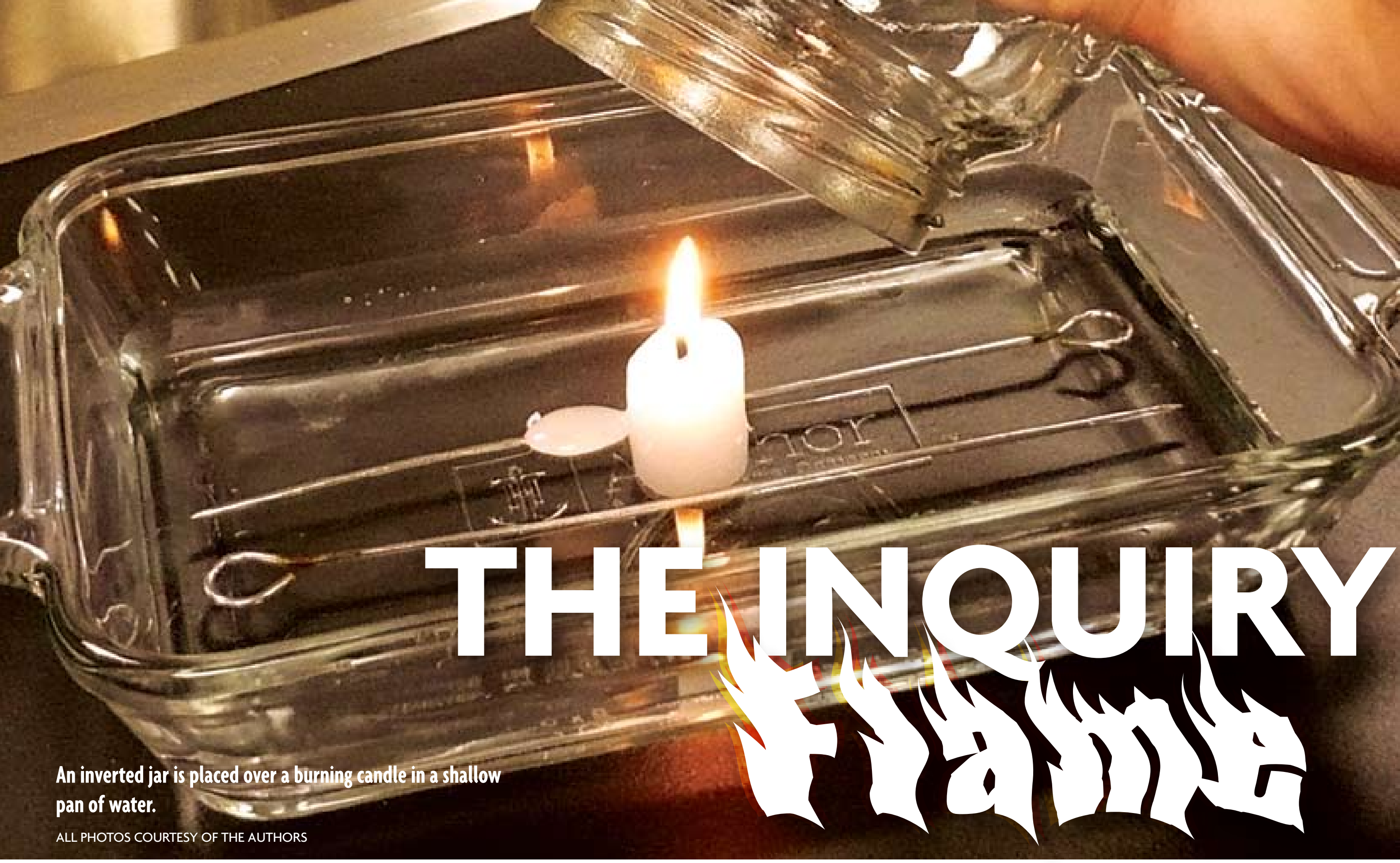


An inverted jar is placed over a burning candle in a shallow pan of water.

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# THE INQUIRY Flame

*Scaffolding for scientific inquiry through experimental design*

**Richard Pardo and Jennifer Parker**

The National Science Education Standards define scientific inquiry as

> "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Scientific inquiry also refers to the activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (NRC 1996, p. 23).

In the lesson presented in this article, students learn to organize their thinking and design their own inquiry experiments through careful observation of an object, situation, or event. They then conduct these experiments and report their findings in a lab report, poster, trifold board, slide, or video that follows the typical format of the scientific community studying the natural world. This article presents a scaffolded approach to inquiry and illustrates its use in the classroom.

## Background

The candle and jar demonstration (ABC Science Online 2005; Hodgkin 1995) is often used in elementary or middle school science classrooms, but secondary teachers might find it helpful as a diagnostic exercise that scaffolds students' experimental procedures. In this article, the classic demonstration is reworked to lead students to design and conduct experiments of their own.

Before using the candle and jar activity in the classroom, teachers should be familiar with common student misconceptions and the scientific principles associated with states of matter, conservation of matter, energy transformations, chemical reactions (e.g., combustion), kinetic molecular theory, and atmospheric pressure and composition.

## The demonstration

To begin the lesson, the teacher presents the class with a discrepant event in the form of a lab demonstration. Students are told to focus their attention on making observations. Statements such as "use your senses carefully, as each of you will need to repeat this" or "observe how this behaves because I am going to ask you to make it behave differently" can help students focus. Then the demonstration commences:

*The teacher holds a glass jar above a burning candle. The candle is positioned between two metal rods in the bottom of a shallow glass pan containing clear liquid (see photo, opposite). The liquid in the pan is high enough to cover the metal rods. The teacher holds the jar above the candle and asks students to come close enough to make careful observations.* (**Safety note:** Both students and the teacher need to wear eye protection [i.e., indirectly vented chemical-splash goggles] during this demonstration.)

CAUTION

*The teacher waits for students to settle and then explains that she is about to lower the jar over the candle and place it on the metal rods—so that the mouth of the jar is below the surface of the liquid, but rests on top of the rods. A space remains between the bottom of the pan and the lip of the jar.*

*The teacher then slowly lowers the jar over the candle and watches her students' faces as the candle is extinguished and the liquid level rises in the jar (see photo below).* (For an explanation of why the flame is extinguished, see "How does it work?" p. 49.)

## Step 1: Careful observation

After the demonstration, students return to their seats to think for a few moments about what they have seen or share observations with a partner or small group. The teacher circulates as students write down their observations, or behavior descriptors, on yellow sticky notes (one observation per note) to place on the Observations Starburst Diagram (Figure 1, p. 46). If this is the first time students have used the diagram, they may be reluctant to start. This scenario describes what might happen next:

*The teacher then leads a whole-class discussion, inviting students to offer their observations as she records them on large yellow sticky notes and places them on a poster-size version of the Observations Starburst Diagram (Figure 1). She places the sticky notes in the square boxes located around the central star, and the object, situation, or event—in this case, the candle and jar demonstration—is written inside it. This models the activity for students.*

*Students then fill out their own sticky notes as the class develops observations for the diagram together. They offer the following observations: The flame went out, there was smoke in the jar, the water rose, and the candle stopped melting. The teacher confirms that the liquid in the pan is water but asks students how they know this.*

The power of this method is that the ideas are coming from students. The teacher does not tell them what they have seen—or what they should have seen. It is important that all observations come from the students and are framed in their own language.

This observation period offers an excellent diagnostic opportunity for the teacher to assess students' level of scientific understanding through their use or misuse of scientific vocabulary and concepts. It is a time to honor student thinking and listen to their conversations as they debate what they did or did not observe.

Students then discuss their observations with one another:

*During the class discussion, one student says, "There was a vacuum created in the jar because the oxygen was gone, so the water got sucked up."*

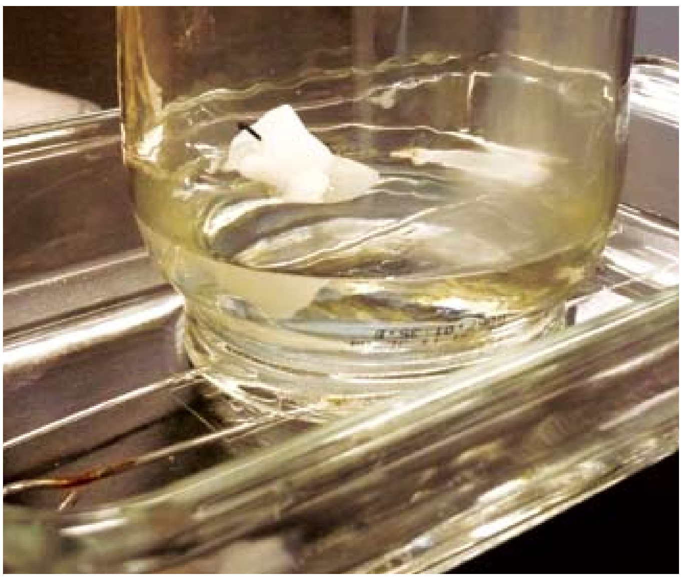
*The teacher's response demonstrates the difference between observations and inferences. She says, "Those are great ideas. However, in the initial stage of an experiment, scientists are careful to make observations without giving reasons why. Since we didn't see, hear, smell, feel, or taste the pressure or the oxygen in the jar, we won't include them in this stage. We will talk about possible reasons for what we observe later on, but for now, tell me only what you observed."*

*The teacher then refocuses attention on the observations of the water rising in the jar and the candle going out, while honoring the student's thoughts and use of scientific vocabulary.*

During this part of the activity, students are encouraged to develop observation skills without attributing cause or attempting explanation. The sticky notes are particularly helpful for reluctant writers and promote risk-taking because they can easily be added, removed, or relocated to match changes in thinking.

## Step 2: Select the dependent variable

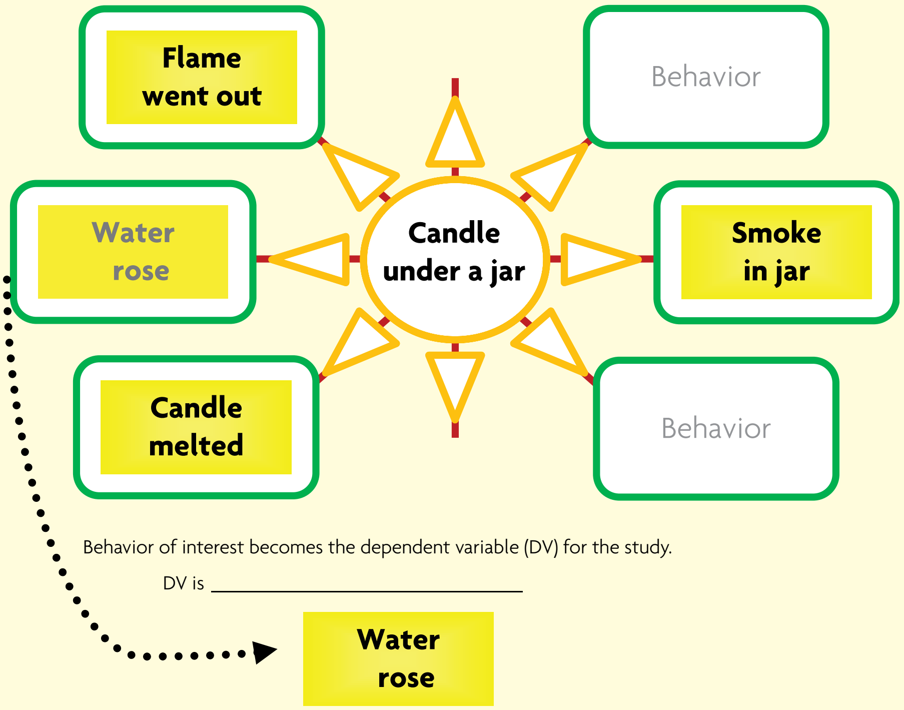
In scientific research, scientists make careful observations of behaviors and then choose one for further study—the *dependent variable (DV)*. In this activity, the teacher or student



**After placing the jar over the candle, the flame is extinguished and the water level rises in the jar.**

**FIGURE 1**

## Observations Starburst Diagram.




selects one exhibited behavior of interest, which becomes the dependent variable.

This is why the Observations Starburst Diagram is helpful—the act of physically separating one sticky note (i.e., behavior descriptor) and declaring it the dependent variable reinforces the importance of isolating a single behavior. It also demonstrates that selecting a new dependent variable creates a new range and variety of possible studies.

A class discussion of how to measure changes in the dependent variable—in terms of instruments, units, and techniques—may be helpful at this point, and ideas will vary depending on students' past experiences. This presents another diagnostic opportunity for the teacher to reflect on the vocabulary and phrasing students use for a specific measuring technique or task. The teacher may want to introduce a new device or procedure for students to consider. Since student groups design their own experiments, those interested in learning new measurement techniques can then be explicitly taught those techniques during subsequent classes.

For the next step in the activity, the teacher needs students to demonstrate an understanding of measurement:

*The teacher explains that although all of students' observations are good ones, she only has the equipment available to investigate the water rising in the jar, and thus moves the corresponding sticky note to the "dependent variable" section of the Observations Starburst Diagram. She then invites students to think about how to measure the rising water (e.g., using a ruler, meterstick, or graduated cylinder), what units will be best (e.g., cm, mm, or ml), and what technique they will use (e.g., at what point they will measure the water, what angle is best for measuring, and whether they will mark the water level on the jar or replace the jar with a graduated cylinder).*

### Step 3: Practice and pilot data

At this point, most students will be eager to get their hands on something. They also need time to practice with equipment and procedures. Student groups are asked to recreate the teacher's candle and jar demonstration as precisely as possible and collect data on the dependent variable. (**Safety note:** Students should be reminded about safety precautions when using open flames and potentially hot glassware. Indirectly vented chemical-splash goggles and aprons must be worn during the entire activity. An ABC fire extinguisher should be available and the lab ventilated to prevent accumulation of smoke.)

Typically, students spend class time recreating the experimental setup and collecting and recording multiple trials. Their goal is to pay attention to their procedure so that they are able to obtain consistent results. The teacher circulates, facilitating this process and reinforcing safety precautions. A class set of pilot data can be created for analysis.

This part of the activity looks something like this:

*Student groups set up their pan, water, candle, and jar and record the height that the water rises in the jar to the nearest 0.1 cm. Some notice that their first attempt results in a much smaller water-level rise than the teacher's demonstration (less than 0.2 cm). The teacher directs students to think about differences between her demonstration and their procedures. Some groups struggle with this, so the teacher recreates her demonstration, suggesting that students watch closely. She silently holds the jar over the lit candle for an extended period (30 seconds seems like forever to some students). Students rush back to their work stations and chatter begins as they discuss how long to wait before lowering the jar and who is going to time the pause.*

Ultimately, the student-generated data from this experiment can be pooled, graphed, and shared with the class. A discussion of the variability of results from scientists following seemingly identical procedures may be helpful here. Students should come away from this stage with an appreciation of the precision required for consistent results and the need for multiple trials.

## Step 4: Brainstorm

Student groups use their knowledge and experiences to consider possible changes and probable effects on the dependent variable. They then write down variables that could affect the dependent variable—from Step 2—on sticky notes of another color (using two different colors helps students separate observed variables from controlled or manipulated variables).

Students place these sticky notes on their Brainstorming Organizer (Figure 2). They move the sticky note representing the dependent variable from the Observations Starburst Diagram to the center of the Brainstorming Organizer to help them focus. This creates another opportunity to share experiences and practice vocabulary introduced at earlier stages.

### Optional research time

Students may need more information to generate ideas or support their facts and preconceptions. The teacher may want to expose students to more background information before the experiments continue—through a more formal lesson, lecture, readings, videos, websites, and so on. More advanced students can start building a reference list of links to websites, articles, and books. The brainstorming session should be revisited and completed following this research time.

## Step 5: Organize variables

Student groups then turn their attention to the Fishbone Experiment Organizer (Figure 3, p. 48), adapted from a diagram developed by Karou Ishikawa (Kondo 1994). The sticky note representing the dependent variable is moved from the center of the Brainstorming Organizer to the oval labeled "DV" on the Fishbone Experiment Organizer. This represents the head of the fishbone—the focus of the experiment.

The sticky notes from Step 4 on the Brainstorming Organizer (Figure 2) represent potential independent variables. Student groups or the teacher select the one that interests them most and this then becomes the independent variable (IV) of the study. The independent variable is placed in the rectangle at the center of the Fishbone Experiment Organizer—representing the body of the fish.

Depending on the desired level of inquiry and other learning outcomes, the teacher may decide that the whole class will complete the same independent and dependent variable combination, have a common dependent variable and select from a short list of preapproved independent variables, or that each group will have a unique combination of dependent and independent variables.

Students understand that the remaining sticky notes on the Brainstorming Organizer represent variables that could affect their selected dependent variable and, therefore, must be held constant. These remaining sticky notes—or *controlled variables*—are placed in the rectangles around the periphery of the Fishbone Experiment Organizer.

The Fishbone Experiment Organizer clearly shows students' ideas for experimental design. Students can jot down ideas and move sticky notes back and forth between the Brainstorming Organizer and the Fishbone Experiment Organizer as they create and modify their plans. Groups who select an independent variable and later change their minds can exchange the sticky note in that rectangle for one in a constant variable rectangle.

Students need to consider how each variable can be measured and the instrument (I), unit (U), and technique (T) they will use (based on research and practice in Step 3). These are then placed along each spine of the Fishbone Experiment Organizer. Student groups that complete their experiments ahead of the rest of the class can experiment with different independent and dependent variable combinations; however—for more authentic practice—they can build a unique Fishbone Experiment Organizer for each experiment they design.

**FIGURE 2**

**Brainstorming Organizer.**

List all variables that may change the DV's behavior.

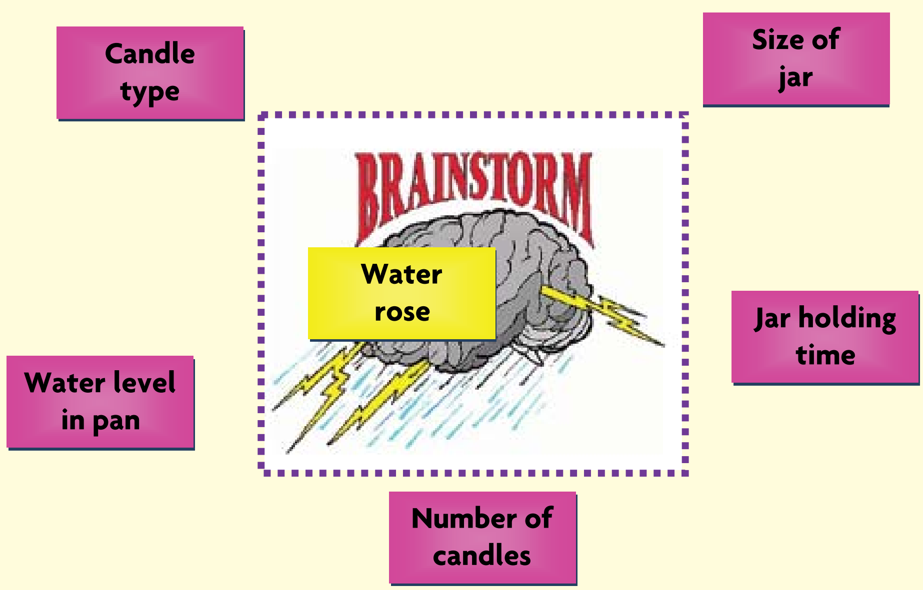
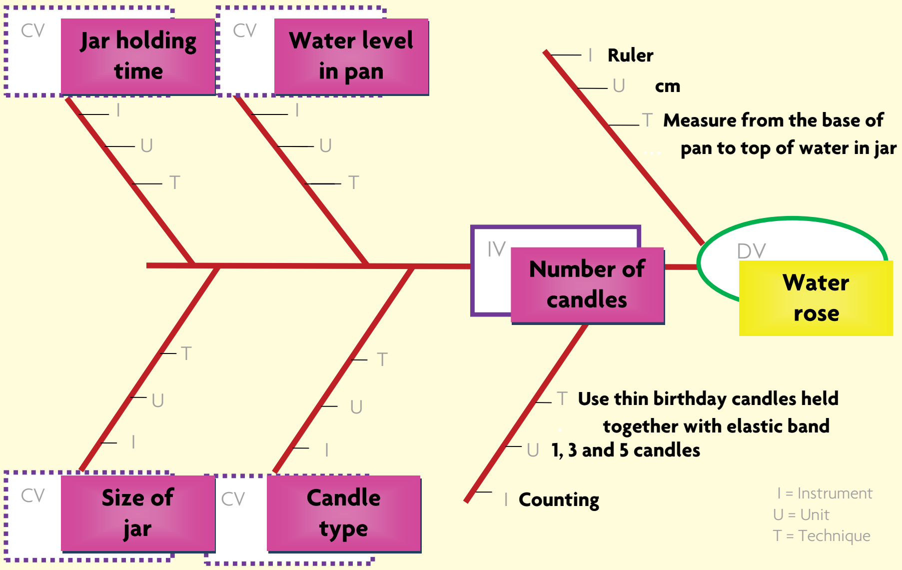


**FIGURE 3**

**Fishbone Experiment Organizer.**




A prediction such as, "If the water level in the pan is higher, then the water level in the jar will change," is unacceptable because it does not precisely state how much the water level changes, or—more important—whether the water level increases or decreases.

## Step 8: Rationale

Student groups then provide an explanation to support their prediction. They can expand on the background discussions and research started in Step 4 by providing more details to support their predictions. As with the prediction statement, the teacher should not judge the content of students' rationale. Students need to express their own conceptions and clarify their own thinking before proceeding with their experiments.

The teacher actively listens, watches for misconceptions, and constructs learning experiences that challenge students to confront these misconceptions. At this point, student groups are almost ready to begin their experiments.

## Step 6: Purpose statement

Science-writing stems are an effective way to help students learn writing conventions. Student groups can successfully create report titles, purpose statements, prediction statements, and procedural writing by placing information from their Fishbone Experiment Organizer in the appropriate writing stem. For example, students can use the following writing stem to state the purpose of the study in terms of the independent and dependent variable: "The purpose of this study is to see how the number of candles [independent variable] affects the water level [dependent variable] in the jar." Student groups' purpose statements should be approved by the teacher before they move on to Step 7.

## Step 7: Prediction statement

A prediction statement commits to a possible outcome without attributing cause. The teacher should take care not to judge these predictions. Student groups write or state a clear prediction statement in "If…then…" form. For example

- "*If* the number of candles [independent variable] is increased [or decreased], *then* the water level [dependent variable] in the jar will increase [or decrease]," or
- "*If* the water level in the pan is doubled, *then* the water level in the jar will decrease by half."

## Methods

The Fishbone Experiment Organizer provides a procedural outline. Teachers should resist the temptation to require students to write out a detailed series of procedural steps at this time—energy and enthusiasm for the project will wane if written procedures are required at this stage. Safety considerations should again be reinforced before allowing students to proceed.

## Step 9: Data-collection table

Requiring student groups to create their own data-collection tables is a good way for the teacher to ensure that students are ready to proceed. He or she may model a data-collection table for the class, but ultimately, student groups should create their own tables. This is an opportunity for

**FIGURE 4**

**Data-collection table.**

| | One candle | Two candles | Five candles |
|---|---|---|---|
| Trial | Water level (cm) | Water level (cm) | Water level (cm) |
| 1 | 0.7 | 1.1 | 1.6 |
| 2 | 0.6 | 1.2 | 1.7 |
| 3 | 0.7 | 1.2 | 1.6 |

## How does it work?

The flame heats the air in the jar and the hot air expands. Some of the expanding air escapes the jar (students might observe bubbles at this point). When the flame goes out, the air cools down and its pressure decreases. Because some air previously escaped, there is now less air inside the jar, and lower pressure. The higher pressure air outside the jar then pushes the water into the jar until the internal and external pressures are equal.

A common misconception is that oxygen consumed inside the jar during combustion is a factor in the water rising. This has a minor impact compared to the expansion and contraction of the gases within the jar. If oxygen consumption were the main contributing factor, the water would rise at a steady rate (rather than rising rapidly when the flame goes out).

students to demonstrate their understanding. Photocopies or black-line masters of perfect data-collection tables, though perhaps more efficient, limit inquiry by taking away the student ownership and student-centered nature of this process.

The teacher must approve the safety of each group's experimental plans before they begin working in the laboratory. Once the teacher is satisfied with the safety of student's procedures and their data-collection tables (Figure 4), students should be ready to conduct successful experiments.

## Conclusion

Scaffolding inquiry science using organizational diagrams and sticky notes—as presented in this article—helps initiate and plan authentic student-led experimental design activities in secondary science classes. It provides a framework for students to organize their experiments, ensuring that they conduct fair tests.

This process aligns with the National Science Education Standards as students develop both their understanding of scientific inquiry and their ability to do scientific inquiry (see "Addressing the Standards"). They document their thinking as they work though the process and provide evidence of their

> "ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments" (NRC 1996, p. 105). ■

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### NSTA connections

For more information on chemical reactions, check out the "Chemical Reactions: Rates of Chemical Reactions" NSTA Science Object. NSTA Science Objects are online, inquiry-based content modules for teachers that are free of charge. For more information, visit *http://learningcenter.nsta.org/products/science_objects.aspx*.

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## Addressing the Standards.

This activity addresses many of the learning goals in the Benchmarks for Science Literacy (AAAS 1993). *Atlas of Science Literacy* (AAAS 2001 and 2007) provides more information on the interconnected nature of the concepts and skills of scientific literacy and how these might develop from kindergarten to grade 12.

This activity addresses the following National Science Education Standards (NRC 1996):

**Unifying Concepts and Processes** (p. 104)
- Evidence, models, and explanation
- Change, constancy, and measurement

**Science as Inquiry** (p. 105)
- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

**Physical Science** (p. 106)
- Structure of atoms
- Structure and properties of matter
- Chemical reactions
- Motions and forces
- Conservation of energy and increase in disorder
- Interactions of energy and matter