PAPERS | SEPTEMBER 01 2022

Exploring to Explain the Marshmallow Phenomenon

Jaclyn Kuspiel Murray

Phys. Teach. 60, 449–452 (2022)
https://doi.org/10.1119/5.0045288

Exploring to Explain the Marshmallow Phenomenon

Jaclyn Kuspiel Murray, Augusta University, Augusta, GA

Discovering concepts through observation, exploration, and constructing scientific explanations of phenomena is best practice in science education. Instead of following lab procedures to verify a known answer or solution, involve students in the work of science. Begin by presenting a phenomenon to ***engage*** students in scientific inquiry and uncover their prior knowledge. Curiosity spurs questions driving investigations to ***explore*** hypotheses in search of ***explanations*** of the phenomenon.[1] This paper describes how engaging in the science practices enables students to explore and explain why marshmallows either shrink or puff up in a dynamic environment containing a closed and open system.

Background

Learning the core ideas and concepts through participating in the practice of science

The Next Generation Science Standards[2] and the College Board AP Physics course framework[3,4] require students to learn science content via active participation in the science practices as is consistent with the findings of science education research. Both sets of standards contain two essential components: the science practices and disciplinary core ideas. The science practices include asking questions; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics and computational thinking; constructing explanations; engaging in argument from evidence; and obtaining, evaluating, and communicating information. Science concepts, or the content, principles, and facts such as the law of conservation of mass, energy, or momentum comprise the disciplinary core ideas. Students observe or collect measurable data by investigating a phenomenon to discover science concepts. Although participating in all science practices during any one investigation is not likely, the consensus view affirms that "doing science" to discover science concepts is more authentic to the work of scientists than what is typically presented in traditional school science.[1,2]

Equally important are the crosscutting concepts—the concepts that cut across all science disciplines. Patterns, cause and effect, systems and system models, and energy are examples of crosscutting concepts. Systems are everywhere. In astronomy there are stellar systems, in biology there are ecosystems, and in physical science there are simple open, closed, and isolated systems to describe the flow of matter and energy into and out of a system.

The 5E model of science instruction provides a framework for active participation in the practice of science.[1] The five-stage sequential model encompasses the phases of Engage, Explore, Explain, Extend, and Evaluate. In the example that follows, an abbreviated version—the 3E model of science instruction—focuses on engaging, exploring, and explaining the phenomenon, yielding priority to creating inferences from prior knowledge previous to investigating. The exploration includes a set of investigations that generate data to provide evidence for a claim. Evidence supported by reasoning is necessary for the construction of a scientific explanation to describe the occurring phenomenon.

Gases, pressure, and system boundaries

Because air is invisible, students often find it difficult to visualize gas as a form of matter. Two common misconceptions about gases are that they do not have mass[5] and cannot exert pressure[6] on objects. The everyday experience of observing a balloon satisfies the notion that matter takes up space and places pressure on an object—the balloon. As air enters a balloon, the mass, volume, and pressure increase, confirming that invisible gases take up space and exert an outward pressure on the inside of the balloon. However, students still have difficulty understanding that gases have mass because the air surrounding them feels weightless.

Filling a balloon with air or water is an example of how mass in an open system crosses the boundary from the outside to inside of the balloon. The system's boundary can be arbitrarily defined as the inner surface of the balloon. The system (air or water, in this case) expands the balloon when mass (air or water) is added to the balloon, and shrinks when air evacuates from the balloon. If the balloon were placed inside an air-filled box of fixed dimensions so the air could not escape the box, the system as defined by the contents of the box would be closed. A closed system does not allow mass to cross its boundary (the box).

Changing the pressure by adding or removing air from a space is difficult to conceptualize because, in most cases, air is imperceptible. Low-pressure regions naturally occur at high altitudes because the magnitude of gravity is lower than at sea level. The air particles are spread out over a specified volume, making breathing more difficult. When air is removed from a fixed volume, the air pressure decreases, creating a hypobaric environment, while adding air to a fixed space causes the opposite effect—a hyperbaric region.

In the following example, students engage in the practices of asking questions, developing a model, planning and carrying out different investigations, and analyzing and interpreting data, to use a developed model and construct a scientific explanation to describe how air pressure affects marshmallows in a test tube.

Engage

The purpose of the Engage phase is to begin a lesson or unit of instruction with a phenomenon to elicit interest and uncover students' prior knowledge and reasoning skills. The instructor may ask general guiding questions like, "What do you notice?" and "What do you think causes that to happen?" or specific questions like, "What do you notice about the size of the marshmallow over time?" or "How does the pumping action change the test tube environment?" Responses reveal

DOI: 10.1119/5.0045288

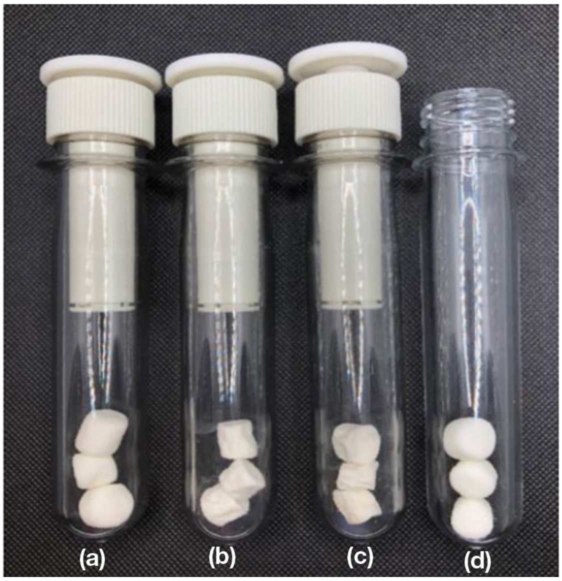

Fig. 1. (a)–(c) Marshmallows in unpumped (a), moderately pumped (b), and highly pumped (c) tubes. (d) The marshmallows return to their original shape when the pump is removed.

Table I. Representative student inferences about why marshmallows shrink in a changing environment.

Student	Inference
A	When the lever is pushed down, air is added to the tube. When the lever is pulled up, air is removed from the tube.
B	We cannot see the air we are pumping or pressure; however, I believe the air is exiting the tube.
C	I think that air being taken away from the marshmallow causes them to shrivel. We can't see the air being taken away from the tube, but we can see the marshmallows shrivel up as a result of air being taken away.
D	We can't see the holes the marshmallow has inside. The holes contain little air pockets. When the air is pushed out of the marshmallows, they dry up from lack of air/oxygen. When air is released inside the tube, it fills the marshmallow back up. This is similar to a deflated/inflated balloon.

what students believe causes the phenomenon to occur. Observing the ambiguous situation causes students to generate inferences to explain the phenomenon.[7,8]

Figure 1 represents four states of the phenomenon. Instructors will need a baby soda bottle test tube, three mini marshmallows, and a pump cap. Let students know that something is about to change as a result of moving the lever of the pump up and down. Remind students to use their observation skills to notice the difference in the way the setup looks before and after the pumping action. Figures 1(a)–(d) illustrate before, during, and after images of the phenomenon. Initially [Fig. 1(a)], the marshmallows look like they do when they are in the bag at the store. After the test tube is pumped, the marshmallows appear smaller, as shown in Fig. 1(b). Excessive pumping results in Fig. 1(c); they are very shriveled, and the lever will no longer move. Next, unscrew the pump to hear a hissing sound. The marshmallows return to their original shape [Fig. 1(d)]. When students observe the marshmallow, they begin to ask questions. Does the pump cause the marshmallows to get smaller? Do the marshmallows weigh less than they did before? Is air entering or exiting the tube? They record inferences based on observations[9] only. Table I represents typical student responses to explain what students believe is happening based on their knowledge of the situation. These inferences form the basis for an investigation to determine the cause of the change in marshmallow appearance.

Explore

The class typically settles on the question, "Does air enter or leave the tube due to the pumping action on the bottle tube?" They arrive at this question because they know that the hissing noise indicates that air is moving. For some, the answer to this question provides evidence for the addition or release of air leading to the idea that the pressure inside the tube will increase or decrease depending on the direction of air flow. For others, lacking knowledge of pressure, the investigation is only about determining if the air is entering or leaving the tube. They do not connect the air flow to pressure and the force exerted on or by the marshmallow system.

Because the question prompts a "yes" or "no" response, have students reframe the question. Something like, "Why do the marshmallows shrink when the test tube is pumped?" elicits an explanation. Framing the question this way directs students to seek patterns in data in search of an explanation.

Every time this phenomenon was presented to undergraduates, students suggested filling a container with water to place a pumped tube in it to observe the slow release of the cap. They believe that if water is pulled into the tube or if air bubbles emerge from the tube, they will know whether air was released or added, respectively. This approach, although not incorrect, poses investigative problems due to the complexity of balancing both ambient air and water pressure. Placing the tube underwater increases the gauge pressure at deeper depths. When the tube is placed so close to the top of the water where the pressure is equalized, it is difficult to completely submerge the mouth of the tube in water or see potential bubbles emerge. Repeated consistent results would be difficult to observe.

Students require a working knowledge of gases as matter and air pressure to be capable of planning an investigation to answer the question by measuring the mass of the open system (tube, marshmallow, air, and pump cap) before and after pumping. The trend of increasing or decreasing mass across each tube [Figs. 1(a)–(c)] provides adequate data for students to analyze and interpret data and support a claim about why the marshmallows shrink when the tube is pumped.

Explain

In the Explore phase, students planned an investigation and collected data they believed could help explain the phenomenon's cause. In the explain phase, students can use the Claims-Evidence-Reasoning (C-E-R) framework to structure their explanation for the scientific phenomenon.[10] A claim is a statement or conclusion that answers a question.[11,12] Evidence is the relevant data that support the claim. And reasoning describes how the data support the claim. Science principles often accompany an account of why the data support the claim. The C-E-R framework scaffolds building scientific explanations and enables students to communicate their understanding of the phenomenon in a structured manner. The framework makes visible students' (1) ideas about what counts as evidence; (2) ability to logically connect evidence and reasoning to support a claim; and (3) comprehension of scientific concepts. Table II exemplifies a scientific explanation created with the C-E-R framework.

In theory, bubbles should emerge from the pumped tube if it is submerged in water, and measurements would indicate an increase in mass because the pump does add air to the tube. If more air is added to the tube, it exerts a force on the marshmallow, causing it to shrink. Students may think that the air inside the marshmallow is squeezed out; however, that is not the case. With introductory physics equipment, students cannot investigate what happens inside the marshmallow.

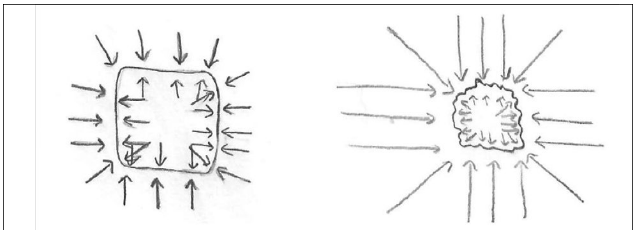

Fig. 2. Example model of the marshmallow phenomenon.

After students have constructed an explanation and perhaps developed a model (Fig. 2) to describe the phenomenon, it is appropriate to tell them that the surface of the marshmallow acts as a boundary to prevent airflow from crossing, thus creating a closed system. When the marshmallow was made, air pockets formed inside the marshmallow. The air pockets' size depends upon the magnitude of the ambient air pressure at the time of creation. When the external air pressure is higher than the pressure inside the marshmallow, it shrinks because the external force is greater than the internal force. The external force pushes on the marshmallow causing it to become smaller. Conversely, when the external air pressure is lower than the air pockets, the marshmallow expands because the internal force is greater, pushing outward on the walls of the malleable air pockets.

Discussion

The abbreviated 5E model, presented here as the 3E model, emphasizes three phases of the scientific inquiry instructional process. The example illustrates multiple science practices and instructional strategies. At the beginning, in the Engage phase, students asked questions about the phenomenon to focus their investigation. They framed their questions in many ways, one of which included, "Why is it increasingly more difficult to push the lever every time I pump the tube?" Others focused on the marshmallow and asked, "Why do the marshmallows shrink?" Both observations from different senses aided in forming conceptual (mental) and physical (expressed) models to describe why the phenomenon occurs via inferences.

Table II. Sample C-E-R response to the marshmallows in a tube phenomenon.

CER Component	Scientific Explanation
Claim	The effect of adding air to the tube increased the pressure, causing the force of the air on the marshmallows to increase and change their shape.
Evidence	Based on the increase in mass of the system after pumping, I think air was added to the tube.
Reasoning	All the evidence justifies the explanation that the tube became hyperbaric, causing the marshmallows to shrink after it was pumped. Because air is a form of matter and it has mass and takes up space, the air pressure had to increase inside the tube. As more air was added to the tube, the force of the air on the closed system marshmallows increased, causing the marshmallows to compress.

Planning and carrying out an investigation takes place during the Explore phase, and students generate data they believe will produce meaningful evidence. The data are then analyzed and interpreted to determine if patterns exist and whether the data support or refute their inferences. After students complete the Engage and Explore phases, they reason from evidence to make a claim about the phenomenon supported by evidence in the Explain phase. The C-E-R framework is one way to support students in constructing explanations to describe why phenomena occur. It is also helpful to have students draw an image (developing a model) with or without consensus-based representations to help them make sense of and communicate understandings of the phenomenon.

Conclusion

Choosing phenomena that align with the content covered in introductory physics courses engages students in the work of science. When that happens, students think like scientists. Observing phenomena elicits questions and ideas about how to investigate student-generated questions. Carrying out investigations produces observational and/or measurable data for analysis. The interpretation of data leads to explanations or solutions that may or may not be supported by science concepts. As students continue to participate in the practice of science, they will develop and refine over time their ability to construct scientific explanations through oral, written, and visual representations.

References

1. R. W. Bybee, "The BSCS 5E instructional model: Personal reflections and contemporary implications," *Sci. Child.* **51**, 10–13 (2014).
2. NGSS Lead States, *Next Generation Science Standards for States, By States* (The National Academies Press, Washington DC, 2013).

3. College Board, AP Physics 1: Course and Exam Description, https://apcentral.collegeboard.org/pdf/ap-physics-1-course-and-exam-description.pdf?course=ap-physics-1-algebra-based, accessed March 20, 2020.
4. College Board, AP Physics 2: Course and Exam Description, https://apcentral-stg.collegeboard.org/pdf/ap-physics-2-course-and-exam-description.pdf?course=ap-physics-2, accessed March 20, 2020.
5. American Association for the Advancement of Science (AAAS), *Benchmarks for Science Literacy* (Oxford University Press, New York, 1993).
6. R. Driver, A. Squires, P. Rushworth, and V. Wood-Robinson, *Making Sense of Secondary Science: Research into Children's Ideas* (RoutledgeFalmer, New York, 1994).
7. M. Bobrowsky, "How can I make science fun and have students learn more by using phenomenon-based learning?" *Sci. Child.* **56**, 70–73 (2018).
8. B. R. Lowell and K. L. McNeill, "Keeping critical thinking afloat," *Sci. Scope* **43**, 64–69 (2019).
9. K. D. Finson, "Inference or observation?" *Sci. Child.* **48**, 44–47 (2010).
10. K. L. McNeill and J. S. Krajcik, *Supporting Grade 5-8 Students in Constructing Explanations in Science: The Claim, Evidence, and Reasoning Framework for Talk and Writing* (Pearson, New York, 2011).
11. S. German, "Scaffolds for scientific explanations," *Sci. Scope* **41**, 30–32 (2018).
12. M. Koppal et al., "Supporting students in writing scientific explanations," *Sci. Scope* **43**, 26–30 (2020).

Jaclyn K. Murray *is an assistant professor of Science & Engineering Education at Augusta University. She is a teacher educator interested in understanding how prospective teachers engage in modeling practice to make sense of phenomena in science content courses for teachers.*
Augusta University, Augusta, GA; murray.jaclyn.k@gmail.com