If students are to understand the way the world works and solve scientific problems, they must first understand the laws of the physical sciences. Yet many students graduate from high school with a poor understanding of important physical science concepts. There is a simple two-part explanation for this observation. First, many students’ alternative conceptions are deep rooted; they often hold on to and continue to use these conceptions to make sense of the world. Second, traditional classroom instruction, which typically consists of lectures, demonstrations, and answering questions at the end of a chapter, is often not an effective way to help students abandon their initial conceptions and adopt and use scientific explanations to make sense of things instead (NRC 2000).

There are, however, alternative instructional techniques that teachers can use to help students develop a more appropriate understanding of physical scientific concepts. For example, teachers can use a Predict, Observe, and Explain (POE) demonstration (White and Gunstone 1992) to promote and support conceptual change (i.e., a process where people abandon or revise their existing ideas, beliefs, or ways of thinking). In a POE demonstration, students first make predictions about what will happen during a demonstration. The teacher then performs the demonstration as students observe. Finally, the teacher guides students to a scientific explanation based on evidence and results from the demonstration, and helps them understand why alternative explanations are insufficient.

The POE demonstration is designed to provide teachers a way to elicit alternative conceptions relating to a particular concept, allow students to discover why these conceptions are inadequate, present a new explanation supported by evidence, and show them why the new explanation is more useful (White and Gunstone 1992). When all four of these conditions are met during a lesson, it is more likely that students will go through the conceptual change process (Posner et al. 1982).

The law of conservation of mass can be counterintuitive for most students because they often think the mass of a substance is related to its physical state. As a result, students may hold a number of alternative conceptions related to this concept, including, for example, the belief that gas has no mass, that solids have greater mass than fluids, or that matter (like salt) is destroyed when it dissolves (Driver et al. 1994). These alternative conceptions can hinder a student’s ability to understand physical science on a conceptual level because this law serves as the cornerstone of other important topics, such as chemical reactions and stoichiometry. Therefore, it is important for students to adopt and use the law of conservation of mass as early as possible to make sense of what they see and do in a physical science class.

Given these issues, we performed a lesson study (Cerbin and Kopp 2006; Chokshi and Fernandez 2004; Fernandez 2002; Fernandez and Chokshi 2002; Lewis, Perry, and Murata 2006) to develop a lesson that can be used by teachers to help students understand the law of conservation of mass and use it to make sense of new observations. This article presents the lesson, which meets the National Science Education Physical Content Standard B for Grades 9–12 (NRC 1996, pp. 176–181), and methods for use in the classroom.
Development of the lesson

As noted earlier, we developed this lesson as part of a lesson study. A lesson study is a process in which teachers work collaboratively on a research lesson. Any type of lesson can be revised using this process, including demonstrations, labs, and lectures. This process involves planning, teaching, observing, analyzing, and refining the lesson over several iterative cycles. Figure 1 depicts the various components of a lesson-study cycle.

Once we selected the law of conservation of mass as the focus of our lesson study, we had to determine how best to teach students about this important concept. Being familiar with the conceptual change literature, we decided to use a POE demonstration. However, as we taught, observed, and refined the lesson, we soon discovered that it was important to formally ask students to explain their predictions in writing as part of the lesson. This refinement enabled us to better assess changes in student understanding and to identify several additional alternative conceptions related to the conservation of mass that we did not find in the literature. Our lesson, therefore, became a Predict, Explain, Observe, and Explain (PEOE) demonstration. In the sections that follow, we describe the final iteration of this lesson, some strategies for use in the classroom, and what we have learned about how students understand the conservation of mass as part of this process.

Preparing for the lesson

To prepare for the lesson, the instructor should first choose two or three demonstrations to illustrate the idea that mass is conserved during a chemical reaction. Students, as noted earlier, often think gas has no mass or less mass than a solid or liquid. In addition, students often think a solid has a greater mass than a liquid. Some even believe that matter can be destroyed (Driver et al. 1994). Therefore, teachers should choose a simple chemical reaction that produces a gas (e.g., the reaction between sodium bicarbonate and acetic acid) or a precipitate (e.g., the reaction between calcium chloride and sodium sulfate) to help elicit inaccurate ideas about the conservation of mass. It is also important to use enough materials so that everyone in the class is able to see the demonstrations. For example, we have found it useful to demonstrate the reaction between sodium bicarbonate and acetic acid in a 2 L plastic bottle using 500 mL of acetic acid and 5 g of sodium bicarbonate. Using these amounts of reactants in a closed container allows students to see the reaction without it producing enough gas to pop the container. Teachers will also need to have a triple-beam balance available so they can measure the mass of the reactants and the products.

Prediction and explanation

The instructor begins the lesson by providing students with a handout on which to write out their predictions and explanations during the demonstrations. Figure 2 (p. 56) illustrates the prompts we include on a PEOE handout. The instructor then describes what he or she will do during the demonstration. For example, when we used this lesson with our class, we told students that when sodium bicarbonate and acetic acid were mixed, a gas would form, and that we...
were using a 2 L bottle for the demonstration so none of the gas would escape. The instructor then weighs the reactants and the container and reports that value to students.

Next, students are asked to make a prediction about what will happen to the total mass once the reactants are mixed inside the container (Figure 2). At this point, the instructor informs students that they will not be graded or judged on their predictions so that they feel comfortable making guesses.

Students are also asked to write down an explanation for their predictions (Figure 2). It is important that students write their ideas on the handout, instead of just sharing them with the teacher. This makes it easier to address each alternative conception during the lesson and to look for changes in student thinking.

When students are explaining their predictions, they should be allowed to talk with their peers. This helps students make sense of what they are thinking and allows them to articulate their ideas in a clear and concise manner. As students work, the teacher questions them about their reasoning but should avoid indicating which predictions and explanations are correct. The teacher should also make students feel that all of their predictions and explanations are valuable and encourage them to respect the ideas of their peers. Ideas should not be dismissed without discussion.

**Observation**

Once all students have made and explained their predictions, the teacher performs the demonstration wearing safety goggles. (Safety note: Wrap-around, splash-proof goggles must be provided for all students, as well.) The instructor should try to involve students in the demonstration process as much as possible. For example, the instructor can ask a student to verify the mass measurements before and after the demonstration by reading the value on the triple-beam balance to the class. This reassures students that the instructor is being forthcoming about the actual outcome of the demonstration. With the reaction of sodium bicarbonate and acetic acid, students are able to visually see the gas-formation reaction take place. Instructors should also allow students to feel the pressure build up in the container. At this time, students take note of what they have observed (Figure 2). Specifically, they should record whether the mass increased, decreased, or stayed the same.

**Explanation of the observation**

The next step in the lesson is to help students explain what they observed during the demonstration. Students use evidence from the measurements (i.e., the mass of the container remained the same) to discover the law of conservation of mass. To facilitate this process, the teacher focuses on a discussion about why the inaccurate predictions (the mass will increase or the mass will decrease) were incorrect and why the various alternative explanations provided in support of the inaccurate predictions are not sufficient. For example, if students predicted the mass would decrease when a gas was formed, the discussion should focus on the incorrect explanation that gases have less mass. This is also a good opportunity to reinforce the fact that atoms cannot be destroyed—since many students seem to believe matter just disappears (Driver et al. 1994).

Next, the teacher focuses on the explanations provided by students who thought the mass would remain the same. The teacher can formally introduce the conservation of mass to students at this point and then encourage them to use it in their new explanations (Figure 2). If students have an explanation for why the mass remained the same that is not consistent with the conservation of mass, the teacher should lead a discussion to help them discover why that explanation is not sufficient. It is also useful to introduce students to balancing chemical equations at this time because it illustrates the process underlying the law of conservation of mass: namely that atoms are simply rearranged in a chemical reaction, not created or destroyed.

**A new context**

To reinforce the concept of the conservation of mass, the instructor can use a second or even a third PEOE demonstration. Additional demonstrations give students a chance to apply the concept and scientific vocabulary to a different context and obtain additional evidence in support of the conservation of mass. This also allows the teacher to assess whether or not students are able to use scientific explanations to make sense of new phenomena. A third PEOE demonstration could be used as an opportunity for students to suggest additional investigations of the conservation of mass. The reactions in any additional demonstrations

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**FIGURE 2**

**PEOE demonstration handout prompts.**

When sodium bicarbonate and acetic acid are mixed, an immediate and vigorous reaction occurs, which produces a gas. What do you think will happen to the mass of the bottle and its contents after the sodium bicarbonate and acetic acid are mixed if a gas is formed?

1. **I predict** the mass will
   - increase.
   - decrease.
   - stay the same.

2. **Explain** your prediction.

3. **Record** your observations.

4. In your own words, **explain** what you observed. Be sure to explain why any alternative explanations discussed in class could not be accurate and use evidence to support your explanation.
should address different misconceptions relating to the law of conservation of mass.

A good continuation of the first demonstration is one that involves the production of a precipitate. For example, the reaction of calcium chloride and sodium sulfate is a nearly instantaneous reaction that produces a precipitate. This reaction helps address the common misconception that when a solid is formed, mass will increase because solids have greater mass than liquids. To produce this reaction, simply mix 10 mL of 2 M aqueous calcium chloride solution with 10 mL of 2 M aqueous sodium sulfate solution, and measure the total mass before and after the reaction.

**Implications for classroom instruction**

Students have many misconceptions about the conservation of mass. Initially, many do not have a clear understanding that matter is neither created nor destroyed during a chemical reaction. A PEOE demonstration can help address those misconceptions and provide a new understanding of these concepts. Our experiences inside the classroom indicate that using two or more PEOE demonstrations (at least one that involves the formation of a gas and one that involves the formation of a precipitate) together during a lesson on the conservation of mass is a productive way to promote conceptual change and help students develop a more appropriate understanding of a counterintuitive concept. These lessons can also be modified so that individual students or groups of students have an opportunity to mass the reactants, mix them, and mass the products themselves, or even design their own experiments to investigate whether or not mass is conserved. These lessons can serve as the foundation for subsequent inquiry-based student investigations.

For a PEOE demonstration or investigation to be effective, however, teachers must be aware of common student misconceptions prior to the lesson. This enables teachers to ask better questions and design better lessons. While giving the lesson, we found many students held the predicted alternative conceptions that gases have less mass than liquids or solids, and solids have more mass than liquids.

Also during our lesson-study project, we discovered one new misconception we needed to address. Even though we had conducted literature research on common misconceptions relating to the conservation of mass, we had overlooked the fact that many students believe mass always increases with volume. For the reaction involving sodium bicarbonate and acetic acid, many students predicted the mass would increase because the gas would occupy a greater volume than the solid, and would therefore weigh more. Once we uncovered this misconception, we were better able to plan for it and address it as we discussed the conservation of mass with future students. All of the students who participated in the final iteration of our research lesson were able to articulate scientific explanations for why the mass remained the same in the final step of both demonstrations.

**Promoting student success**

Our goal as educators is to provide the best lessons possible for our students. In a lesson-study project, teachers work together in professional learning communities to improve instruction and student comprehension. As a result of this lesson-study project, we were able to identify the aspects of our lesson that needed to be altered to facilitate a clearer understanding of the concept. If we did not take a critical look at what students did and did not learn during this lesson as part of this process, we would have undoubtedly subjected these students to the same old lessons with the same old results. We consider student success the ultimate goal of education, and believe teachers will be able to produce more effective lessons if they are developed through the process of lesson studies. We encourage other teachers to engage in this process as a way to learn more about student learning and to improve the impact of classroom instruction.

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