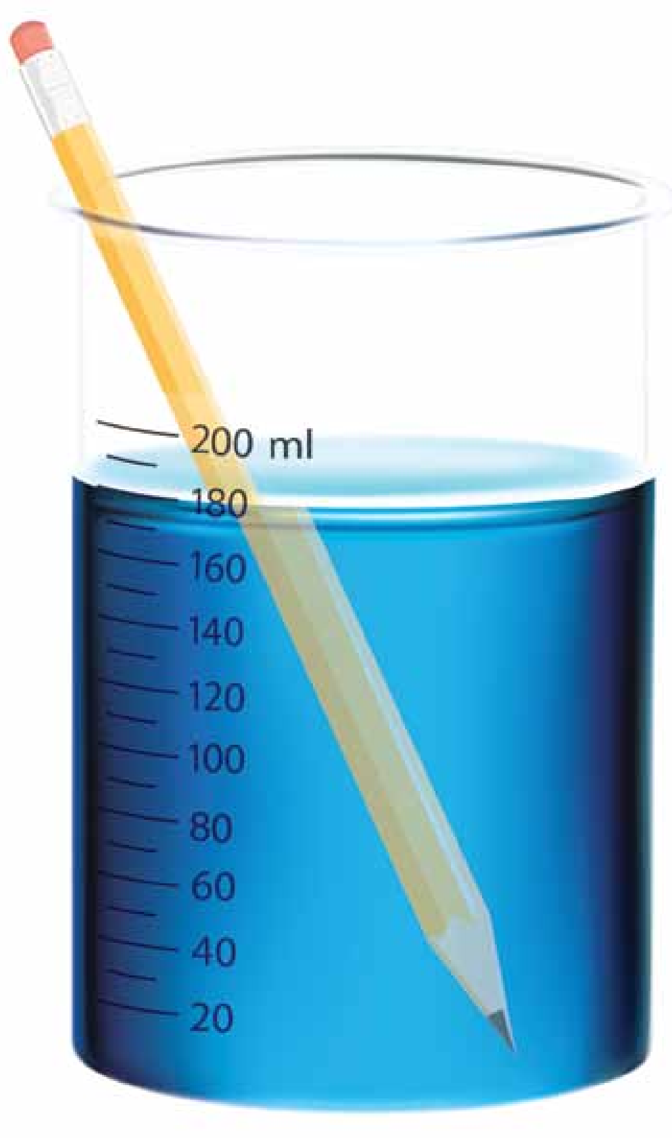
Investigating change using the invisible-test-tube demonstration

by Patrick Brown



Have you ever reached for something underwater to find that the object was not exactly where it appeared? This is because light rays are influenced by different substances (such as air and water), depending on the substances' physical properties. The word *refraction* is used to describe the phenomenon of light rays bending as they pass from one substance to another substance. Although many students experience the property of refraction in everyday life, research indicates they have difficulty explaining how light rays are influenced by different mediums (Driver et al. 1994). Students have success learning about refraction by examining patterns of change that occur during hands-on, minds-on science investigations. This paper describes a simple, inexpensive, engaging way to teach refraction that students will talk about for the entire school year. First, a useful teaching tool for designing science demonstrations called the PSOE (Predict, Share, Observe, Explain) model is explained. Second, I present a PSOE demonstration I use to begin teaching the National Science Education Standards content standard about "light interact[ing] with matter by transmission (including refraction)" to eighth-grade physical science students (NRC 1996, p. 155). In addition, this paper highlights the *Framework for K–12 Science Education,* and students engage in essential practices such as investigating scientific questions, working collaboratively to formulate ideas, and analyzing, interpreting, and making scientific claims based on data (NRC 2012).

The PSOE model

The PSOE instructional sequence is based on a model of teaching and learning called "conceptual change" and consists of the following stages: Predict, Share, Observe, and Explain (Stepans 1996). The Predict stage interests students in the lesson and allows the teacher to identify students' initial conceptions (including misconceptions). The Share stage is a time for students to collaborate, reformulate, and refine scientific ideas. The Observe stage provides students firsthand experiences with quantitative or qualitative observations, data, or other evidence. Finally, in the Explain stage, students generate scientifically accurate ideas based on data they have collected or observed during the demonstration. Using this approach, teachers can help students identify, redefine, and change their initial conceptions through observations, collaborative interactions, and scientific data. Making scientific claims based on evidence, through both individual and collaborative experiences, is a key scientific practice that cuts across science topics (NRC 2012). In addition, the PSOE instructional model can be an inquiry-based teaching approach that incorporates many of the essential features of classroom inquiry and helps students understand that evidence-based reasoning is used to construct science knowledge (NRC 2012). In summary, the PSOE instructional sequence is a simple way to make demonstrations less teacher driven and include opportunities for minds-on, inquiry-based experiences that are necessary to learn science.

The invisible-test-tube demonstration

Predict

The lesson begins by having students make a prediction about how different substances, called mediums, change the behavior of light. Teachers can help elicit students' ideas about the behavior of light by asking them to think about how different mediums influence how objects appear for two different setups that will be revealed during the Observe stage of the demonstration: (1) a test tube filled nearly to the top with water submerged in a 50 mL beaker filled with water and (2) a test tube filled nearly to the top with cooking oil in a 50 mL beaker of cooking oil (Wesson brand cooking oil works well for the demonstration). At this point in the demonstration, it is beneficial to have a beaker with water, a test tube with water, a beaker with oil, and a test tube with oil available to support visual learners. The test tubes are not in the beakers at this point. Next, students individually record their predictions on a sticky note as a way to commit to an idea and make their conceptions explicit.

Teachers can promote the Framework's crosscutting concepts for stability and change by asking students to identify factors (e.g., glassware, light, and mediums) they think will change or remain unchanged during the demonstration. Having students write down their ideas makes their thinking concrete, and they can revisit their initial conceptions later in the lesson. Students' written predictions are not graded during this stage so they will feel comfortable expressing their conceptions of science phenomena.

Share

The next phase of the lesson provides students with collaborative opportunities to share their thinking. During this time, students tell a partner sitting close by what they predict they will see when the two different setups are unveiled. In addition, students give a reason for their prediction and explain their thinking. Students do not need long to share their ideas, and a short amount of time ensures students' conversations stay on task; two minutes total (one minute for each partner) is sufficient. During this time, the teacher should walk around the room and listen to students' ideas, but not assess the accuracy of students' conceptions. Once students have shared their ideas with a partner, the teacher can quickly go around the room and have students say "same" or "different" (to indicate whether students had the same or different idea than their partner). This is a quick check to make sure all students shared ideas.

Next, the teacher can have a whole-group discussion (5–10 minutes) to allow students to share ideas. Students are encouraged to engage in an argumentation-type discussion and provide explanations from their everyday experiences for their ideas. Teachers should remain active listeners during this discussion, encouraging students to talk with each other, but not providing feedback indicating whether students' conceptions are correct. Teachers should be aware that students can develop inaccurate ideas based on discussions with their classmates, and some will assert they know what will happen from prior experiences; however, I find the latter is rarely the case. Therefore, at this point in the PSOE sequence, I do not grade students' predictions.

At the end of the Share stage, I have students draw and label in their notebooks what they think is happening in the different mediums that explains their prediction. Teachers will find that most students think the portion of the test tube filled with water submerged in a beaker with water will look magnified. For example, some students will draw a test tube filled with water in a beaker filled with water larger than the actual test tube and use lines to represent rays of light. Students explain that the water acts as a magnifying glass and causes light rays to spread out, making the test tube appear larger than in real life. Students support their ideas with their real-life experiences. One of my students talked about how a spoon placed in a glass of water appears magnified. Others have mentioned that when looking at a coin in water from above, the coin appears larger.

FIGURE 1 Water-filled test tube submerged in a beaker of water

FIGURE 2 Oil-filled test tube submerged in a beaker of oil

Students are less sure about what will happen when a test tube filled with oil is placed in a beaker of oil. Students recall their knowledge of properties of liquids to formulate predictions about the oil and glass. Most students pull from their experiences looking at objects underwater and predict that the submerged portion of the test tube will appear either larger or smaller than the actual test tube. The students' predictions reveal their beliefs that (1) oil will cause light rays to spread out, making the test tube look bigger, or (2) oil will cause light rays to bend inward, causing the object to appear smaller. Some students think that the submerged portion of the test tube will be difficult to see and claim that the outline of the test tube will be "blurry" and unclear. These students explain that the density of the oil will block some light from traveling through the beaker, making it difficult to see the test tube. Students' research show light rays becoming fainter as they enter the oil (some of my students have illustrated this by showing a thick line turning into a dotted line when the light ray enters the oil). If students have similar conceptions to each other, teachers may find it helpful to tally their ideas on the front board for everyone to see. The result of the Share stage is that students change, revise, elaborate, or retain their initial conception based on their conversations with their peers.

Observe

During the Observe stage, teachers can get students excited by unveiling each of the setups at approximately the same time. (Note: The two setups are prepared ahead of time and placed in a location out of students' sight.) Teachers need to take two safety precautions when performing the demonstration: First, all participants need to wear indirectly vented chemical splash goggles. Second, all spills must be cleaned immediately to prevent slip-and-fall accidents. One way to ensure engagement is by having multiple setups for students to observe. For example, the teacher can bring the setups to three different stations in the room. It is important that students remain seated so everyone can see the demonstration. This will allow all students to observe the demonstration and prevent disruptions. Many students are surprised by how much the submerged portion of the water-filled test tube in the beaker of water is magnified compared to the non-submerged section of the test tube (see Figure 1). Students write on their PSOE worksheet what they observe and record whether their prediction was supported or rejected. Students are then able to revise the model they had drawn in their notebooks during the Share phase. I mention to students that in order to be able to see an object, light rays have to bounce off the

FIGURE 3 Comparison of the two setups

object and return to the eye (i.e., reflection). I challenge students to show in their drawings how light rays bounce off the test tube and travel back to their eyes. At this point in the Observe stage, students are pleased to find that their predictions are accurate.

When the second setup is revealed, the energy, enthusiasm, and interest in the room quickly reach a new height. Students' eyes widen and their jaws drop, and they are completely shocked by the results. It is rare for a single student to have an accurate prediction (see Figure 2). Students notice that in the setups, the submerged portion of the test tube appears invisible. In order to achieve maximum engagement from students without disruption, teachers should unveil the demonstrations as close to the same time as possible. Some students react to the demonstration by saying that it's a magic trick. They claim that the "test tube is broken" and that they are being "tricked" by the teacher. Some students believe the test tube does not actually have a submerged portion and is possibly a broken test tube resting on top of the oil. However, when the test tube is lifted out of the oil by the teacher and students see that it is a whole, unbroken test tube, they are stunned. When the test tube filled with oil is placed back in the beaker with oil, the submerged portion of the test tube again disappears. This part of the demonstration gets a lot of "wows," "oohs," and "ahs." At the end of the Observe stage, students write down what they observed for each of the two setups in the demonstration (see Figure 3), record whether their initial prediction was supported or not based on the demonstration, and explain what changed in the two setups. By introducing the idea that seeing an object is related to light rays bouncing off the object (i.e., reflection), the demonstration helps students revise their drawings for the test tube in a beaker of oil. With guidance, students draw light rays passing through the test tube in a beaker of oil with no light rays being reflected. This is an excellent opportunity to illustrate to students how small changes in the system can dramatically influence their perception of objects, because it is not until the test tubes are submerged in the beakers that the test tubes look different. Teachers can challenge students to think about how science can be thought of as a "system." Students discuss how systems are composed of many factors and variables that are smaller, subcomponents. Understanding the subcomponents, and their interrelationships, is important for gaining a deeper conceptual understanding of science.

Explain

During the Explain stage, teachers should provide students with data to help them make scientific claims based on evidence. In this lesson, students use a table that has been modified from their textbook (Padilla, Miaoulis, and Cyr 2007) and includes the refractive index of Pyrex glass (i.e., the beaker and test tube) (the data needed to create such a table are available in their textbook and at *www.pgo-online.com/intl/katalog/pyrex.html*; see Figure 4).

FIGURE 4 Refractive indexes

Material	Approximate refractive index
Air (gas)	1
Water (liquid)	1.33
Corn oil (liquid)	1.47
Pyrex glass (solid)	1.47

Students find patterns in the data that help them make sense of the two setups in the demonstration. First, students infer from the data that the value of the refractive index is an indicator of how much a material bends light. Values that are close to 1, such as air, do not noticeably bend light. Second, students are able to make scientific claims about how refractive indexes that deviate from a value of 1 influence the bending of light. Students use the refractive index of water (1.33) and Pyrex glass (1.47) to make the scientific claim that as the value of the refractive index deviates from a value of 1, the amount that light bends changes. Thus, water (1.33) and Pyrex glass (1.47) bend light more than air (1). This is evidenced by students' firsthand experience where the submerged portion of the test tube in water appeared magnified.

The most difficult concept for students to understand is the second setup: the test tube filled with oil submerged in a beaker of oil. Students benefit from working in pairs to explain how the refractive indexes of cooking oil and Pyrex glass relate to what they observed about the combination of these materials in the demonstration. Students observe from data that the indexes of refraction for cooking oil and Pyrex glass are virtually the same (both are approximately 1.47). From their firsthand experiences with the demonstration and from data, students are able to infer that when the refractive indexes of two materials are the same, an object can seem invisible. Thus, students explain that the matching refractive index is the factor that changed in the demonstration and the reason that the submerged portion of the test tube appears invisible.

Once students have had an opportunity to formulate an explanation, teachers can support their understanding by having students carry out library research to explain the demonstration. Students learn that the matching refractive indexes remove reflections (when some light bounces back) and refractions (when light bends) where the test tube and oil meet. As a result of removing the reflection and refraction of light, there is no visible boundary between the test tube and oil. The object seems invisible because light is transmitted through it without bending, bouncing back, or being absorbed. To support this idea, teachers can place another object, with a different refractive index than water, oil, or Pyrex glass, such as a metal spoon, in the oil. Teachers may find it helpful for students to draw their predictions, including light rays and reflected light, in their notes. After students have drawn their predictions, they should discuss their ideas and provide evidence for their thinking. Students will observe that the spoon in the oil is visible because it reflects and absorbs light. Teachers can also place a test tube of water in the beaker of oil so students can see mismatched indexes of refraction. Students will observe that the test tube of water looks magnified when placed in the beaker of oil. Finally, teachers can further extend student learning by discussing real-life examples that use this principle. For example, camera lenses use matching refractive indexes to reduce the reflection of light to lessen the glare on an object and allow photographers to capture fine details and colors of objects.

Conclusion

The teacher's role during a PSOE demonstration is to get students excited about exploring science phenomena before explaining new content. The PSOE model helps teachers focus on important concepts they want students to think about and appropriately sequence activities to facilitate student learning. In addition, the PSOE demonstration helps students develop an understanding of systems and think deeply about factors that change or remain unchanged in science investigations (NRC 2012). In this regard, the invisible-test-tube demonstration promoted higher-level thinking for the rest of the school year. Students engage in analytical and logical thinking and argumentation to identify the important factors and relationships within a system. This skill facilitates students' understanding that science is a process of analyzing and interpreting phenomena and data to construct scientific explanations.

During PSOE demonstrations, students benefit from both verbal and written opportunities to present their views and have the opportunity to work collaboratively to develop and refine their conceptions. Once students have had the opportunity to form explanations, teachers can promote deeper learning by building on students' knowledge to provide them scientifically accurate descriptions and elaborations that connect the content to students' real-life experiences. This sequence (exploration before explanation) aligns with current views of science teaching and learning that highlight that students learn best when they are actively engaged in thinking and in doing and have the chance to build new ideas before teacher explanations (Bransford, Brown, and Cocking 2000). The end result of the PSOE sequence is that students develop deep and lasting conceptual understanding of science because they have generated new ideas based on firsthand experiences. ■

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Patrick Brown (*plbtfc@gmail.com*) is an eighth-grade science teacher at DuBray Middle School in St. Peters, Missouri.