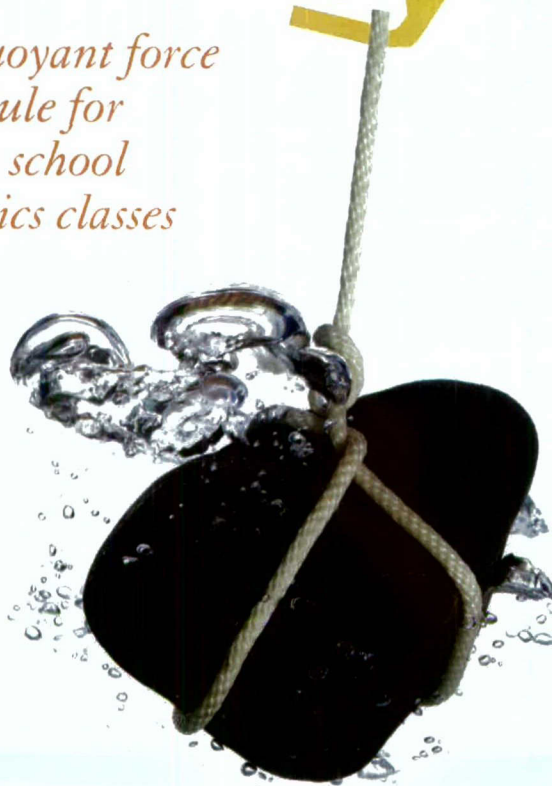


Model-Based Inquiry

A buoyant force module for high school physics classes



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and Benjamin Allred

Model-based inquiry (MBI) is an emergent instructional strategy that is gaining acceptance among science educators. Oh and Oh define MBI as a process in which students develop questions and procedures, carry out experiments, and make and communicate conclusions in an effort to “explore phenomena and construct and reconstruct models in light of the results of scientific investigations” (Forthcoming, p. 22). This approach to learning realistically mirrors the work of scientists, who develop and test hypotheses to construct more sophisticated understandings of the natural world.

This article details how we—a high school physics teacher, university science teacher educator, and student teacher—collaboratively taught a high school physics unit using MBI. In the case study presented here, students are asked to develop a model that describes buoyancy. With traditional inquiry-type laboratory work, teachers are often concerned about limited learning and a lack of participation from all students. MBI helps teachers address these concerns by requiring that students take ownership of their investigations—they make all the decisions needed to move an experiment from idea to practice.

Introduction

In MBI, students are asked to create a model that demonstrates their understanding of a concept (Oh and Oh, forthcoming; Windschitl, Thompson, and Braaten 2008). This model serves as the anchor for learning; students rely on it to guide and shape their scientific inquiries.

Figure 1 outlines a road map for MBI that engages students in the three components of this multidirectional cycle: modeling, focused inquiry, and iterations:

- ◆ Through *modeling*, each student creates diagrams, supported by written articulations, to demonstrate his or her understanding of a specified concept.
- ◆ Through *focused inquiry*, students engage in “the processes embraced by science that allow us to extract explanation from evidence” (Johnston 2008, p. 12).
- ◆ Through *iterations*, students connect emergent evidence and explanations to their broader understandings of the MBI focus, which, in the module presented here, is buoyancy.

By following the MBI road map in Figure 1, students experience firsthand a science that “demands and relies on empirical evidence...[and] is a highly creative endeavor”—both tenets of the nature of science as described by McComas (2004, p. 24).

The buoyancy force module

When our students began this project, they were about halfway through a year-long conceptual physics class. At this point in the school year, they had already developed and demonstrated a general understanding of Newton's laws and density. (Note: See "On the web" to learn how this buoyant-force module meets national and state science standards.)

The seven-day module is described in the following sections. Over a year and half, we implemented several adaptations of the MBI module in our high school physics class. The case study presented in this article is the most recent and successful variation.

Day 1

Day 1 aligned with the modeling component of the MBI road map (Figure 1). After reviewing the concept of density, students were asked to consider why they felt lighter in water than on land—and the possible causes for this phenomenon. Because of their previous experiences in water and their knowledge of forces, the discussion quickly became focused on the upward force that water exerts. After some discussion, students were convinced that the only possible reason for this force was that water must push upward on submerged objects. The students and teacher decided this force could be called *buoyant force*.

Next, to clarify the unit's goals and objectives, students were given the Buoyancy Model Guidelines and Rubric (Figure 2, p. 40) and asked to work individually on an initial draft of their model. They focused on

- the cause of the buoyant force, and
- any factor they thought might affect the magnitude of this force.

Day 2

Days 2–6 aligned with the focused inquiry component of the MBI road map (Figure 1). Day 2 started with another, more detailed review of density. Students were asked how they might find the density of an irregularly shaped brass object. Although finding the mass was simple, determining the volume was not, because of its irregular shape.

One student suggested putting the object in water and measuring the change in water

level. Without directly relating water displacement to buoyancy, this idea—along with the earlier discussion of the upward force exerted by water—offered students a context for beginning their study.

This then led to a discussion about experimental design. Students were told that they would be testing two of the factors they thought affected buoyancy (from their brainstorm models on Day 1), and paired up to outline their experimental design. They compared their draft models, chose the factors they felt were most likely to affect buoyant force, and began to outline a model that incorporated both partners' ideas. The two factors selected to test in the lab were identified as potential, but uncertain, influences on the size of a buoyant force.

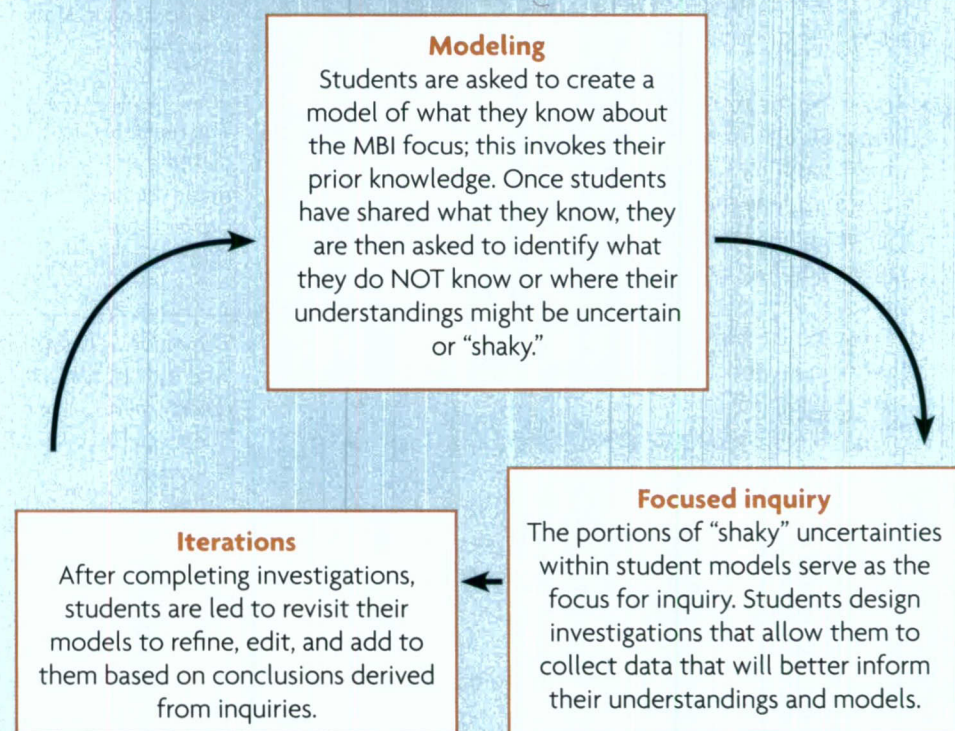
Students then shared their completed experimental design outlines with the class. This led to a brief discussion of good versus bad designs and science language and vocabulary (e.g., *controls*, *independent variables*, *dependent variables*, *accuracy*, and *precision*).

Day 3

In past implementations of buoyancy MBI modules, students had trouble identifying an effective mechanism for testing buoyant forces. Therefore, in the case study presented in this article, students were explicitly shown one particular method. The teacher demonstrated how force probes could be set up to measure buoyant force (Figure 3, p. 41).

FIGURE 1

Road map for model-based inquiry (MBI).



(**Safety note:** This allowed for a teacher-led demonstration and modeling of how to safely use probeware around or near water and to remind students of lab safety expectations [i.e., safety, cleanup, behavior].) Students were allowed to suggest and try alternative methods if the approaches were approved by the teacher and supported by convincing rationale.



Students spent the rest of Day 3 preparing for the start of their experiments (which commenced on Day 4). This time was used for planning

- ◆ exactly what materials would be used;
- ◆ the personal protective equipment (e.g., safety glasses or goggles) needed and safety issues to be addressed;

- ◆ how experiments would be varied to facilitate data collection and subsequently inform conclusions about the two factors being tested;
- ◆ the number of trials to be conducted; and
- ◆ how data would be collected.

In essence, students thought through and designed their experiments before actually conducting their labs. This process helped students learn how to prepare for lab work, focus their efforts, and maximize lab time.

Days 4 and 5

Students spent Days 4 and 5 in the lab completing their experiments. During these two days, students stayed engaged

FIGURE 2

Buoyancy model guidelines and rubric.

Although you will be working with a partner to develop your models, you must turn in your own model. This paper is to be turned in with your model and will be used as a grading sheet according to the rubric provided here.

The force that causes you to feel lighter in water (or any fluid) is called *buoyant force*. This is the same force that makes it possible for objects to float. You will create a model that describes buoyancy.

Guidelines

The purpose of this model is to illustrate and explain the concept of buoyancy. Your model should

1. show the mechanism (i.e., show what happens under all plausible circumstances);
2. show causality (i.e., show and explain why something happens the way it does); and
3. predict phenomena (i.e., predict the behavior and outcome of an untested experiment).

It may be helpful to design your model with the following questions in mind:

- ◆ What factors affect whether something floats or sinks?
- ◆ How do these factors affect buoyant force?
- ◆ How does the sinking or floating process occur?
- ◆ What unusual circumstances might exist that need to be taken into account?

(**Note:** Guidelines are shaped by guidance from Schwarz et al. [2009]).

Rubric

The model clearly shows the mechanism as stated in guideline 1. <i>Comment:</i>	__/20
The model provides causality as stated in guideline 2. <i>Comment:</i>	__/20
The model is able to accurately predict phenomena as stated in guideline 3. <i>Comment:</i>	__/20
The model is neat, orderly, and pleasing to the eye. It is apparent that the student made a concerted effort to make it look presentable. <i>Comment:</i>	__/20
The model is easy to understand. Someone who did not understand buoyancy could quickly make sense of it and learn from it. The model is not overly complicated. <i>Comment:</i>	__/20
The model is refined, added to, or validated by experimentation. <i>Comment:</i>	__/20
Total	__/120

and on task. Authentic discussions and problem solving were evident.

Student experiment example

One example of a student experiment is shown in Figure 4 (p. 42). This group used the force probe illustrated in Figure 3 to investigate whether the shape of a submerged object affects the buoyant force on that object. (**Note:** Figure 4 shows the group's final model, which also included its testing of mass. The groups' model was also informed by other groups' tests that were shared with the class [e.g., density and depth of submersion]).

Wearing safety glasses or goggles, the group first determined the force of three different-shaped objects—by hanging them on a string that was connected to the force probe—outside of a container of water. Next, the force of each object was determined when the object—again hung on a string connected to the force probe—was submerged in water, but not touching the container's floor. The buoyant force the water exerted on each object was equal to the difference between the force probe readings of an object outside of water versus an object submerged in water.

For this particular investigation, students found that if the submerged objects' volumes were controlled, a change in the shape of the object did not result in a change in buoyant force.

Another student example

Although many groups completed their investigations with little to no problems, a few students encountered issues that offered additional opportunities to learn about science processes. A common problem occurred with experiments that included floating objects.

For example, one group was trying to determine the effect of an object's mass on buoyant force. In an attempt to control variables, these students made sure that all of the objects used in the experiment had the same volume. They chose cubes of different material—iron, copper, aluminum, wood, plastic, and Styrofoam—and weighed them outside of water and then submerged in water. This method worked well for the cubes that sank beneath the water's surface, but (obviously) did not work for the objects that floated.

The group was reminded that to make comparisons between the cubes' buoyant forces, only one variable could change each time. Originally, the students' experimental design focused on mass as the changing, independent variable. However, an object's flotation acted as a second, confounding variable that affected the data gathered—any final conclusions about buoyant force could therefore not be attributed solely to a change in mass. Students quickly realized that two variables had changed when objects floated, instead of one; they therefore needed to redesign the project to only include objects that could be submerged in water.

FIGURE 3

Force probe set up to measure buoyant force.



PHOTO COURTESY OF THE AUTHORS

(**Safety note:** Given the potential for water spillage, make sure that any electrical components [e.g., computer] being powered by an electrical receptacle in the lab are protected by a ground fault circuit interrupter.)



Once students removed the confounding variable and used only submerged objects, they were able to correctly discover that mass has no effect on buoyant force.

Day 6

By the end of Day 5, students had completed their investigations and summarized their individual results. Day 6 began with each group sharing independent findings with the class. Based on these findings, a whole-class buoyant force concept map was created (Figure 5, p. 43). After reviewing the completed concept map, students discussed the results of different experiments.

Many groups tested the impact of mass—as one of their factors—and had similar results. This led to a discussion about the nature of science and how confidence in results increases as more researchers (i.e., students) report common findings. One group tested the impact of the depth from the water's surface on buoyant force. The group's results conflicted—some data demonstrated that depth might have an impact, while other data showed the opposite.

After students discussed these inconsistent results, they decided to redo the test as a class. The class's results showed that depth did not have an effect on buoyant force. These results led to a discussion about students' confidence in their results on the effect of depth, compared to their results on the effect of mass. Because less testing had been done on the impact of depth, students agreed they felt more confident about the results of the mass experiments.

In addition to these experiments, another group used the force probe illustrated in Figure 3 (p. 41) to investigate the impact of the fluid's density on the buoyant force exerted on a submerged object. This was accomplished by submerging the same object in different liquids (e.g., oil and water).

Day 7

Day 7 of the module aligned with the iterations component of the MBI road map (Figure 1, p. 39). To revise and finalize their models for submission, students were asked to consider everything they had learned over the last six days. The finalized models were assessed using the Buoyancy Model Guidelines and Rubric (Figure 2, p. 40).

Figure 4 is an example of one group's final model. This group tested two factors—the impact of a submerged object's shape and mass. In addition, based on other groups' presentations, the group also included statements about the impact of a submerged object's density and depth from the water's surface. The results of the tests led the group to conclude that, for objects of equal volume, “the density, surface area, and depth of an object [do not] affect the buoyant force in the water.” Based on the group's reflections, the students also concluded that “no matter the mass of an object, the buoyant force stays the same if the volume stays the same.”

Conclusion

The American Academy for the Advancement of Science (AAAS 1989) states that “teaching should be consistent with the nature of scientific inquiry” (p. 147). MBI is widely considered to be a meaningful emergent instructional strategy in science education (Passmore and Stewart 2002; Passmore, Stewart, and Cartier 2009; Schwarz et al. 2009; Windschitl, Thompson, and Braaten 2008). Its roots can be found in the works of Gobert and Buckley (2000), who describe model-based teaching broadly as “any implementation that brings together information resources, learning activities, and instructional strategies intended to facilitate mental model-building both in individuals and among groups of learners.” Passmore, Stewart, and Cartier (2009) liken the process of modeling to the work of scientists:

[A]ll scientific disciplines are guided in their inquiries by models that scientists use to construct explanations for data and to further explore nature. The development, use, assessment, and revision of models and related explanations play a central role in scientific inquiry and should be a prominent feature of students' science education (p. 295).

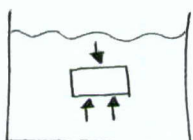
It should be a goal for student experiences in science classrooms to more realistically mirror the work of scientists (Clement 1989). Using MBI as a learning anchor for students in high school physics aligns with this goal.

The approach shared in this article offers one possible way to structure MBI experiences for students—but this is just one example of how to translate the framework into practice. Because the MBI instructional strategy focuses on deeply connecting science concepts, science processes, the nature of science, and communication in science learning, it can be used in conjunction with any science discipline. We hope that more science teachers and university science

FIGURE 4

Example of group buoyancy model.

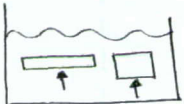
Buoyant Force: How much water pushes up on an object.



- * pressure is influenced by the depth of water. The deeper in the water, the more pressure. This causes a buoyant force because part of an object is deeper in the water so it has more pressure than the top of the object causing an upward force.
- * an object sinks if the buoyant force is less than the objects force downward & floats if the buoyant force equals the objects weight. (the water can't push up on an object more than the object pushes down on the water)

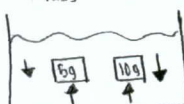
Tests: mass & shape

Shape



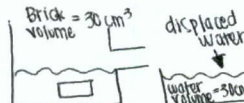
- * no matter the shape of an object, the buoyant force stays the same if they have the same volume
- * the density of the object, surface area, and the depth of an object don't affect the buoyant force.

mass



- * no matter the mass of an object, the buoyant force stays the same if the volume stays the same
- * the only things that do affect the buoyant force are volume & the density of the liquid

Brick volume = 30 cm^3 displaced water



- * the volume of the displaced water equals the volume of the object
- * Archimedes principle: the buoyant force equals the weight of the displaced water

* Bigger volume → Bigger displaced water → Bigger buoyant force

* Bigger density of liquid → Larger weight of displaced water → Bigger buoyant force

* Part of model refined by experimentation

educators will continue to share how they have translated the MBI framework into practice. ■

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On the web

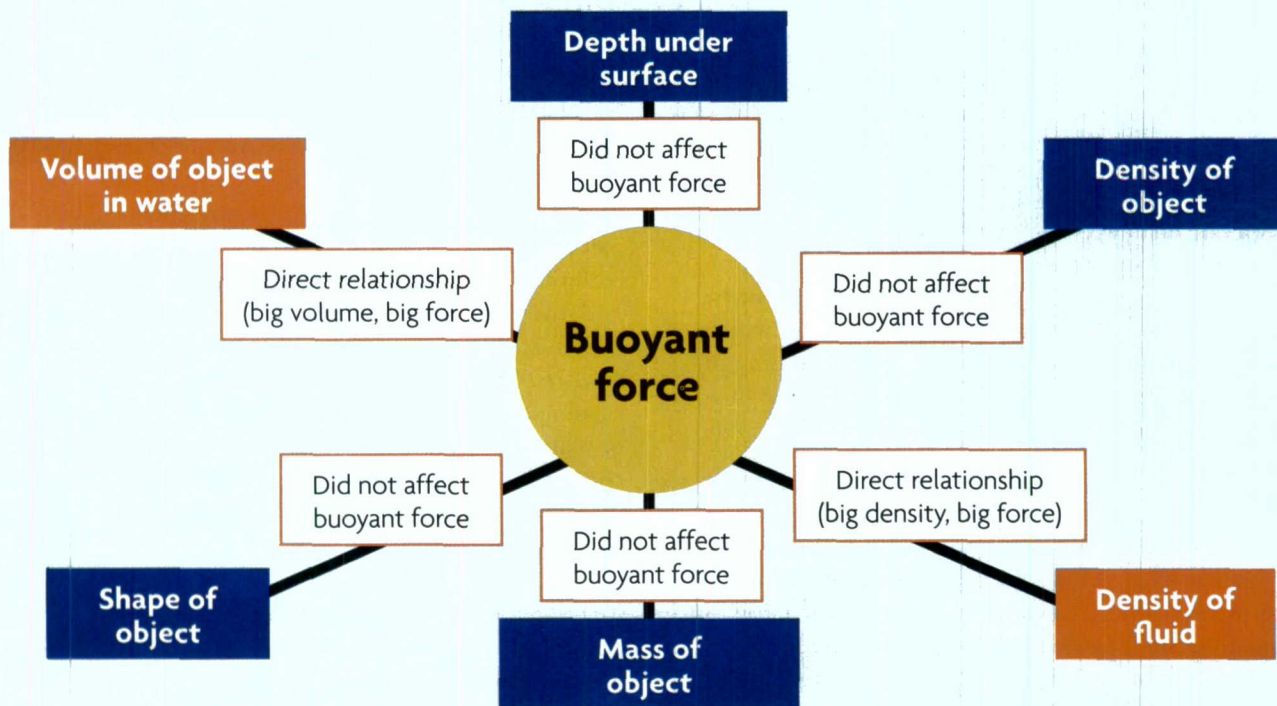
National and state science standards addressed: www.nsta.org/highschool/connections.aspx

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FIGURE 5

Whole-class buoyant force concept map.



(Note: The four factors that did not affect buoyancy hold true only when volume is held constant—a condition that held true as groups tested these four factors.)

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