious, but here we first describe the demonstrations, which will be helpful in clarifying the goals of the hands-on activities.

Consider, for instance, the location of images on the surface of a mirror. Looking through the reflect-view, a student can be asked to "touch" the image of an object by moving a finger behind the mirror. For example, as the student tries to overlap the image of a candle with a finger that can be seen through the mirror, the student will find that the finger is not on the surface of the mirror (the teacher should provide safety instructions for the use of candles before this demonstration (see Figure 2). This observation is simple enough for even younger students; they are entertained by and educated about the notion of image formation by the fact that the candle behind the mirror does not burn their finger. Moreover, students see that the image is upright and unmagnified (see Figure 1).

A ruled sheet of paper placed horizontally on the table, with the reflect-view mirror placed on top near the midline, can be used for activities leading to a more detailed understanding of image location. Ask a student to mark with a pencil, behind the mirror, the location of an image of a small object. After marking the image location on the sheet, the student removes the reflect-view and explores the relative locations of object and image. This activity is vastly enriched by varying the location of the object, for example, by moving it well to the side of the mirror. Students are usually surprised by the location of the image. Note that this activity, combined with the concept of light ray and reflection, can even lead to an intuition of the law of reflection: Have a student draw an arbitrary incident ray joining the object with a point at the base of the mirror, and a reflected ray joining the marked position of the virtual image with the same point of the mirror. Students will then be able to discover the equality of the angles of the incidence and reflection.

There are other advantages to using this tool. For example, even after instruction, students often believe that an image is formed along the line of sight between an observer and an object. This misconception can be easily addressed with a reflect-view mirror by having two students, sequentially and from different viewpoints, mark the position of the image of the same object: They will coincide.

It is sometimes hard to convince students that a plane mirror does not produce a left-to-right inversion (Ford 1975; Galili and Goldberg 1993). The real inversion, in a perpendicular direction to its surface ($x, y, z \rightarrow x, y, -z$), can be shown with a simple experiment with the reflect-view. Ask a student to place the reflect-view on a white sheet of paper and write a word on the paper in front of the reflect-view. Next, have the student

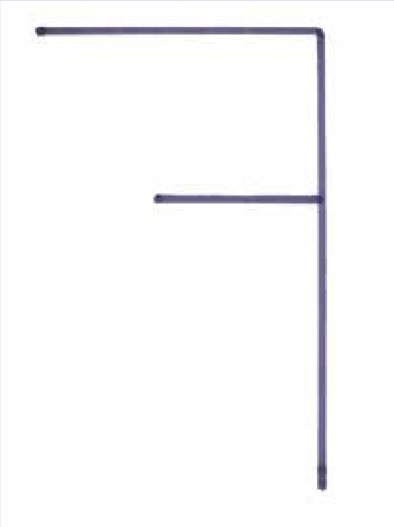
Next Generation Science Standards
(Achieve Inc. 2013)

Standard MS-PS4: Waves and their applications in technologies for information transfer
Performance expectation: MS-PS4-2: Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.
Disciplinary core idea: PS4.B: Electromagnetic radiation

Component ideas:

- When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light.
- The path light travels can be traced as straight lines, except for surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends.

FIGURE 4 The left-to-right inversion



write with a pencil over the word (behind the mirror), as shown in Figure 3. The student is then asked to remove the reflect-view and should conclude that the correct inversion is back to front $(x, y, z \rightarrow x, y, -z)$, not right to left. As a follow-up, have students predict what will happen if they use a single letter by asking, "How will the letter appear?" Most students, especially after having had the experience of seeing a printed page reflected in a mirror, will answer that the letter will appear left-to-right inverted, as shown in Figure 4. A student can confirm this for the class by writing a letter on a piece of paper and placing it vertically in front of the mirror; a reflected F will appear as shown in Figure 4, apparently a left-to-right inversion. With the use of foam letters, such as described in Figure 5, they can be led to realize that the image of the letter on the piece of paper facing the mirror looks left-to-right inverted because to see the letter, an observer facing the mirror has to turn it by 180°, about an axis parallel to the mirror. Through these simple experiences, students come to realize that in daily life, their image in a mirror seems to exchange left with right because it is facing in the opposite direction of their own.

Finally, ask students to consider the size of an image. Place the reflect-view mirror on a piece of paper and ask a student to write the same word in two places on the paper in front of but at different distances from the mirror. Next, have the student write over the corresponding images behind the mirror. After the reflect-view is removed, students compare the size of the two words written behind the mirror; it may surprise them to see that they are of the same size.

Lab stations

While the reflect-view mirror provides very interesting options for class demonstrations, as described above, the improvement in students' results after teaching with this device, as measured in pre- and posttests, in comparison with control groups with little or no use of demonstrations, were not as significant as we had hoped. The main reason for these results is most likely that the limited participation of the majority of students in the demonstrations did not promote active learning. We quickly realized the reflect-view could be more effective in laboratory activities performed by students than in demonstrations, where the room for exploring and testing of their own ideas is more limited.

We designed a lab to allow students to explore and understand image formation in plane mirrors. The lab is divided into four completely independent, though related, experiment stations, each with different ap-

Students, working in groups of three or four, travel from station to station within a predefined time frame. The stations can be done in any order and they have the same level of difficulty.

FIGURE 5 Lab station 2

Materials

- 1 sheet of 8½ × 11” paper (per group)
- 2 sheets of A5 paper, or paper cut to approximately 5.75 × 8” (per group)
- Foam letters (R, I, S, and K)
- Reflect-view mirror
- Marker
- Die
- Plane mirror

This lab station is related to the type of inversion that occurs in plane mirrors. The first step is to create a context for students to understand that, in daily life, the image in a mirror seems to exchange left with right because the object is turned 180° before it is in front of the mirror. After, there is an open question (question 4) through which the teacher will be able to identify students’ ideas. Then students can discover the real inversion occurring in a mirror with simple experiments using foam letters and a die. The die is an important object because it enables students to understand there is no way that the real die and its image can be made to overlap (the die is not symmetrical under inversion).

Procedure

1. Write the letter *R* on one of the sheets of A5 paper. Imagine turning the sheet so you can see the letter reflected in a mirror. How will the letter appear? Discuss this question with your group and draw what you think you will see.
2. Repeat the previous task with the word *RISK* (in capital letters).
3. Place the foam letter *R* on your table (standing). Imagine that you want to see the image of this letter through the mirror (each foam letter has two faces, a soft part and a rough part; the rough part will be facing you). How will the letter appear? Discuss this question with your group and draw what you think you will see.

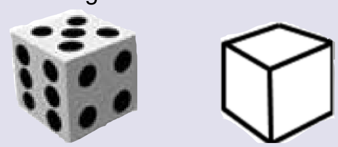
Stop: Call your teacher to evaluate your drawings.

4. Test the three previous predictions with the reflect-view mirror. What conclusions can you draw?
5. It is time to discover what type of inversion occurs in a plane mirror. Place the reflect-view mirror on the 8½ × 11” sheet of paper.
6. Lay the foam letters horizontally on the sheet to form the word *RISK*. Write over the image with a pencil (behind the mirror) and then remove the reflect-view mirror. Draw a sketch of the object and the image.

OBJECT SIDE

MIRROR

7. Put the die in front of the plane mirror, as represented in the picture (with the edge common to the faces with 4 and 6 toward the mirror and the 5 facing up). Draw a sketch of the image.



8. What type of inversion occurs in a plane mirror?
   a. A left-to-right inversion
   b. A front-to-back inversion
   c. A top-to-bottom inversion
9. Suppose you were to paint a white die with dots to make it look like the image you see in the mirror. Could you ever turn it so that all of the faces have the same orientation as the original die?

FIGURE 6 Misconception addressed by each lab station

Misconceptions	Lab station
• An image in a plane mirror is on/inside/in front of the mirror. • Objects' images appear when we look into the mirror. There is no image in the mirror when we are not looking at it.	1
• Plane mirrors exchange left and right.	2
• An image is formed along the line of sight between an observer and an object. • If an observer facing a plane mirror moves, the position/size of objects' images in the mirror changes. • Images become smaller as objects move away from a mirror. • The larger a plane mirror, the larger the image in it.	3
• An image is formed along the line of sight between an observer and an object. • Visual field does not depend on an observer's distance from a plane mirror or its size. • The position of an observer is not important in determining whether a mirror image can be seen.	4

paratuses/materials. Students, working in groups of three or four, travel from station to station within a predefined time frame. The stations can be done in any order and they have the same level of difficulty. Each student group has a limited time to perform each station, after which it will have to move to the next one; this constraint helps to keep students focused on their activities. These lab stations were designed according to our teaching experience, the school's financial resources, and previous research (see Figure 6).

The stations are diversified and range from simple tasks, such as simulations or simple measurements, to tasks that involve a higher cognitive ability. At every station, in addition to conducting experimental activities, students answer theoretical questions on a worksheet (Figures 2, 5, 7, and 8). This formative assessment allows teachers to know, in real time, students' ideas and how they understand a specific topic, so teachers can plan the next lesson.

The lab session, preceded by a lecture on plane mirrors, is centered around reflect-view mirrors. In all of the activities, we tried to stimulate students to think about what they'd learned in the lecture and to make connections between the content studied and the real world.

Figures 2, 5, 7, and 8 are photos of each lab station, a brief summary of the station, a materials list, and a lab worksheet/procedures. Each lab station takes 10 minutes to complete.

Feedback

Students enjoyed having lab stations because they could work with their peers, explain their ideas, and share knowledge. Doing all of the activities and completing the worksheets required inward reflection, critical thinking, and scientific literacy. Students actively shared what they learned with their peers and expressed their thoughts in writing (they completed the lab worksheets in lieu of writing a lab report).

During the lab session, it was fundamental to listen to the discussions within the groups, identify students' main difficulties (whether in understanding procedures, making predictions based on previous experience, drawing conclusions from their observations, or answering the worksheet questions), and address the corresponding conceptual conflicts. Students often posed additional questions, thus creating a favorable learning environment. Information obtained during class and from students' completed lab worksheets made it easier to build an effective next class, which was a follow-up to the labs.

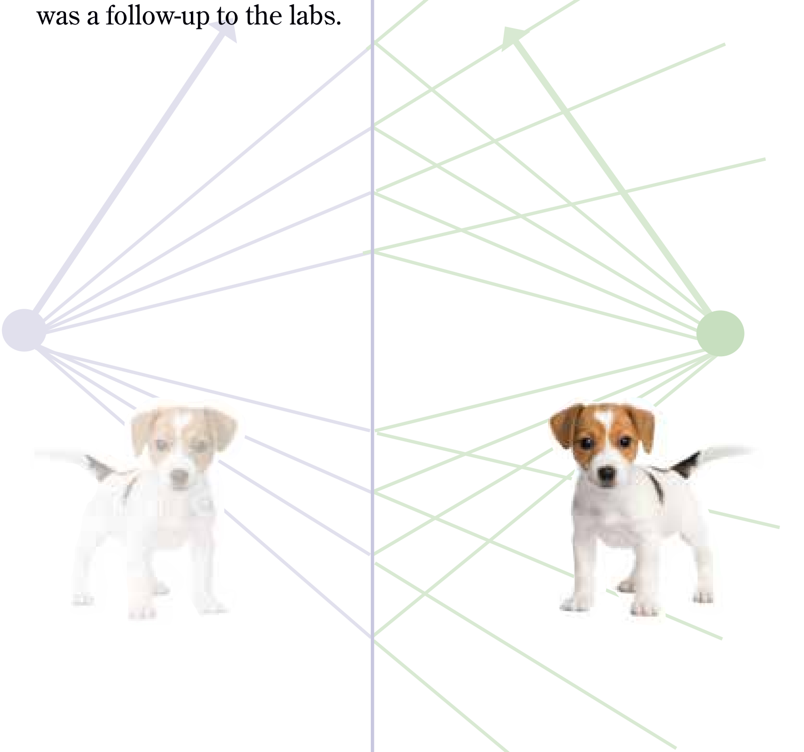


FIGURE 7 Lab station 3

Materials

- 1 transparency sheet (per group)
- 1 8½ × 11" sheet of paper (per group)
- 4 transparency markers of different colors
- Reflect-view mirror
- 1 Ping-Pong ball
- Ruler

This lab station is focused on the empirical belief that an image is formed along the line of sight between an observer and an object, and that the position of the image only depends on the observer's position. Two students sit sequentially, and, from different viewpoints, mark the position of the image of the same object; they conclude that they coincide. On the other hand, students can see that the image size is always the same size as the object, and if the size of the mirror changes, the image size does not change.

Procedure

1. Sit side-by-side in front of the reflect-view mirror so that you can all see the image of the ball. Place the reflect-view mirror on the transparency.
2. Each of you should now mark the position of the image on the transparency with different-color markers. What can you conclude?
   a. The image position does not coincide for all of the observers, and it is always formed along the line of sight between an observer and the ball.
   b. The image position does not coincide for all of the observers, and it is not always formed along the line of sight between an observer and the ball.
   c. The image position coincides for all of the observers, and it is always formed along the line of sight between an observer and the ball.
   d. The image position coincides for all of the observers, and it is not always formed along the line of sight between an observer and the ball.
3. Imagine that you all moved to the right. Would the position of the image also change? Why or why not?
4. Move the ball to the right edge of the mirror. What conclusions can you draw?
   a. The image moves to the left for all of the observers. The image position coincides for all of the observers.
   b. The image moves to the right for all of the observers. The image position coincides for all of the observers.
   c. The image does not move. The image position coincides for all of the observers.
   d. The image moves to the right for all of the observers. The image position does not coincide for all of the observers.
5. In front of the mirror, write the word *car* on two locations of the horizontal sheet of paper at different distances from the reflect-view mirror. The distance between them should be bigger than 10 cm. Then write over their images behind the mirror. Remove the reflect-view mirror and compare the size of the two words written behind the mirror. Do the images become smaller as the object moves away?
6. If you replace the mirror with a larger/smaller one, does the image size change? Experiment with the mirror by rotating it.

FIGURE 8 Lab station 4

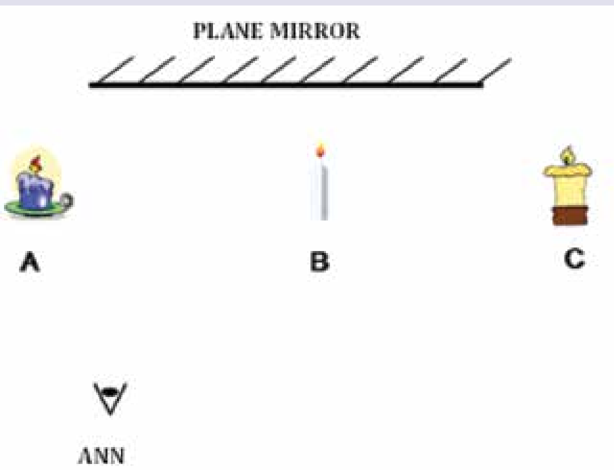
Materials

- Reflect-view mirror
- Ruler/protractor
- Toy car (or other small object)

This station is concerned with the relationship among an image, an object, and an observer. After this lab, students should be able to answer in a real situation whether an image can be seen by someone and how it will be seen. It is important for students to recognize that the observer position is decisive in order to see the image. The same image can be formed, be seen for some observers, and not be seen by others. The visual field depends on the distance/position of the observer to the plane mirror and, obviously, the size of the plane mirror.

Procedure

1. Working with a partner, place the toy car in front of the reflect-view mirror so that you can see its image. Have your partner sit in a place where he/she cannot see the image of the car in the reflect-view mirror. Make a sketch of the relative positions of each one of you, the mirror, and the car. Draw light rays to understand why your partner does not see the car and you do.



2. In the image to the left, Ann is at the front of a plane mirror. Which candle(s) can she see?
   a. A and B
   b. B and C
   c. A, B, and C
   d. B

3. Which of the following statements is true?
   a. The position of the observer is not important in determining whether the mirror image can be seen.
   b. For an observer to see the mirror image of an object, the object must either be directly in front of the mirror, or if not directly in front, it must be along the observer's line of sight to the mirror.
   c. Images cannot be formed by objects that are not directly in front of the mirror.
   d. Images can be formed by objects that are not directly in front of the mirror.

Conclusion

Our experience with these activities showed that students became actively engaged in the learning process and demonstrated significant improvement in understanding, either when compared with control groups, using pre-/posttest methodology, or as assessed from experience with our own classes.

The students involved in this activity were exposed to this methodology of lab stations on a weekly basis. We find that this training is essential to create a productive work flow, without which students would not have been able to carry out the four lab stations in a 45-minute session. Moreover, this model is ideally applied to classes with 12 to 16 students. For larger classes, it is necessary to duplicate the lab stations.

Should a teacher wish to motivate more practically minded students with possible engineering applications of plane mirrors, we suggest one exciting example. Micro-mirror array devices are made with many extremely small square plane mirrors, which can be oriented independently and in a matter of microseconds. The light reflected by each of these micro mirrors can thus be directed to a specific location, as a consequence of the law of reflection. These systems, when properly illuminated with a light source, can be used to create an image by controlling the orientation of the micro mirrors with an electric (digital) signal such as the one produced by a computer. Teachers can find examples of micro-mirror arrays online to show students or ask students to research the topic.

A more day-to-day application concerns the use of rearview mirrors, the field of view they afford, and the dangers of the "dead angles," where the image of approaching vehicles disappears. Figure 8 addresses this very issue of when an image becomes visible to an observer in a specific position. This may even motivate a discussion on the need to use other types of mirrors (curved ones for instance).

In summary, the misconceptions identified by previous research concerning images in plane mirrors were used as a guide to design a set of activities. When performed as hands-on lab, they were particularly effective in promoting students' correct understanding of the position and characteristics of the image in plane mirrors and of the visual field (relationship among the observer's position, the object, and the image). ■

References

Achieve Inc. 2013. *Next generation science standards.* Washington, DC: National Academies Press.

Ford, K.W. 1975. Why is your image in a plane mirror inverted left-to-right but not to top-to-bottom? *Physics Teacher* 13 (4): 228–339.

Galili I., and F. Goldberg. 1993. Left-right conversions in a plane mirror. *Physics Teacher* 31 (8): 463–66.

Galili, I., F. Goldberg, and S. Bendall. 1991. Some reflections on plane mirrors and images. *Physics Teacher* 29 (7): 471–77.

Goldberg, F.M., and L.C. McDermott. 1986. Student difficulties in understanding image formation by a plane mirror. *Physics Teacher* 24 (8): 472–80.

Operation Physics. Children's misconceptions about science. *http://amasci.com/miscon/opphys.html.*

Ana Rita Lopes Mota (*anaritalopesmota@gmail.com*) is a middle/high school physics and chemistry teacher and a researcher in the Department of Physics and Astronomy at the University of Porto in Porto, Portugal. ***João Lopes dos Santos*** (*jlsantos@fc.up.pt*) is a professor in the Department of Physics and Astronomy at the University of Porto in Porto, Portugal.