Teaching and Assessing Science Process Skills in Physics

THE "BUBBLES" TASK

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In the teaching of physics, bubbles are both an affordable resource and an enticing subject. Many instructional activities using bubbles are available to science educators. Among them are Boys' (1940) talk series on the physics of bubbles and Cook's (1938) and Kuehner's (1958) guided investigations on the preservation and resilience of bubbles. In addition, Thompson's (1961) and Stevens' (1974) classic books on form, structure, and function contain thorough discussions of the principles that govern the formation of structures of soap films and soap bubble clusters. Recent materials include the *Exploratorium* magazine's issue on bubbles (Preuss 1982) and three hands-on instructional units: "Soap Films and Bubbles" (Wiebe 1990) (Grades 4–9); "Bubble Festival" (Barber and Willard 1994) (Grades K–6); and "Bubble Science" (Solano-Flores and Shavelson 1994) (Grades 5–6).

The "Bubbles task" described in this article is a challenging, hands-on activity related to the concepts of force and motion. The task promotes and assesses science process skills through experimentation with bubbles and soapy solutions (Solano-Flores 1994). Students are given both relevant and irrelevant pieces of equipment. They are then asked to conduct experiments to find out which one of three soapy solutions makes the longest- and which makes the shortest-lived bubbles. Teachers can use the analysis of student performance to make decisions on their teaching of science process skills in physics.

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Preparatory Activities

Before beginning the activity, the students should become acquainted with the properties of different methods of making bubbles, keeping them, and suspending them in the air and on a tray. The students should also have a thorough understanding of the phenomenon of surface tension in liquids and be aware that even tiny amounts of soap can change the properties of water. Almgren and Taylor (1976) and Isenberg (1992) provide in-depth discussions and illustrations of the chemical and physical phenomena involved in the formation of soap films and bubbles that teachers can use in conducting guided discussions with their students. There are other resources that describe methods for making and keeping soap films and soap bubbles (e.g., Cassidy and Stein 1989; Isenberg 1974; Zubrowski 1979). If teachers prefer, economic versions of the equipment relevant to the "Bubbles" task can be made with household products (see Solano-Flores and Shavelson 1994). Table 1 describes the preparation of equipment and the use of five methods to familiarize students with the making of bubbles. Also, the students should practice holding bubbles in the air, on a soapy, smooth surface, and on a dish filled with soapy solution.

Table 2 compares the five bubble-making methods in terms of manageability and relevance to bubble duration. The table provides a framework for developing in the students an appropriate conceptual understanding of some of the factors that affect bubble durability—without "giving away" the solutions to the "Bubbles" task. Two physical factors that the students should be aware of are bubble internal air pressure—which is larger for smaller bubbles because their walls bend more—and shaking, which affects the stability of a soap film. One chemical factor is the presence of CO_2—which is a byproduct of respiration that changes the chemical composition of a soap film.

Table 1. Preparation of Equipment and Use of Five Methods of Making Bubbles

Method	Preparation of equipment	How It Works
Wire ring	Use commercially available wire rings or make them with fine hanger wire	Conventional mouth air blowing
Straw	Use commercially available plastic straws	Conventional mouth air blowing
Baster	Cut the shaft of a plastic kitchen baster to make it 2 cm long	Raise soapy solution with the end of the baster. Pump air onto a surface by slowing squeezing the baster's pump.
Inverted funnel	Use: one plastic funnel; one 20-cm tall bucket filled with water; and 50 cm of plastic tubing whose diameter fits the narrow end of the funnel. Connect one end of the tubing to the nar-	Raise some soapy solution with the free end of the tubing and immerse the wide end of the funnel in a bucket filled with water to the bottom. The water displaces the air in the funnel and pushes it out through the other end of the tubing, thus making a bubble. Gently place the bubble onto a surface or a dish filled with soapy solution.
Syringe	Use disposable, new plastic syringes without a needle	Pull the embolo backward to the desired volume of air. Raise some soapy solution with the other end of the syringe, or place it gently on a surface. Inject the air slowly.

Table 2. Characteristics of Different Methods of Making Bubbles

Method	Practice needed	Allows to select number of bubbles made?	Helps keep bubbles from shaking?	Volume of bubbles made	Concentration of CO_2
Wire ring (mouth air blowing)	None	No, often makes one bubble	No	Variable	High
Straw (mouth air blowing)	None	No, often makes one bubble	No	Variable	High
Baster (air pumping)	None	Yes, always makes one bubble	Yes	Fixed	Low
Inverted funnel (air displacement)	Some	Yes, always makes one bubble	Yes	Fixed	Low
Syringe (air injection)	Little	Yes, always makes one bubble	Yes	Selected by experimenter	Low

ACTIVITY: THE "BUBBLES" TASK

Problem

Give the students three soapy solutions on plates labeled A, B, and C. Ask them to conduct an experiment to determine which soapy solution makes the most durable soap bubbles and which soapy solution makes the least durable soap bubbles. This task is amenable to a wide variety of solutions with varying degrees of scientific soundness. The correct solution can be arrived at using different strategies.

Materials (To make a soapy solution)

(one set per student)
Bucket filled with water
3 funnels with plastic tubing
3 basters
3 syringes without needles
3 straws
3 wire rings
"Bubbles" notebook

Additional materials

Stopwatch
Hourglass
Protractor
Magnifying glass
Ruler

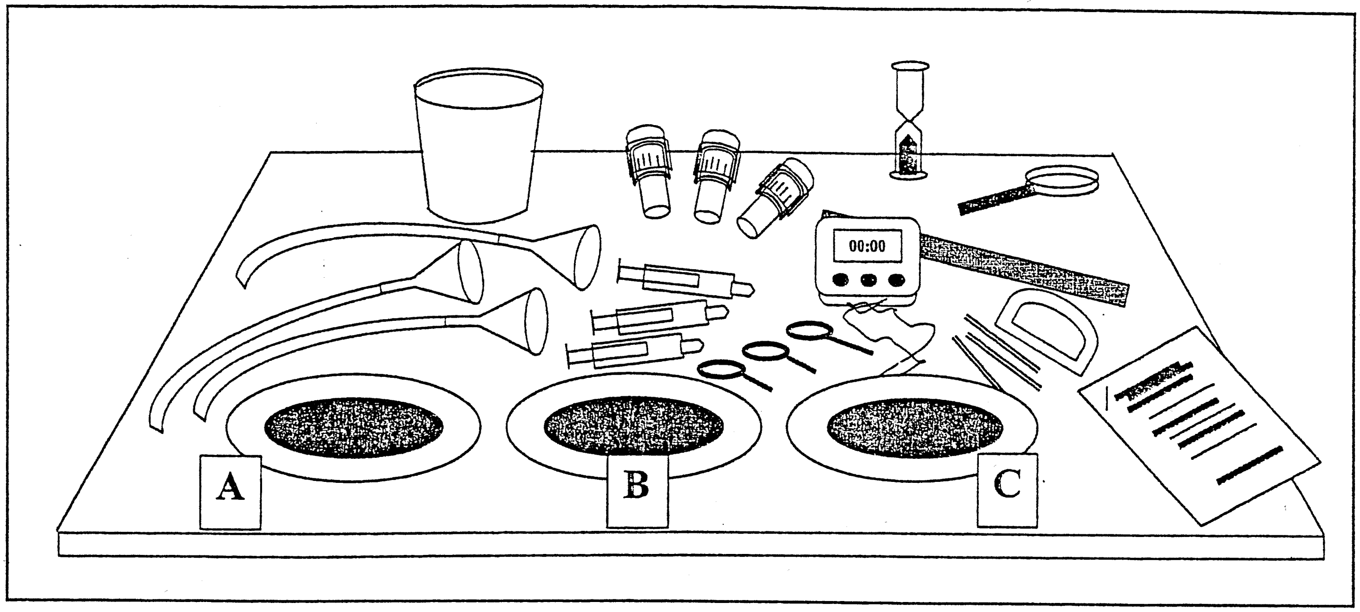

Figure 1. Equipment used in the "Bubbles" task.

Figure 1 shows a picture of the materials needed to make bubbles and to measure time. The materials differ in their effectiveness in making bubbles of the same size. If the students are given three pieces of each device for making bubbles, this will allow for a well-controlled experiment in which soapy solutions are not mixed. The last three pieces of equipment are irrelevant to the task, but they act as distractions, which makes the task more challenging.

To ensure that the soapy solutions behave reliably, the equipment must be clean. Any previously used materials should be thoroughly rinsed with water before reusing them. Otherwise, the soapy solutions will be contaminated and their properties will change.

Preparation of Soapy Solutions

To ensure the reliability of the soapy solutions, three conditions must be met. First, the longest-lived bubbles should not last too long, so that students can make several bubbles for each soapy solution within a reasonable time period (e.g., 45 minutes). Second, there should be a small variation in the duration of bubbles made from each solution, so that students do not arrive at erroneous conclusions because of a sampling error. Finally, the frequency distributions of the duration of bubbles made with the three different solutions should not overlap. See Table 3 for an example of a set of three soapy solutions that meet these conditions. Prepare the soapy solutions 24 hours before doing the activity to ensure that their properties do not change.

Response Format

The judicious use of notebooks can be a good surrogate for real-time observation (Baxter et al. 1992). Teachers can use them to obtain valuable information on their students' scientific skills in an efficient manner. Have the students describe their actions and reasonings in the "Bubbles" notebook.

The "Bubbles" notebook consists of five sections: *Problem* (which includes directions on the use of equipment); *Notes* (for the students to write their thoughts as they conduct their experiments); *Results*; *Steps in the Experiment*; and *Questions*. Figure 2 presents some notebook excerpts. The notebook material focuses on both the outcome (*Results*) and the process (*Steps in the Experiment*, *Questions*) of the investigations, which is a defining characteristic of hands-on instruction and assessment. In addition, the *Questions* section lends insight into the students' step-by-step performance (e.g., their use of the equipment) that they do not ordinarily reveal, but which can be valuable to the teacher. The particular words and phrasing used in the notebook's prompts are the result of a series of pilot tests and revisions conducted to ensure that the language is comprehensible to students (Solano-Flores and Shavelson 1997). (See Note.)

Assessment of Student Performance and the Scientific Soundness of Student Actions

Teachers can assess the students' performance on the basis of their problem-solving processes and their investigation results. The focus should be on the scientific soundness of the students' actions, the rationales they provide for those actions, and the interpretations and explanations they offer to account for the results they obtain.

Figure 3 shows an analysis of the seven components of the students' actions: method of making bubbles; method of keeping bubbles; measurement of bubbles' life length; control; data; results; and replication. Each component comprises one or several attributes—actions that the students took or the results of those actions. The scientific soundness of a given students' performance on a component is determined on the basis of the attributes observed. This assessment approach has been used as a conceptual basis for developing a scoring rubric for the "Bubbles" task (See Note). Such a scoring system has made it possible to

Table 3. Preparation of Soapy Solution and Duration of Bubbles

Solution: % dish soap (name)	To 100 milliliters of tap water add: Dawn dish soap (ml)	Glycerin (drops)	Bubble duration in seconds: Minimum	Maximum	Mean* ($N = 10$)	Standard deviation
37.50 (B)	60	0	8.00	26.70	17.87	6.430
4.76 (A)	5	3	45.00	82.00	62.61	11.281
1.96 (C)	2	3	82.10	140.60	117.22	17.943

*Mean bubble duration differences across soapy solutions statistically significant at $p = .01$ (Tukey's pairwise test of mean differences).

Problem

In front of you are three soapy waters, marked with the letters, **A**, **B**, and **C**. Do an experiment to answer these questions:

1. Which soapy water makes the longest-lived (most durable) soap bubbles?
2. Which soapy water makes the shortest-lived (least durable) soap bubbles?

Look at the equipment in front of you. Think about how to use it to do your experiment. You do not have to use all the equipment.

Notes
(blank space for students to write as they conduct their investigation)

Results
Circle the right answers:

Which soapy water makes the longest-lived bubbles?
A **B** **C**

Which soapy water makes the shortest-lived bubbles?
A **B** **C**

What happened in the experiment for you to tell which soapy water makes the longest-lived bubbles and which soapy water makes the shortest-lived bubbles?

Procedural Steps
Describe step-by-step what you did in your experiment. Indicate the equipment you needed to do your experiment and how you used it. Do not mention the items you only played with.

Questions
1. What pieces of equipment did you use to make the bubbles?
2. Were the bubbles the same size?
   If so, how can you tell they were the same size?
3. Where did you place the bubbles to observe them?
4. Did you test all three soapy waters?
5. Did you test each soapy water separately?
6. How many bubbles did you make for each soapy water?
   For soapy water **A**
   For soapy water **B**
   For soapy water **C**
7. When you made or observed the bubbles, what did you do to keep the soapy waters from mixing together?
8. How did you measure how long the bubbles lived?

Figure 2. Directions and prompts from the "Bubbles" notebook (excerpts).

Components with mutually exclusive attributes (1 = maximum quality)

Manipulation: method used for making bubbles

Syringe, selecting a specific volume of air [1] or
Inverted funnel [2] or
Baster [2] or
Syringe, without selecting a specific volume of air [3] or
Wire ring [4] or
Straw [5]

Manipulation: method used for holding bubbles
On liquid [1] or
On smooth, dry surface [2] or
Hanging [3]

Measuring: method used for measuring bubbles' life length
Stop watch [1] or
Hourglass [2] or
Verbal counting [3] or
Visual comparison, compensating for differences in blowing times [4] or
Visual comparison, without compensating for differences in blowing times [5]

Components with additive attributes (1 = maximum relevance)

Control across soapy solutions
Tests all soapy solutions [1] and
Tests each soapy solution with a different piece of equipment of the same type [2] and
Makes same number of bubbles across solutions [3]

Data
Uses/records measurements on the bubbles' life length [1]

Results
Correct for longest-lived [1] and
Correct for shortest-lived [1]

Replication
Uses more than one bubble per solution [1] and
Completes an extra experiment with another method to make/hold bubbles [2]

Figure 3. "Bubbles" task: Scientific soundness of student actions. Attribute quality/relevance in brackets.

observe that students' performance quality can vary considerably across components (Shavelson et al. 1991, 1992).

Student Thinking

The ideas that students have about scientific phenomena may differ considerably from the ideas that teachers intend to give them through formal instruction (Gentner and Stevens 1983). Teachers can inform their teaching if they can identify and understand how students interpret the results of their investigations. The scientific knowledge that the students possess and the mental models that they use to make sense of their observations shape the way in which they justify their actions and account for their results. Figure 4 shows two student responses (Carlton's and Linda's) to selected prompts in the "Bubbles" notebook.

Apart from the fact that Carlton's results are incorrect and Linda's results are correct (solutions C and B are, respectively, the longest- and shortest-lived solutions; cf. Table 3), an analysis of their notebooks reveals important differences in the way they think about the physical phenomena involved. Because they have different mental models of how soap concentration affects bubble duration, they propose totally opposite explanations of their results. For Carlton, thicker (denser) solutions make thicker and more resilient bubble walls. In contrast, for Linda, denser solutions make heavier bubbles that burst more easily—which is consistent with the notion that bubble walls made with a denser soapy solution dissolve sooner because the solution drains more quickly.

Linda's methods for making bubbles (funnel) and keeping them (on the trays) control adequately for bubble size and stability. Although Carlton's methods are flawed, he realizes that bubble size is critical to the goal of the investigation—the bubbles "looked about the same [size]." His response

	Carlton	Linda
Which soapy water makes the longest-lived bubbles?	B	C
Which soapy water makes the shortest-lived bubbles?	A	B
What happened in the experiment for you to tell which soapy water makes the longest-lived bubbles and which soapy water makes the shortest-lived bubbles?	Well since B was the thickest it was more protective than A was so thin so when it touched an object it would pop.	Soapy water B was denser, causing it to be heavier, so the bubbles pop with ease. Soapy water C was the lightest, and less dense, so they were more durable.
Steps in the experiment: Describe step-by-step what you did in your experiment. Indicate the equipment you needed to do your experiment and how you used it. Do not mention the items you only played with.	First I blew one bubble out of solution A with A wire ring then solulotion B with a wire ring then soultion C with a wire ring all the bubbles were about the same size. Then I did the same thing with the funnels with plastic tubbing. I tried all the bubbles on the carpet so it would be fair. Because if I was suppust to put some bubbles in the carpet and some in the table it would-n't be the same. Because the carpet is softer than the table.	I first took the funnels with plastic tubing and (separate-ly) blew a bubble with it, using the water. I [immediately] used the stop watch to time how long they lasted. I then jotted down the times on the section marked "notes". Next, I took the syringes and filled each one. I looked at the odor, and made a note of that. I also felt how dense each one was. I also made a note of that. I finally had come to a conclusion, and answered the questions asked.
Were the bubbles the same size?	Yes	Yes
If so, how can you tell they were the same size?	They looked about the same.	The funnels only let the same amount of air in each bubble.
Where did you place the bubbles to observe them?	In the carpet	On the soapy trays
How many bubbles did you make for each soapy water? (A, B, C)	5, 5, 5	2, 2, 2
When you made or observed the bubbles, how did you ensure that that soapy waters did not mix together?	There was three of everything and three soapy solutions. So I put one in each [solution]	I used different tubing.
What did you do to measure how long the bubbles lived?	With the stop watch however long they lasted in the carpet	I used the stop watch.

Figure 4. Example of two students' responses to selected prompts in the "Bubbles" notebook.

reflects an understanding that the three soapy solutions should receive the same treatment—"so it [would] be fair."

Their approaches to replicating results are also different. Whereas Carlton uses a bigger sample of bubbles (five for each solution), Linda intends to perform a systematic replication of their results by using syringes. However, instead of using the syringes to inject air into the soapy solutions, she fills them with the soapy solutions and focuses on their colors—an approach that is irrelevant to the investigation.

Conclusions and Recommendations

"Bubbles" works as a successful hands-on classroom activity because the students are given the opportunity to construct their own solution strategies. The intent of the activity is to promote higher-order thinking skills, so the students should not be coached or given hints while they conduct their investigations. A careful analysis of the scientific soundness of their actions and the way that they think about the physical phenomena involved, however, makes it possible to give students very specific feedback and to guide rich group discussions.

Because the activity simulates experimental problems that scientists continuously face, "Bubbles" allows a wide variety of solution approaches. Therefore, educators should not attempt to teach "the correct way to solve the problem." Although there is a specific set of results in the "Bubbles" task, there are many possible, valid strategies that meet the paradigm for comparative experimental investigations.

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Note

A full copy of the "Bubbles" notebook and the "Bubbles" scoring form is available from the author upon request.

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