

# Ready, Set, SCIENCE!



## Putting Research to Work in K-8 Science Classrooms

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NATIONAL RESEARCH COUNCIL  
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# Science Class

## MOLECULES IN MOTION<sup>2</sup>

The following case study involves a classroom of seventh graders struggling to understand a set of new and difficult concepts. It focuses on a specific domain of scientific knowledge—the nature and properties of matter, including gases. At least some of this material will be unfamiliar to most educators—in fact, most adults struggle with the properties of gases and air pressure. Focusing on a specific example of teaching that incorporates all four strands demonstrates the power of using the strands together to engage kids in actively doing science. It also makes it possible to dig deeper into some of the new perspectives on conceptual understanding and scientific proficiency that offer so much potential for science education.

Michelle Faulkner, a seventh-grade science teacher, was beginning a unit on air, called “Molecules in Motion,” as an introduction to the atomic-molecular theory of matter.

### THE ATOMIC-MOLECULAR THEORY OF MATTER

The atomic-molecular theory is a well-established body of scientific thought that helps make clear the properties of substances, what things are made of, and how things change (and do not change) under varied environmental conditions, such as heat and pressure. The atomic-molecular theory accounts for visible as well as invisible (microscopic) aspects of substances.

Ms. Faulkner had two reasons for starting with air pressure demonstrations at the outset of this unit. The first was that the textbook she used in class introduced the atomic-molecular theory with dramatic air pressure demonstrations. Her second reason was that she knew these demonstrations would produce surprising and unexpected outcomes that would elicit students’ thinking about experiences they’ve had with air pressure. The students

were likely to think they knew what was happening in the demonstrations, because they would be observing and working with everyday objects and situations familiar from their own lives. This familiarity and assumed knowledge would elicit a number of predictions and theories from them. Ms. Faulkner knew, however, that her students would quickly discover that their usual explanations or assumptions did not, in fact, work well to explain what was going on. This, in turn, would encourage them to be more open to exploring new tools and models and to developing new explanations.

The air pressure demonstrations were dramatic because, although air is invisible, air *pressure* pushes in every direction with 14.7 pounds per square inch at sea level—a huge amount of force. Once students began to discover how air pressure works, Ms. Faulkner hoped they would be motivated to greater exploration and mastery of other related scientific phenomena, such as the nature of molecular motion and the effects of heat.

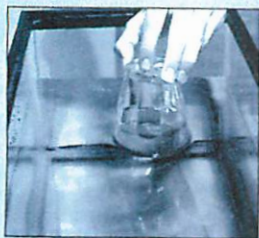
Ms. Faulkner’s seventh graders loved to see chemical reactions, and the grander the better. The problem with many of the demonstrations in their science textbook was that they never really understood the concepts behind the outcomes they produced. They predicted what would happen, invariably found the results surprising and interesting, but due to time constraints were forced to move

on too quickly to other demonstrations, memorizing vocabulary, and completing worksheets. The demonstrations also often overestimated the students' knowledge and experience, subtly communicating the message that, if only they were smarter, they would be able to understand the outcomes better. This time, Ms. Faulkner was determined to make sure that her students saw themselves as "doing science," not just seeing cool effects or memorizing vocabulary for tests.

The day she began the new unit Ms. Faulkner arranged in front of the class an empty 10-gallon aquarium, several different-sized drinking glasses, and an empty glass milk bottle. She asked two students to fill the aquarium with water. Then she added some blue food coloring so they could better see the contrast between the water and the air.

Ms. Faulkner had chosen this particular demonstration because she believed it made sense to start with something her students had probably seen before and could demonstrate to their parents later at home. As her science students entered the classroom, she called for them to join her around a central work area with the aquarium on a table in the middle.

"You've probably had this happen to you while doing the dishes," she said. "And it's very strange." She chose a small drinking glass from the several she had gathered and put it into the aquarium, turning it sideways so that all the air bubbled out. When the glass was fully immersed in the tank, she turned it upside down and slowly raised the bottom, bringing the glass almost completely out of the water (see Figure 3-1).



**FIGURE 3-1**  
*Small inverted glass being submerged in water.*

The students watched as the water stayed in the glass above the tank, as if by magic. Someone said,

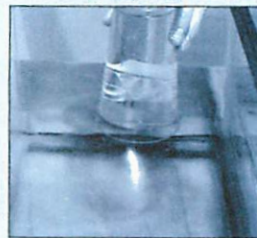
"Cool, it's like the water's stuck in the glass." At that moment, the rim of the glass broke the surface and the water flowed out in a rush. Everyone laughed.

"Do it again," someone called.

"Do it with the taller glass," Alliyah said, "and see if that works."

"That's a great idea," Ms. Faulkner said. She was thrilled that the kids were proposing their own ideas for demonstrations, and she was happy to follow their lead. She asked Alliyah to try the experiment with the bigger glass, since it was her idea.

Alliyah placed the glass in the aquarium, turned it upside down, and filled it with water. As she lifted the bottom of the glass slowly from the water in the tank, the water came with it (see Figure 3-2).



**FIGURE 3-2**  
*Large inverted glass being lifted out of the water.*

"Could we try it with an even taller glass?" asked Eriziah. "Or how about that graduated cylinder?"

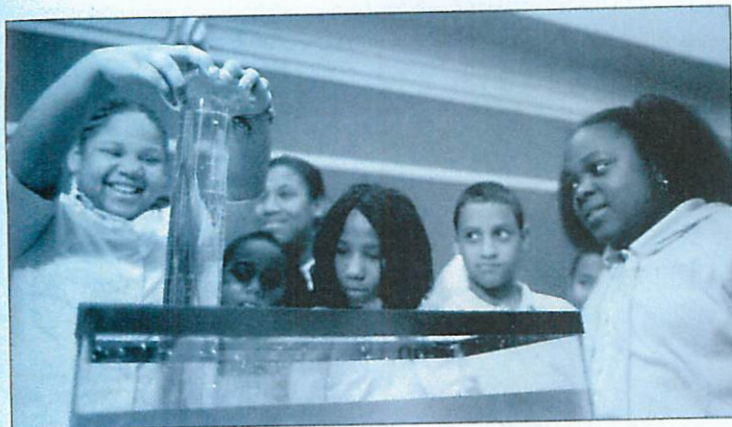
"Go ahead and try it, Eriziah," said Ms. Faulkner. As with the other two glasses before, the water stayed

in the graduated cylinder as Eriziah lifted it out of the tank (see Figure 3-3).

"So what's going on here? What's *making* the water stay in the glass?" Ms. Faulkner asked. No one answered. Then Damian called out, "Suction! The water gets sucked up into the glass like a vacuum!"

"You know what, Damien?" Ms. Faulkner responded. "A lot of adults would guess the same thing. They would say, 'A vacuum sucks the water up into the glass.' But I'll tell you a saying that I learned in my physics class in college: 'Science never sucks!'" The group erupted in laughter.

Ms. Faulkner had expected that one of her students would suggest suction or a vacuum as the cause. This happened every time she taught students about



**FIGURE 3-3**

*Graduated cylinder being lifted out of the water.*

air pressure. Suction as an explanation made sense to students because they'd had actual experience with it. Drinking a milkshake through a straw, for instance, felt like "sucking" liquid into your mouth.

Ms. Faulkner wanted to give her students some time to think about this explanation, rather than simply telling them it was not valid. She also wanted them to question their assumptions and move beyond the idea of suction just because it sounded scientific. She told them that they would explore the issue in depth, amazing themselves and their parents by the end of the unit by knowing more about the physics of air pressure than most college graduates do.

Then she briefly set out the plan of action. She would do one more group demonstration. Then they would work at different stations around the room, called "situation stations," in groups of four, exploring different activities with air and water. They would have a short amount of time to rotate through all of the different stations, after which they would choose one station to focus on. Each group would put together a report for the rest of the class, trying to explain what was going on at their particular station.

After explaining the plan of action, Ms. Faulkner took the top off a clean mayonnaise jar and passed the jar around, asking the students to tell her what was in it. They turned it upside down, examining

it closely. One student sniffed it and said, "Nothing." Another said doubtfully, "Air?"

"So we have two different ideas on the table," Ms. Faulkner said to the class. "What do the rest of you think?" Surprisingly, the students had a lot of different ideas about this. Some thought both ideas were possible, because, as Jessa said, "air sort of is nothing, except if the wind is blowing."

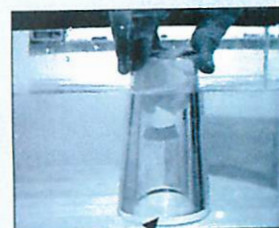
As the students shared their ideas, Ms. Faulkner recorded them on a large piece of chart paper. She titled the chart "What We THINK We Know About Air," reminding them that this was just the beginning of the investigation and their ideas were sure to change. She explained that it was important for them to record their ideas now so they could look critically at them later and see how they had changed over time, as more evidence was gathered.

Finally, Ms. Faulkner said, "Let me do one more demonstration that will add a little more data and help us think about air."

The demonstration was designed to show the students that air took up space even though it was invisible. Ms. Faulkner balled up a paper towel and stuck it in the bottom of a large glass in such a way that it would stay there and not fall out when turned. She turned the glass upside down so the opening was facing the water in the tank (see Figure 3-4).

"I'm going to push the glass down into the water. What do you think will happen? Will the paper get wet?"

Everyone wanted to talk at once. Ms. Faulkner told each student to turn to the person next to them and discuss their ideas. The room filled



**FIGURE 3-4**

*Partially submerged upside-down glass with balled-up paper towel. Will the paper get wet?*

with talk as the students discussed with their partners the experiment they were about to try. Ms. Faulkner



circulated around the room and listened in on different conversations, noting a range of predictions.

After a few minutes, she brought the students' attention back to the front of the room and asked different partners to share their predictions, which she wrote on the whiteboard. There were four different predictions:

1. The glass will be filled with water and the paper will get wet.
2. A lot of water will go in the glass but the paper will not get wet.
3. A little water will go in the glass but the paper will not get wet.
4. No water will go in the glass and the paper will not get wet.

Ms. Faulkner asked the students to vote, by a show of hands, for the prediction they agreed with. She explained that the voting was intended not as a basis for determining correctness but to let everyone get a sense of each other's views of the most likely outcome.

Most of the students voted for Prediction 1, several for Prediction 2, and a few for Predictions 3 and 4. Then Ms. Faulkner asked the students to explain the reasons for their predictions, telling them they were free to change their minds at any point if they heard something that convinced them to rethink their position. April went first because she and her partner had proposed Prediction 1.

"At first we thought the water would just go into the glass, because, you know, it seems like there's nothing in there," April said. "But then I heard someone else saying they'd done it and no water went in, and I changed my mind. I guess, like Joanna said, there's air in the glass and the air won't let the water in."

Phuong spoke next. She was from Vietnam and had lived in the United States for only two years, but she was fascinated by science.

"I say 4. I don't think the water will go in because air is everywhere in the glass but not where the paper is."

Ms. Faulkner said, "So are you agreeing with April? You're both saying no water at all will go in the glass and the paper will be dry?" Both girls nodded.

Phuong continued, "I know air is real. It takes up space and keeps water away from the paper."

Ms. Faulkner asked for someone who had voted for Prediction 3—predicting that a little water would go into the glass—to explain their reasoning. Joanna volunteered.

"Well, actually, I think this is probably wrong, but me and Tanika were thinking that water is heavier and has more force than air, and it might force the air into a smaller and smaller space, and even squish up the paper. But we agree with Juanita and April. We're pretty sure the paper won't get wet."

Finally Ms. Faulkner did the demonstration. The students watched, craning their necks and getting

out of their seats to see the aquarium, as she pressed the upside-down glass slowly into the water (see Figure 3-5).

It was difficult to see what was happening because everything looked blue. One of the students pointed out that the paper wasn't getting wet, and the water went only a little way up into the glass. Someone else noticed that the farther down into the water the glass was pushed, the more water went into it.

Ms. Faulkner pulled the glass out of the water, took out the paper, and showed it to everyone. It was completely dry! To prove it, she passed the paper around to each student.

"So what have we figured out with this experiment?" Ms. Faulkner asked. "Which prediction fits the results the best, and why didn't the paper get wet? Go back to your seats and let's talk about this."

As soon as he sat down, Jeremy waved his hand excitedly. Ms. Faulkner waited patiently for more hands to go up. After about 10 seconds she called on Tanika, who didn't typically volunteer to speak.

"I think what we figured out is that the glass has air in it and that the air keeps the water out," said Tanika. "Even though you can't see it, it's there. And the reason the water went in a little, is like what Joanna and I were saying, that the water is maybe stronger than the air and kind of forces it into a smaller space."

"Can you say more about that?" asked Ms. Faulkner.

"Maybe it's like forcing a suitcase closed. You press all the clothes down and even though it's the same amount of clothes, they take up less space."

"That's a really interesting way of thinking about the same amount of stuff taking up less space,"



**FIGURE 3-5**  
*Fully submerged glass: only a small amount of water gets in.*

said Ms. Faulkner. "Let me see if I understand what you're saying. Are you saying that the air is getting pressed up by the water, or compressed?"

Tanika nodded. "It's like the air is getting squished."

Ms. Faulkner added the words "air is squishable or compressible" to the "What We THINK We Know" chart.

"Are there any other things we think we know about air? Turn to the person sitting next to you and talk for a minute about both of the demos we've done. I want you to think about anything you think you know about air. And talk about what the bases for your claims about air are and how certain you are about your ideas."

Ms. Faulkner circulated among the students. Everyone seemed to be talking, even students who were usually reluctant to speak in a large group.

After calling the group back into session, she decided to start with Jorge and Salizar, who felt certain that air was everywhere. She'd overheard them speaking both in English and Spanish, and she'd heard the word *moléculas*. She called on Jorge, the quieter of the two, to explain what he and his partner had come up with. Ms. Faulkner stood poised to write on the "What We THINK We Know" chart, and she reminded them again that these were just "first draft" ideas, as she called them, that would probably change a lot over the course of the unit.

Jorge spoke first. "Me and Salizar, we think air is everywhere. *Pequeñitos, moléculas.*"

"I read in a book that molecules are really, really small, too small to see without a microscope," Salizar said.

Ms. Faulkner wrote, "Air is everywhere, made up of tiny molecules."

Other students shared their ideas. Joanna spoke for herself and Sherrie.

"Well, we sort of agree and sort of disagree. We don't think there's air in space. Maybe there's

air everywhere on earth, but not really *everywhere*. We're not completely sure if there's air on the moon, but we're pretty sure there's no air in space. That's why astronauts have to wear spacesuits." Everyone laughed.

Ms. Faulkner said, "Do you want me to change our 'What We THINK We Know' chart?"

Jorge suggested adding "on earth" to "air is everywhere."

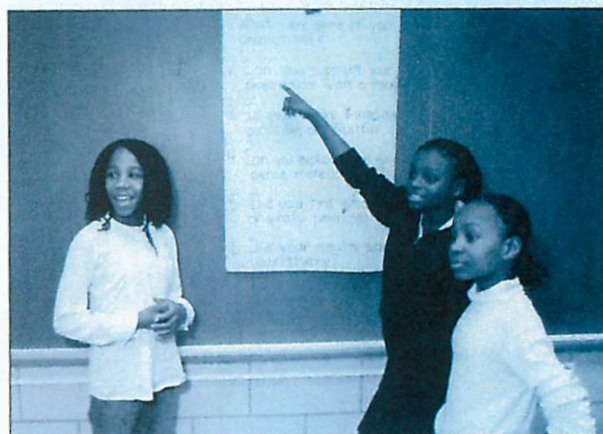
Shanita went next. "Air is a gas, right? Not a liquid or a solid. The molecules are moving around really, really fast. We learned this in sixth grade, but I can't remember the difference between molecules and atoms."

Ms. Faulkner recorded these ideas, with question marks next to "moon" and "atoms." She felt the class had made a great start. She directed them to a much smaller wall chart, which showed their eight assigned groups and the stations they'd specialize in. Around the room were four very different set-ups, each involving air and water, making use of soda bottles, cups and paper, straws, and large and small graduated cylinders. She told her students they would have 5 minutes to spend at each of the four different stations. They would then have 15 additional minutes to spend at the station they would specialize in, and they would continue the next day as well. Because there were two different versions of each station, each of the eight groups had its own set-up to explore in depth.

For the next 20 minutes, the students moved from station to station in 5-minute blocks, reluctant to leave each station when Ms. Faulkner's timer rang. When it was time to specialize, the students settled around their designated stations and began working. They took notes and drew pictures in their lab notebooks, talking excitedly.

After 15 minutes, the bell rang. The students were so engrossed in their stations they didn't want to stop. Ms. Faulkner was pleased and told them they'd have more time the next day.

Over the next several days, each of the groups attempted to explain what was happening at their specific station. Each group developed a poster that showed the demonstration in action and



tried to explain what was pushing what. Groups presented to the class, and the students in the audience responded with questions, challenges, comments, and suggestions based on what they had discovered at their own stations. Ms. Faulkner made sure that the discussion stayed focused on what was pushing what, in what direction, and on what was causing change to occur.

After the last group presented, Ms. Faulkner told the students she wanted to try to consolidate their findings. The "What We THINK We Know" chart was now full of new notes that the students had added on their own, such as "air pushes up and down and sideways," "air has more force than water," and "air is squishable and can be made smaller." There were still, not surprisingly, several explanations that used the notion of a vacuum or suction.

Ms. Faulkner told the class that she was going to start a chart called "Wall of Accepted Scientific Facts."

"These are ideas about air that are currently accepted as fact by the scientific community," she said. She pointed out that some of the facts were the same as the ideas the students themselves had

come up with, while others had taken scientists hundreds of years to figure out. Some ideas, she explained, might be hard for them to believe.

"I'm going to put up these facts, and we're going to see if we understand and accept them or if we still have questions." She told the class that 100 years ago a wall of facts about air would have looked different, and it might look a bit different 100 years from now. "We still might want to add to these, or rephrase them a bit as we continue our unit, but these have a different status than the ideas in our 'What We THINK We Know' chart."

Of the facts she put on the "Accepted Facts" chart was one they'd already proposed—that air was all around them, even though they couldn't see it. She confirmed that it was made up of tiny, tiny particles—air molecules—so small they couldn't be seen with a regular microscope. As Shanita had said, air molecules are constantly moving, very fast, in every direction.

Ms. Faulkner demonstrated this fact, pointing up under her chin, pressing on the outside of her nose, even on the inside of her nostril. She explained that the air was pressing equally everywhere, on the front and back of her ear lobe and on the outside of their noses as well as the inside. "Otherwise your nostrils would collapse (she pressed her nostrils closed) and you wouldn't be able to breathe! So there's just as much air pressure on the inside of your nostril as on the outside. If something is not moving, it doesn't mean that there's no air pressure. It means the forces of the air are balanced—pushing equally in all directions. So air molecules are bouncing every which way—down, sideways, up—on every square inch of my body. But here's something really important. Scientists don't say that the air molecules *want* to move or *decide* to move. They just move. They don't want or try or desire to move. There's no intention or knowledge. It's not like they *know* there's a door open and decide to go out the door. Instead, they get pushed by another molecule and

hit a wall, bounce off, and by chance, they bop out the door." She wrote on the "Accepted Facts" chart:

- Air molecules are constantly moving, but without intention or knowledge.
- Air molecules are moving very fast in every direction, and they don't stick to one another, so they can't pull; they only push.

Then Ms. Faulkner added some more "surprising facts," as she called them. She told the kids that scientists often say we live at the bottom of an ocean of air. "Scientists think of both air and water as fluids. Fluids push in every direction—up, down, and sideways—just like you saw in your stations. And with both air and water, there's more push, more force, the deeper down you go. Remember when you found that it got harder and harder to push the drinking glass into the aquarium?" The students nodded.

Shanita said, "Oh yeah, and remember how we pushed an empty, upside-down glass into the aquarium and the further down we pushed it, the more the air got squished, or um, compressed? It seemed like the water had more force the deeper in the tank we went."

"That's another demonstration of the way that the pressure in a fluid is greater the deeper down you go," Ms. Faulkner said. "And air is also a fluid. The air molecules at the bottom of the 'ocean of air' are more squished together, or compressed, at sea level because of the weight of all the air molecules above them. In fact, at sea level, there's 14.7 pounds of air pushing on every square inch of your body! Who can think of something that weighs that much, almost 15 pounds?"

Eriziah said, "I have a 15-pound dumbbell at home, and man that thing is heavy!" "Maybe two gallon jugs of water one on top of another?" Shanita volunteered.

"Yes, but I'm talking about 14.7 pounds per square inch, don't forget," said Ms. Faulkner. An adult man has about 100,000 pounds of air, pushing in every direction, on his body, up, down, sideways." She drew a square inch on her arm in blue magic marker. "There's 14.7 pounds, almost 15 pounds, of air pressing down right here."

"How come we can't feel it?" Eriziah asked.

"Great question." Ms. Faulkner said. "We can't feel it because we're used to it. Our bodies—and every living thing on earth—have evolved to live under these conditions. So it's normal for us. But the change in air pressure is why your ears pop when you hike up a mountain or fly in a plane. If you took an inflated balloon that you blew up here, where we're close to sea level, and carried it all the way to Denver, which is a mile above sea level, the balloon would be larger in Denver because there'd be fewer air molecules hitting the balloon on the outside, so there would be less resistance against the molecules inside the balloon."

A few of the students were beginning to think about the first demonstration again, which many still explained as having to do with suction.

"Wait a second," Damian said. "You're saying the water is *pushed* into the glass, not sucked in?"

Ms. Faulkner asked if anyone could put into their own words what Damian had said. Eriziah wanted to try.

"Damian said the air wasn't sucked into the glass like with a vacuum, like he first thought it was."

Ms. Faulkner nodded. "But why can't the water get sucked into the glass? Why can't the air in the glass suck up the water?"

Ms. Faulkner used her trick of silently counting to 10 before speaking, in order to give her students time to think.

Finally, Tanika raised her hand. "Is it because the air molecules are moving so fast, like it says on the wall of facts, they can't pull, they can only push?" She paused. "So air can't pull or suck? It can only push?"

"I'm getting it, I think," said Damian. "The water is *pushed* into the glass by the air pressing down on the surface of the water in the aquarium? It's like the air is forcing or squirting the water up into the glass. Like if you slap your hand down on water, it sort of splashes up?"

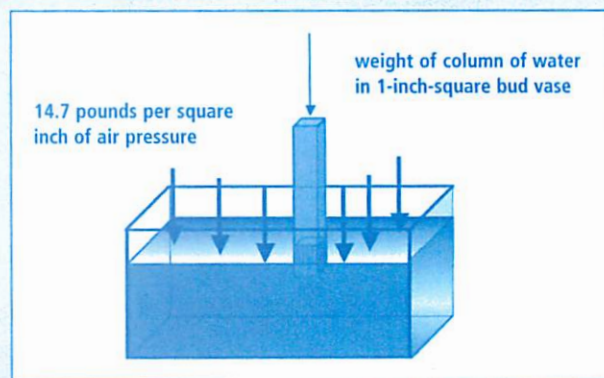
"Can anyone remember how much pressure there is, how much force there is on every square inch of the water in the fish tank?"

Jorge looked up at the wall of facts and said, "14.7 pounds per square inch of air pressing on the water."

Then Ms. Faulkner gave them an example, which she sketched on the board (replicated in Figure 3-6). If instead of using a regular glass, upside down, to pull out of the aquarium, they used a glass that had a one-square-inch opening, like a rectangular bud vase, the water in the vase would weigh however much a column of water one inch by one inch weighs. That depends, of course, on the height of the column of water, because the more water in the column, the more it would weigh. Still, there was no way that the water in a column of 5 inches would weigh 14.7 pounds. As a result, the air pressure on the surface of the water would keep the water in the glass.

Ms. Faulkner's diagram looked something like this:

Phuong asked a question that Ms. Faulkner wasn't anticipating. "How much *would* the water weigh in that bud vase if it was like 5 inches high?" Ms.



**FIGURE 3-6**

Ms. Faulkner's diagram of air pressure.

Faulkner decided she would follow Phuong's lead and take a bit of a detour to explore her question. She sensed that figuring out the weight of a column of water that was one inch by one inch might help her students, down the road, in thinking about pressure more generally as a ratio of force per area.

She asked the students to propose ways they could investigate the answer to Phuong's question. Again she wrote proposals, figuring someone might come up with a solution that the class could work on as homework. A number of suggestions were proposed:

- ✦ Get a hollow one-cubic-inch container and weigh it before and after you fill it with water and subtract the weight of the container. Then multiply that by 5, for the 5-inch height.
- ✦ Measure the aquarium carefully to find out how many cubic inches it holds, and then weigh it both empty and filled with water. Then subtract the container and divide the total by the number of cubic inches. Multiply that by 5.
- ✦ Ask a scientist!
- ✦ Get a syringe and fill it with the number of milliliters of water that would equal a cubic inch of water and weigh the syringe with and without water.

Finally, much to Ms. Faulkner's surprise, Salizar called out, "Just Google it!" He walked over to the computer and "Googled" *weight of cubic inch of water* and less than 5 seconds later said, "I've got it! Water weighs 0.036 pounds per cubic inch or 8.33 pounds per gallon." Ms. Faulkner wrote down the results. Shanita added, "That's way less than the 14.7 pounds per square inch that the air is pressing down with."

Ms. Faulkner directed the students back to Phuong's original question. "How much would the water in this 5-inch-high bud vase weigh? Everyone

take a minute to figure it out and then talk to the person sitting next to you."

There was silence for a few moments as students worked alone, and then partner talk took off. Two students showed their work—drawing 5 cubic inches on top of one another and multiplying Phuong's results of 0.036 pounds per cubic inch by 5 inches, with the answer of 0.18 pounds of water. There was uniform agreement that this was how much the 5-inch column of water would weigh.

Jason asked if there would be more force pushing the water into the glass in a larger aquarium because there would be more total pounds of air on the surface of the water. "Or what if it was like a huge swimming pool full of water?"

"Jason has asked a really important question," Ms. Faulkner said. "He asked if there would be more air pressure pushing down on the water in a bigger tank, or a swimming pool, or an ocean? The answer that the science community would give is that the pressure would be the same on every square inch, so the amount of water doesn't matter. It's the weight of the air per unit area." She reminded them that pressure is always a ratio, a relationship between two things—force per area.

The concept of a ratio, Ms. Faulkner knew, was an important one in science, and the class had spent a great deal of time learning about ratios and using different analogies to understand them.

This time, Ms. Faulkner used an analogy that related directly to pressure. She asked her students to imagine all of the girls in the class walking across a lawn in high heels versus flat-soled running shoes. Everyone could imagine right away that the girls would make a deeper indentation in the dirt if they were walking in high heels.

"You weigh the same, but the pressure on the high heel is pressing on a much smaller area. Pressure is a ratio: how much force there is in relationship to how much area there is." Then Ms. Faulkner

brought them back to the situation in the aquarium. "So even if the surface area of the water is huge, what matters is how many and with how much force the air molecules pound each square inch of the surface of the water. Wherever you are, at sea level or in the mountains, you don't have to calculate the surface area in a container, or in a swimming pool, or in a huge lake, because at the same elevation, every single square inch has exactly the same amount of air pressure on it."

After a moment, Monica asked, "How tall a glass could we pull out of the aquarium? How far could the column of water be pushed up, by air?"

"Could it go all the way up into space?" someone else asked.

Salizar quickly responded, "It couldn't go that far up because there's only 14.7 pounds per square inch pushing down. If the water weighed more than 14.7 pounds per square inch, it wouldn't stay up. The water would win in the battle of the forces!"

"So how far can the air push the water up?" Monica asked again.

"I don't know the answer to that question," Ms. Faulkner admitted. "But I'm sure we can figure it out. Any ideas about how to get started? What would we need to know?"

There was silence. Finally, Tanika said, "How many cubic inches of water does it take . . . um, to weigh more than the air pressure—like 14.7 pounds?"

As if finishing Tanika's sentence, Monica continued, "Like how many cubic inches of water can push down on that spot to outweigh the air pressure that's forcing the water up?"

Phuong said, "I think I get it. It's like the air pressure is pressing down on the surface of the aquarium, everywhere, like a piece of plywood pressing down with a lot of force, like a *lot* of force. And then we cut a hole in the plywood, like a one-square-inch hole. And right there, on that square

inch, there's no air, no nothing, I mean no pressure pushing the water down. So the water would squirt up through the hole! If we had the *one-inch* glass there, the bud vase thingy, then the water would squirt up into it. When the water column goes higher and higher it gets heavier and heavier, and at some point, eventually, the water will weigh as much—down—as the air is pushing up. That's as far as it could go." After a long pause he said, "So how many of Salizar's little cubic inches could we pile up on top of one another? How many would equal up to 14.7 pounds?"

"Phuong's on the right track when she asks how many of Salizar's little cubic inches could we pile up on top of one another to equal the air pressure at 14.7 pounds per square inch," Ms. Faulkner said. "It's really a question of balancing forces. It's like a seesaw. We've got someone on one side who weighs 14.7 pounds. That's the air pressure. On the other side, we've got a one-inch-square column of water. With what we've figured out already, see if you can figure out how tall that column of water could be. And, even more interesting, see if you can figure out a way we could test it to see if our calculations are right. Think about it tonight, and we'll talk about it tomorrow."

By the next day, the class had calculated that the air could hold up a column of water 34 feet tall. They had come up with many different methods, but the simplest was building on Salizar's fact that a cubic inch of water weighs 0.036 pounds. They divided 14.7 pounds by 0.036 pounds (per cubic inch) and came up with 408.3 cubic inches. That's how many cubic inches of water could be piled on top of each other to equal 14.7 pounds. They then divided that by 12 to determine the feet and got 34.03 feet.

Ms. Faulkner applauded her students' hard work and amazing results—they had truly changed their conceptual thinking in many ways.