A GLUE FROM SLUG SLIME?

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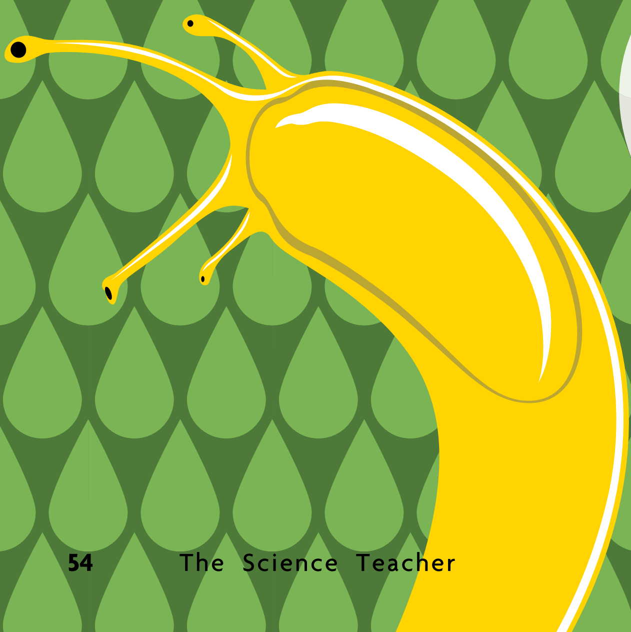
Student-made Sticky-O-Meters and measuring the effectiveness of glue

"Yuuuck!" "Gross!" "Cool!" The response to slugs is never indifference. These slimy creatures are perfect for captivating students' imagination and curiosity, and they are ideal subjects to introduce investigative science. This article describes a classroom activity in which students design a research investigation to answer the question: "Is slug slime a good glue?" Through a series of guided steps, students work in small groups to decide how to measure the success of an adhesive. Each research team invents a unique tool, the "Sticky-O-Meter," to quantify glue stickiness. Students compare results for slug slime with those from a commercial adhesive.



This lab was originally developed as a Howard Hughes Medical Institute–funded workshop for teachers on experimental design and has been used successfully with middle and high school students in life science and biology classes. While the lab emphasizes the importance of quantifying the responding or dependent variable in an experiment, it is also just plain fun!

Slugs, slime, and bioadhesives

My own fascination with slugs began many years ago when I was looking for a research system for studying cervical mucus. My graduate adviser, Ingrith Deyrup-Olsen, an animal physiologist at the University of Washington, was then a leading slug expert. Affectionately called "the slug lady," she brought banana slugs national attention by appearing (with her slugs) on such popular television shows as *Bill Nye the Science Guy* and *The David Letterman Show.* Deyrup-Olsen's own research used banana slugs as a model for studying the biological properties of mucus (Deyrup-Olsen, Luchtel, and Martin 1983). The basic biochemistry she described provided insights into many other areas, including the chemistry behind mucus buildup in the lungs of people with cystic fibrosis (Marmor 2004).

Mucus, an enormously interesting material, is the general term for specialized secretions of epithelial cells of multicellular animals (except arthropods). It is composed mostly of water, salts, and small amounts of mucin—a carbohydrate-protein (glycoprotein) molecule. Wherever living cells are in contact with elements of the environment, mucus can be found: in the lungs, stomach, eyes, ears, nasal passages, cervix, and on the living skin of slugs. Delicate living cells are protected by a coating of mucus from potential insults such as particles of dust, harmful chemicals, and bacteria.

Mucus, like glue, is also a kind of adhesive. People have made glues from diverse sources, such as egg whites, milk, horses' teeth, and spruce gum. The natural world is filled with examples of highly effective adhesives, from the slime a limpet uses to stick to rocks, to the hardened foam egg-cases the female praying mantis wraps around a plant stem, to the silk rope the spider uses as glue. For an adhesive to work, it must stick well to both of the materials it is joining together. Most adhesives stick to some materials better than others. Starch-based glues work well with materials such as paper, wood, or cotton but not with plastics. What kind of glue could effectively glue skin? The answer may be bioadhesives! Research scientists are working hard to develop this new generation of nontoxic adhesives made from natural materials for use in the building industry and for medical applications such as setting bones, surgery, and drug delivery.

A slug's slime acts as both a glue and a lubricant, allowing the slug to crawl up walls and across ceilings without falling off. The slug pushes until the structure of the glue gives way and the slug slides forward. When the slug stops, the glue structure reforms and the slug sticks securely to the surface.

Can we make a glue from slug slime? The remarkable physical properties of mucus make it a good candidate for research, especially in the K–12 science classroom.

Classroom guidelines

Students need time handling and familiarizing themselves with slugs before they are ready to apply themselves to the research activity (see "Collection and care of slugs," p. 57). Handling slugs has its own particular charm—the inevitable slimy mess left behind on our hands. Not only is mucus very sticky, but it can also be very slippery. Mucin—the molecule that, along with water and salts, makes up mucus—has an enormous capacity to hydrate when exposed to water. Hence, washing hands immediately after handling is not recommended. Rather, students and teachers should first wipe hands with a dry paper towel to remove most of the slime, then wash thoroughly with soap and water.

(**Safety note:** One or more studies have provided evidence that slugs from an environmental source can act as vectors of *Escherichia coli* and other bacteria. The bacteria can be found in feces of slugs and have a relatively long external and internal survival time. This could be a health issue, especially for immune-suppressed

About slugs.

Land slugs are one of the most successful groups of mollusks, inhabiting nearly every type of terrestrial ecosystem. The long soft body of the slug is unsegmented—basically a stomach on a large foot—and is well protected by a thick layer of mucus, which is necessary because it has no full-sized shell for protection. Production of mucus also helps prevent desiccation (drying out), as does the slug's preference for damp habitats. North America is home to a wide variety of slugs, but my favorite is the beautiful banana slug, *Ariolimax columbianus.* Truly a magnificent creature, banana slugs are native to the wet forests of the Pacific Northwest, where they serve an important ecological function in nutrient cycling. They can grow to more than 30 cm in length and range in color from yellow to green.

Many slugs from the very abundant slug genus, *Arion,* are invasive and have made their homes in gardens from the east to west coasts. Well-known (but probably not well-loved), they include such species as *Arion ater* (the European black slug) and *Arion rufus* (the European red slug). Another exotic slug, *Limax maximus* (the great grey garden slug or leopard slug), is similarly found everywhere. Leopard slugs can also grow very large, often reaching 10 cm in length. No matter where teachers live, it is likely there are slugs to be found, which can be used in this activity.

students. Students should be advised to keep their hands away from their mouths and eyes. Vinyl gloves are recommended when handling slugs. No food or drink should be allowed in the laboratory. After use, desks should be cleaned off with soap and water.)

Interacting with live organisms can be a highlight for biology students of any age. Richard Louv, in *Last Child in the Woods* (2006), claims that many of our children suffer from nature deficit disorder. The opportunity to observe, handle, and admire living slugs is one small opportunity for students, especially urban students, to connect with the natural world.

I begin the lesson by picking up a large slug to model how interesting and harmless these slimy creatures are and to demonstrate how to clean hands after handling. Individual containers of slugs are then passed around to students. This generally elicits a lot of excitement. I have found that the majority of students, when given the chance, are very intrigued and quite willing to handle a slug. Having a camera available for taking photos is a big incentive. A question-and-answer session typically ensues, in which we pool our combined knowledge about slugs and other mollusks. Questions about anatomy, adaptation, habitat, and

FIGURE 1

Research project guidelines.

Problem

Does slug slime make a good glue? How does it compare to other glues? Is it a better glue than common commercial glue stick? What materials would you bond together using slug slime?

A good research question is both comparative and quantitative. In this experiment, you will compare "slug slime glue" to a commercial brand of glue stick. Slug slime glue is the *test;* glue stick is the *control*. The *manipulated (independent) variable* in your experiment is the type of glue (slug slime versus glue stick). How you measure the stickiness of glue is up to you—this will be the *responding (dependent) variable* in your experiment.

Background reading

Write a short essay on bioadhesives and why you think slug slime might be a promising new source for a bioglue. Listed below are suggestions for reading. You may find other sources of information. Please include all references.

- About slugs: *Field Guide to the Slug* (Gordon 1994)
- About glues: *Adhesives and Glue—What Sticks?: http://inventors.about.com/od/gstartinventions/a/glue.htm*
- About natural adhesives:
    - Nature of adhesives: *http://student.britannica.com/comptons/article-195763/adhesive*
    - Adhesives: *www.mnsu.edu/emuseum/prehistory/ancienttech/adhesives.html*
- About the search for better glues:
    - "Frog Glue": *www.abc.net.au/catalyst/stories/s1705318.htm*
    - "Super Sticky Stuff": *www.sciencentral.com/articles/view.php3?type=article&article_id=218392997*

Materials

Index cards, paper plates, paper cups, string, craft sticks, small pieces of cotton cloth, various weights (e.g., paper clips, pennies, marbles), balance, live slugs, commercial glue sticks, vinyl gloves.

Procedure

1. *Brainstorm*. Brainstorm the kinds of surfaces you could glue together to test the stickiness of slug slime (e.g., paper to paper, paper to skin, wood to wood). Brainstorm what you could measure to test the stickiness of the glues (e.g., the weight needed to break the glue bond or the amount of time before the glue bond fails). Brainstorm different ideas about how you might measure stickiness using the materials provided.
2. *Choose variables*. Decide what you will measure about the stickiness of glue (e.g., the amount of weight a paper-to-paper glue bond will hold before breaking). This is your responding (dependent) variable. What is the manipulated (independent) variable in the experiment?
3. *Ask a testable question*. Write the experimental question that you will actually test. Try to use both the manipulated and responding variables in the question. For example, the question "Is slug slime stickier than glue stick?" can be written more accurately as "Does a paper-to-paper glue bond made with slug slime glue hold more weight than one made with glue stick?"
4. *Predict an outcome.* Base your prediction on your readings and observations about slug slime.
5. *Set up the experiment.* Invent an apparatus to measure the stickiness of the glue. Construct the test Sticky-O-Meter using slug slime. Collect slug slime from the dorsal surface of a slug using a craft stick and apply it to the surfaces you want to glue together. Construct an identical control Sticky-O-Meter using glue stick instead of slug slime. Give yourself plenty of time to try out several different Sticky-O-Meters and decide which works best. Do your best to keep everything about the test and control Sticky-O-Meters the same (e.g., amount of glue, drying time, pressure applied to the glue bond). These are your controlled variables.
6. *Record results.* Design a data table such as Table 1 to record what you will measure (i.e., the measurable units of your

reproduction are common. David Gordon's book, *Field Guide to the Slug* (1994), is an excellent resource. Inevitably, the topic of mucus comes up, and we move on to the research topic: "Is slug slime a good glue?"

Students are given the Research Project Guidelines handout (Figure 1), in which they are presented with the problem of testing a potential bioglue made from slug slime and given a list of references for background reading. Working in teams of four to five, students brainstorm and design an experiment to answer the testable experimental question, "Is slug slime stickier than glue stick?" The outline follows the eight-step inquiry method for introducing students to experimental investigations: brainstorm, choose variables, ask a question, predict an outcome, set up test versus control, record results, look for patterns, and answer the question (Buttemer 2006). Students should keep careful notes of every step in a lab notebook and then use these notes to summarize their experiment in the next step: a formal lab report.

Lab Report Guidelines (Figure 2, p. 58), the second handout, leads students through the logic of writing a lab report—from asking a testable research question to answering the original question using evidence—and can serve as an assessment tool for teachers. The lab report emphasizes the parts of an experiment: manipulated variable (independent variable), responding variable (dependent variable), controlled variables, test, control, and number of trials (n). As with all investigative science, it ends with the all-important question: "What is the next step?"

Guidelines for Whiteboard Talk (Figure 3, p. 59), is the final handout, which helps students organize a short 5-minute research talk. The major items for the talk include the testable research question, a picture or drawing of their Sticky-O-Meter, a labeled graph, a conclusion, and a list of uncertainties. Figure 4 (p. 59) shows an example of a student's whiteboard outlining the experiment,

Sticky-O-Meter). Record results for the test Sticky-O-Meter and the control Sticky-O-Meter. Decide how many times you will repeat the experiment. In an experiment, n = number of trials. Repeat the experiment at least two times. Refer to the sample data table below.

TABLE 1

Manipulated (independent) variable: ***Type of glue***	**Responding (dependent) variable:** ***State the units you used to measure glue stickiness.***				
		Trial 1	Trial 2	Trial 3	Average
	Test: Slug slime glue				
	Control: Glue stick				

7. *Analyze results.* Is slug slime stickier than glue stick? Look for a pattern by averaging results for all trials for slug slime and compare to the average results for glue stick. Is slug slime stickier, less sticky, or no different than glue stick? Construct a graph to reflect this trend.
8. *Answer the testable question.* Rewrite your experimental question from Step 3 and answer it with a "yes," "no," or "uncertain." How confident are you that your answer is accurate? For instance, each time you repeated the experiment did you get the same "winner," or were the results different each time? If different, what might have accounted for the variation? What would you do differently next time? Summarize your experiment in a written lab report (Figure 2, p. 58). Prepare a short talk about your experiment (Figure 3, p. 59).

Collection and care of slugs.

While slugs occur in wild and cultivated habitats of almost every description, including urban areas, they are most readily found in wet habitats such as riverbanks, moist woodlands, and meadows; under damp boards; or near garden sprinklers. Since slugs are generally crepuscular creatures that are most active at dusk and dawn, early mornings or evenings are the best time to look for them.

Care for these living creatures is most humanely done by keeping them cool, moist, free of waste, and well fed. I keep slugs in the refrigerator—two to three slugs are kept in a cottage cheese tub lined with moist paper towels and filled with lettuce, carrots, potatoes, and yams. With weekly attention, they can be successfully maintained this way for many months.

Slugs, like any animal used in the classroom, should be treated with respect and care must be taken not to harm them. Surfaces they come in contact with should be free of chemicals such as soaps or salts, which can interfere with mucus function. Native slugs, such as the Pacific banana slug, should be returned to their natural environment after classroom use. Teachers should decide the fate of the nonnative slug species, since many are invasive pests. A dilemma such as the disposal of exotic slugs is a wonderful opportunity for the biology teacher to engage students in ethical thinking about the responsibility and relationship of humans to the natural world.

"Is slug slime stickier than glue stick when gluing skin?" The diagram of the Sticky-O-Meter is clear enough that the viewer understands what was measured in order to test how well glue bonds two skin surfaces (in this case, fingers). The graph clearly shows that a Sticky-O-Meter made with slug slime holds more weight than one made with glue stick. The uncertainties listed demonstrate that students understand the limitations of their experiment. (**Safety note:** Instant glues [cyanoacrylate], two-part epoxy, and some other glues are dangerous for student use. Students should not breathe in solvent-based glues.)

CAUTION

Examples of Sticky-O-Meters

Figure 5 shows examples of two student-designed Sticky-O-Meters. Each apparatus is constructed to test how well an adhesive (slug slime or glue stick) holds up when used to glue together different types of materials (i.e., paper to paper, paper to wood). The final weight held before the glue bond fails is the dependent or responding variable. Alternately, students could have used a fixed amount of weight and measured the amount of time the glue bond held.

In Sticky-O-Meter 1 (Figure 5), glue is used to hold the bottom of a paper cup to an index card (paper-to-paper bond). A second paper cup has been attached to hold weight (e.g., pennies) and put stress on the glue bond. In Sticky-O-Meter 2 (Figure 5), glue holds a wood craft stick to an index card. The apparatus is laid flat on a table and a cup for holding weights is attached to the craft stick, which hangs over the table edge to add leverage to the glue bond. Weight is added until the wood-to-paper bond fails. The final weight is measured on a scale.

Conclusion

Providing students with the opportunity to design scientific equipment is important and often overlooked. Too often we hand students pieces of equipment to use in experiments and rob them of an engaging, creative aspect of science. The need to quantify an outcome in an experiment is central to the experimental process. By inventing their own Sticky-O-Meters to measure glue adhesiveness, students operationally define the responding variable and learn that the outcome of an experiment can be influenced by the tool used to measure that outcome.

Naturally, there will be conflicting answers to the question "Is slug slime stickier than glue stick?" based on the parameters of the Sticky-O-Meter developed by

FIGURE 2

Lab report guidelines.

Introduction

- Explain what your investigation was about, including any relevant background research.
- Write the experimental question you tested.
- If you have a prediction, state it here and explain why.

Procedure

- Draw a diagram of your experiment. Label the Sticky-O-Meter made with slug slime "test setup." Label the Sticky-O-Meter made with glue stick "control setup." Be sure to label what you measured and where the glue bond is located on your Sticky-O-Meters.
- Answer the following:
  - What is the manipulated (independent) variable in your experiment? (Hint: This is the difference between the test Sticky-O-Meter and the control Sticky-O-Meter.)
  - What are the controlled variables? (Hint: These are the things that are the same about the test and the control Sticky-O-Meters.)
  - What is the responding (dependent) variable? (Hint: This is what you measured with your Sticky-O-Meters.)
  - How many times did you repeat the experiment (n)?
- Briefly describe how you conducted the experiment.

Results

Include the following:

- Data table to display your results with what you measured (responding/dependent variables) labeled.
- Graph to display your conclusion with a title, short statement explaining what the graph shows, and axes labeled. (Hint: Place the responding [dependent] variable on the y-axis and the manipulated [independent] variable on the x-axis.)

Uncertainties

- State your results in words.
- How confident are you in these results? Was it a fair test? Were the results from each trial consistent?

Answer your experimental question

- Based on your results, which is stickier: slug slime or glue stick? Or neither? Unsure? Why?
- How did other teams' results compare to your results? Can you suggest possible explanations for those results?

What is next?

- What would you do next to further investigate the effectiveness of slug slime as a potential glue?

FIGURE 3

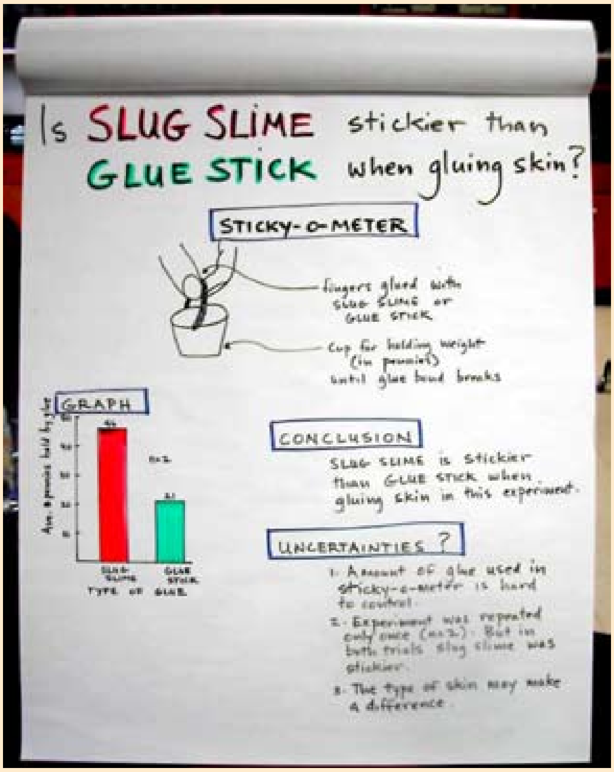
Guidelines for whiteboard talk.

Prepare a 5-minute talk about your team experiment. Summarize your experiment on a whiteboard (or poster) including the following:

- testable research question
- labeled picture of your Sticky-O-Meter
- labeled graph
- conclusion (answer to your testable question)
- uncertainties (any reasons why you are not confident in your results or conclusion)

FIGURE 4

Sample whiteboard.



various teams of students. We always end this activity by having students present oral seminar-type reports on their results. Good science experiences challenge students to defend their conclusions, and the robust discussions that ensue when students debate the merits of various Sticky-O-Meters, uncontrolled variables, and insufficient repeats is a good testament to the success of this lab. Slugs? Well, they are just the icing on the cake! ■

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FIGURE 5

Examples of Sticky-O-Meters.

Sticky-O-Meter 1: Glue bond is between the upper paper cup and index card; pennies are added to a second cup until glue bond breaks.

Sticky-O-Meter 2: Glue is holding a craft stick to an index card; the paper cup is for holding weights.

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