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HANDS ON!

Hands-on math and science learning

Fall 2000 Volume 23, No. 2

By *Joni Falk* and *Brian Drayton*

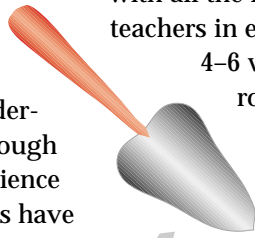
Educational reform programs at the national and state levels have mandated changes to promote a deeper understanding of science concepts through an inquiry-based approach to science education. Yet once the mandates have been issued, what does the reform actually look like in the classroom?

Since 1998 we have been conducting a study that explores how middle school science teachers interpret and implement a shift to inquiry-based science. The study, "The Inquiry-based Classroom in Context," examines science programs in six school districts which have been

Even when school districts have a clear vision, teachers are often left on their own.

part of the State Systemic Initiative (SSI) in Massachusetts. Our goal was to listen to teachers' voices, watch their practice, and explore the school and district context within which they are enacting their understanding of inquiry. We have found that one strong influence on teachers' enactment of inquiry-based science is the degree of coherence provided by the district's vision of this reform.

Our study involved 40 teachers from 6 schools in 6 districts. We worked with all the middle school science teachers in each school for a period of 4–6 weeks, observing in classrooms, examining student work, and interviewing



Cultivating a Culture of Inquiry

teachers, principals, district personnel, and superintendents.

Despite seeing signs of inquiry in individual classrooms in the three schools studied during the first year, there was only one district, Allenville¹, that exemplified a culture of inquiry. In this article we examine the factors that contributed to this culture. The case provides an illustration of how a school system can work to create a coherent vision of inquiry-based science through its practices, support structures, and other reform agendas.

Setting the context

To interpret the results of our study, it is important to understand the context of teaching in Massachusetts. The insights that emerge, however, may well apply to districts trying to implement similar mandates and reforms across the country.

¹Pseudonym.

In Massachusetts, as in so many districts nationwide, inquiry-based science is a component of state standards and frameworks. In 1992 the National Science Foundation awarded a State Systemic Initiative grant to Massachusetts. The grant funded PALMS, the Partnerships Advancing the Learning of Mathematics and Science. This program espoused a definition of inquiry that emphasizes students' ownership of their learning, their engagement with problems and open-ended investigations, and their learning to reason with real-world data. In 1996 the Massachusetts

Department of Education published its first science curriculum frameworks, which mandate that "curriculum, instruction, and assessment are based on inquiry, problem-solving, discovery, analysis, and application of essential concepts."

School districts then undertook to define how they would implement the frameworks in the district's choice of content, materials, and professional development plans, for each grade

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Try the Quick-Build activity from Construct a Catapult on page 11 in this issue of Hands On!



From the Editor

In many ways the title of our cover article, *Cultivating a Culture of Inquiry*, captures the essence of the work we do at TERC. As we state in our mission, "We imagine a future in which learners from diverse communities engage in creative, rigorous, and reflective inquiry as an integral part of their lives." It should be no surprise then that the articles in this issue focus on factors critical to creating an environment where inquiry can flourish for teachers and students.

While the authors focus on different factors—school and district policies, teaching practices, curriculum, and assessment—they all consider the impact of high-stakes standardized tests on the inquiry-based classroom. In *Assessment: Educate or Audit?*, June Foster asserts that it is indeed appropriate for parents and citizens to demand accountability, however, "many of the tests now being used as instruments of accountability are driving teachers back into a 'drill and practice' mentality." Pressures to abandon inquiry-based approaches for didactic drilling are likely to intensify. The articles in this issue illustrate the results possible when administrators, teachers, and curriculum developers resist those pressures and seek to enact a vision of teaching and learning consistent with the goals of the standards movement. ✨

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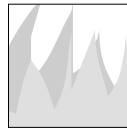
Designer, Production Manager
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Hands On! is published semi-annually by TERC, a not-for-profit education research and development organization dedicated to improving mathematics, science, and technology teaching and learning. A contribution is requested to help defray costs of publication.

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All opinions, findings, conclusions, and recommendations expressed herein are those of the authors and do not necessarily reflect the views of the funding agencies.

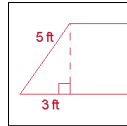
ISSN 0743-0221



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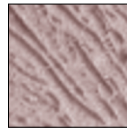
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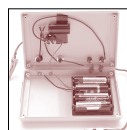
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By Teresa Lara-Meloy and Apolinario Barros

A Quiz

Think back to your high school days, when you frantically tried to memorize all sorts of formulas and definitions for a geometry test: the Pythagorean theorem, the proof for parallelograms, the rules for special triangles. Do you remember them? Let's find out. Calculate the area of the parallelogram in Figure 1. (Hint: you need to figure out the height of the parallelogram first.)

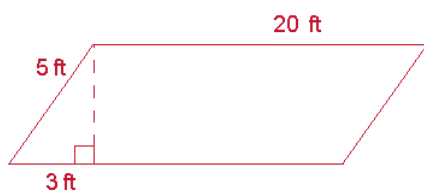


Figure 1. What is the area of this parallelogram?

You can use the Pythagorean theorem to determine that the height of the parallelogram is four feet. (The algebraic formula is $a^2 + b^2 = c^2$, where a and b are the legs of the right triangle and c is the hypotenuse.) To find the area of the parallelogram multiply the base times the height: the area is 80 square feet ($4' \times 20'$).

Geometry students in a Boston public school tackled this same question during an exam.¹ After grading the exam, the teacher asked students to form groups and help each other understand and correct their mistakes. While reviewing the area of the parallelogram, one group of students, Edgar, Felipe, and Omar,² began discussing the relationship between the area of a rectangle and that of a parallelogram. Initially their inquiry may seem somewhat irrelevant to finding the area of the parallelogram, but a

¹Many of the students are recent immigrants from the Cape Verde Islands. Their class is part of a transitional bilingual program at Jeremiah E. Burke High School and is conducted in Cape Verdean Creole.

²Student names are pseudonyms.

closer look reveals that it was a significant learning opportunity for the students and the teacher. Their conversation also provides insight into some misconceptions students have about the formula for the area of the parallelogram and, more importantly, for area in general.

Observing how the students made their arguments and formed their understanding of area can inform the current debate over traditional and new mathematics teaching, which has tended to oversimplify a complicated landscape. The path the students follow raises questions about the implications of trying to separate the teaching of concepts from the teaching of procedures.

Transforming a rectangle

Edgar, Felipe, and Omar debated what would happen to the area of a rectangle if it "collapsed" into a parallelogram. Imagine a rectangle whose

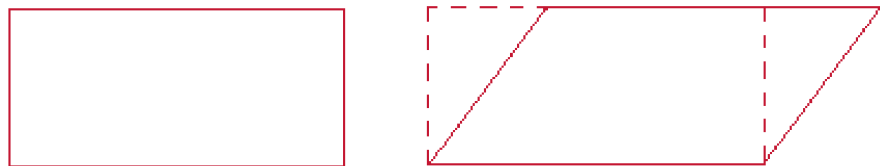


Figure 2. How Edgar visualizes his argument.

base is fixed and whose sides remain the same length throughout the transformation. What happens to the area of the rectangle as you push the upper corner of the left-hand side towards the right, creating a parallelogram?

Is the area of the initial rectangle and the area of the newly formed parallelogram the same? Does it decrease? How would you go about convincing someone of your answer? As you join Edgar, Felipe, and Omar in the discussion captured in this case study, reflect on the interplay between the conceptual

and procedural skills you bring to each phase of the inquiry.

Before recounting the students' strategies it is relevant that only one of the three students, Omar, correctly calculated the area of the parallelogram on the exam. Edgar and Felipe did not complete the problem. While they knew the formula for area, they could not apply it because they could not find the height of the parallelogram.

Omar and Edgar attend class regularly and do their homework consistently. Felipe, on the other hand, often misses a few days of class a week and doesn't hand in homework on a regular basis. Considering this background information and the exam results, you might conclude that Omar knows how to find the area of a parallelogram, while Edgar and Felipe do not. The

discussion following the test suggests that knowing how and when to apply the formula does not necessarily imply that one understands area. Edgar and Omar believe that the area of the shape remains the same throughout the transformation. Felipe argues that the area of the parallelogram has to be less than the area of the rectangle.

Edgar argues that the area of a parallelogram with a given length and width is the same as the area of a rectangle with the same measurements (see Figure 2). He claims that whatever



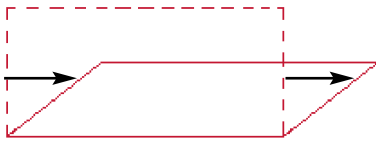


Figure 3. How Felipe sees his argument.

area is lost on the left side of the rectangle as it falls to the right will be gained on the right side of the parallelogram. He represents the two areas with the triangles.

Felipe counters that the parallelogram has to be “shorter” than the rectangle. Figure 3 represents what Felipe thought would happen to the rectangle if it were collapsed into a parallelogram. He explains that the figure would lose more area than it would gain from the part that was left outside of the original rectangle. Therefore, we would see a net loss of area. Not all the area that is lost is regained on the other side, argues Felipe, because some is lost “on top.” Felipe concludes that if the figure continued to collapse, it would become a line, which would contain “no area.”

Edgar may have derived his comparison of “triangular” areas from the way in which most textbooks introduce the area of parallelograms (see Figure 4). In the formal proof of the area of parallelograms, students conclude that the area of a rectangle with a given height and base is equal to the area of a parallelogram with the same height and base. Edgar maintains throughout the discussion that the area of the rectangle and the parallelogram stay the same, and to prove his argument he claims that the area “lost” on one side of the parallelogram is “gained” on the other.

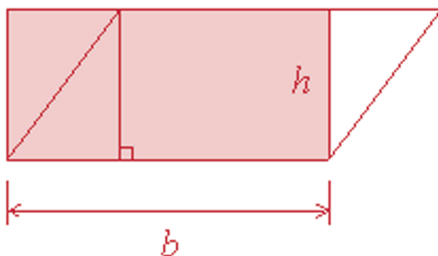


Figure 4. Formal proof of a parallelogram.

If we were to use the parallelogram in Figure 4, Edgar would be correct. However, the transformation of a rectangle into a parallelogram as the students originally posed the question, implies that the perimeter of the shape does not change. The side length of the rectangle becomes the side length of the parallelogram, not its height. Felipe seems to understand the implications of the transformation for the area of the figure. His argument that the area of the figure decreases because the height of the figure decreases is very powerful visually and conceptually. But for some reason it does not convince Edgar, at least not during this first conversation.

A week after this discussion, the teacher asked the three students to continue the conversation after school. During their one-hour taped conversation, the students restate their positions. Felipe spends most of the time trying to convince the others that the area of the figure decreases because the height decreases. Initially, he presents the same visual arguments as before. He suggests that the transformation of the rectangle into a parallelogram is like that of a box being flattened.

Even though the example of the flattened box seems convincing, when the teacher pushes Edgar and Omar to say whether they agree with Felipe, they continue to disagree. Up to this point, Felipe’s arguments do not seem to have a formal mathematical basis, and perhaps that is why Edgar and Omar are not convinced. Felipe’s next strategy shows he understands that Edgar and Omar are not going to be convinced until he uses numbers to show that the height of the original rectangle is greater than the height of the parallelogram with the same perimeter. Felipe changes the focus of his argument from the “space inside” the figures to the numerical height of the parallelogram.

Felipe: Look, the height of this [rectangle] is from here [Figure 5, A] to here [B], the height of this [parallelogram] is from here [C] to there [B’]. You think that the height, right here [AB] is 4, you think that this [CB’] is 4 also?

Edgar: This right here [CB’] is 4? If you come and do a perpendicular thing, which—

Omar: Clearly this here [CB’] is not 4.

Edgar: If this [AB] is 4, right? Mr. Barros has already pulled it here like this [AB’], so, that over there [AB] has to be greater than this [AB’], if we said that this is 4—

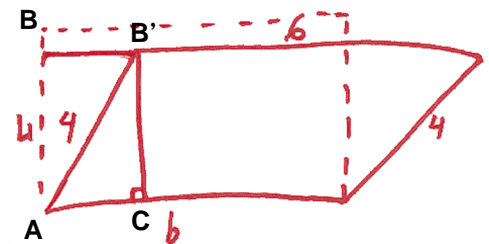


Figure 5. Teacher’s drawing. Numbers were added by students and teacher as conversation progressed. Black letters added for clarity.

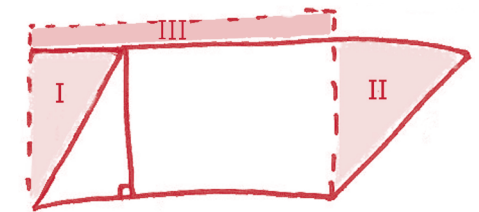


Figure 6. Shading and roman numerals added to illustrate the different arguments.

Felipe: So you’ve clearly seen that it loses height.

Edgar: It loses height.

Omar: But it gains to the side, too!

Felipe: It doesn’t gain to the side if it loses... If you say that it loses on the side here [Figure 6, I], a piece on the side here, that example, that imaginary piece that was there [II], you can see that imaginary piece is being gained over here... no, it gains it here [III]. Doesn’t it gain it here? It gains it inside here [II], for example. You

can see it, what it loses here [I] is what it gains here [II]. What is being lost now? [Edgar: um—] What is being lost there [III]? Height. Don't you see that the height is what is being lost there.

Felipe compares the height of the parallelogram to the width of the parallelogram (the latter being the same as the height of the rectangle). He claims that the height of the parallelogram has to be less than the width of the parallelogram (which is the same as the hypotenuse) when he states, "So you've clearly seen that it loses height." At this point Edgar agrees that "it loses height." Although Omar doesn't disagree that the parallelogram loses height, he clearly still believes that the area it gains to the side is enough to compensate for the loss of height. Felipe returns to his earlier argument about the area inside the figure, which so far hasn't convinced Edgar and Omar.

What Felipe does next is surprising, considering that he doesn't appear to have a strong handle on formulas and procedures. It is less surprising, however, given his visual understanding of area. To make his point, Felipe asks Omar for help in calculating the height of a specific parallelogram. Together they create an example which shows that the height of the shape decreases in the transformation. Because the area is the product of the base times the height, the example also shows that the area as a whole will decrease when the height decreases.

Felipe: The area of this [Figure 7] is 2 times 6, right?

Omar: Yes, the area is 2—

Edgar: Area is 2 times 6.

Felipe: The area of, when you put this 2 here, this is, when we bend it, right? It stays 2 times 6. But, if you come and do the area here [pointing to parallelogram], Omar, now you have to help me.

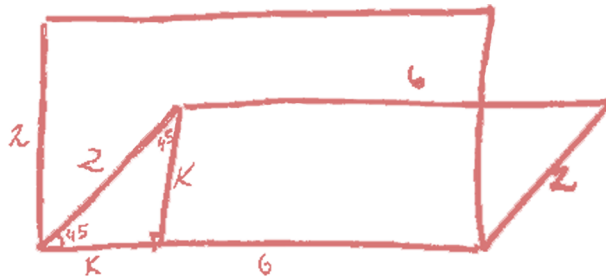


Figure 7. The drawing starts with a 2 x 6 rectangle. Felipe adds the parallelogram. The teacher makes an argument to create a 45 degree angle. "K" is added in conversation.

Which of these two [legs] is the greater leg? [...]

Omar: This leg [pointing to one of the legs].

Teacher: The problem is that we don't know this [height of parallelogram] or this one [base of right triangle].

Edgar: Mr. Barros?

Teacher: Felipe, suppose you bent it [the side of the rectangle]—if you had a protractor, you bent it, bent it, bent it until you reach 45 [degrees]. You can make it 45, and Omar can help you now. This [angle] is 45.

Edgar: This [angle] is 45, and this [angle] 90, so this one [angle] has to be 45 as well.

[After a short discussion on special triangles, they name the two unknown legs "k." To move the inquiry along, Mr. Barros tells them to assume the hypotenuse is 2. He explains the formula for special triangles, which states that in a 45-45-90 triangle, $\sqrt{2}a=c$, where a is the side and c is the hypotenuse.]

Omar: "K" times square root of 2 has to result in 2.

Edgar: Who gave you that "k" square root of 2 just now?

Omar: This is "k" [pointing to k], for example, this is "k," you want to know the value of that [height], we know that in a special triangle, a 45-45-90 triangle, these two [legs] are equal. These two [legs] here are equal to the hypotenuse, so the hypotenuse is equal to the

leg times the square root of 2, and you get it like that.

[After some calculations and further discussion about where Omar gets his formula, they continue.]

Omar: So, "k" is equal to 1.4.

[More discussion about the formula for special triangles.]

Teacher: Now you've found "k," Felipe, continue.

Felipe: If you find—We'll go back here [Figure 7]. Two times 6. We found that the area of this [rectangle] is 12, right? When you slant it [the height of the rectangle], it [the parallelogram] has the same side—height, no, the same base of 6. But, see when we do the area of this [parallelogram] here is 1.4 times 6, which is the base.

Edgar: It comes out to 6.4.

Felipe: No, 8.4. So, I proved that the area of this [...] We have to find the height, only the height that we, height times base, so, no, height times base, so [...] Edgar, you can see that the area of this [parallelogram] is less, after you slanted it, than the area that it had when it started. For example, so it gives you this here [pointing to 12, the area of the rectangle], it has to remain 2 and 6, but the height of this [parallelogram] already is not this [2], it's this [1.4], while this height is still 2.

Edgar: So, you are telling me the height is 1.4 now.

Teacher & Felipe: Yeah, it's 1.4.

Edgar: So, the height decreased.

Felipe: Yeah, the height decreases, if the height decreases, doesn't the area decrease, then? If the area is height times base. Every time it decreases more, it becomes 0.5, 0.000000 until it becomes this [draws a straight line], more or less.

Felipe needs help to find the height. He understands the transformation conceptually but has trouble applying formulas. It took him the first hour of the discussion to get to the point where he tries to find the numerical expression for his argument. If Edgar had agreed immediately, Felipe would not have had the opportunity to explore and build on his intuitive knowledge of the shape and the transformation. Edgar and Omar pushed Felipe to construct an increasingly formal argument to support his view.

In this short transcript there are a few instances where we see that Omar is the only one with clear knowledge of formulas. The others look to Omar because he can recall the procedure for finding the height of special right triangles. Felipe is determined to prove that the height of the parallelogram is less than the height of the rectangle, but he is often side-tracked by comments from the other students. With a little help from the teacher, the three students manage to find the height of the parallelogram and Felipe concludes his argument.

Why isn't Edgar convinced until the very end? Since the height of the rectangle is 2, Edgar may have thought that the height of the parallelogram was also 2, until Felipe proved with numbers that the length of the height and side were different. However, there are other reasons why Edgar maintained his position. For example, looking at the drawings the students made (and we've only shown you a few), it may be difficult to tell whether the area inside each figure actually decreases.

Perhaps Edgar had a different transformation in mind when the discussion started. Imagine that the rectangle wasn't collapsed into a parallelogram but rather extended into one. The area of the two shapes could be maintained because the height could be maintained. Regardless of the reason, Edgar's hesitance made part of this discussion possible. A few

weeks after the conversation the teacher gave a short quiz with another parallelogram. This time Edgar and Omar got the answer right, but Felipe again did not.

Why did Felipe, whose arguments reveal he knew how to find the area of the parallelogram, fail to answer the exam question correctly? Perhaps he still didn't know how to calculate the height of a parallelogram or forgot one of the formulas. For his teacher, the question remains unanswered since Felipe no longer attends the school.

Transforming an exam

The quiz tested the ability to recall and apply the formula for finding the area of the parallelogram, but it did not allow students to explain what they understand or do not understand beyond the application of the formula. By encouraging group discussion after the exam, the teacher allowed for the exploration of broader concepts. What would have happened if the teacher didn't or couldn't take the time to follow up? Based on the exam, the teacher might assume that Omar had a good conceptual understanding of area. The teacher may never have come to understand Felipe's particular perspective of area, and Edgar and Omar would not have benefited from Felipe's reasoning.

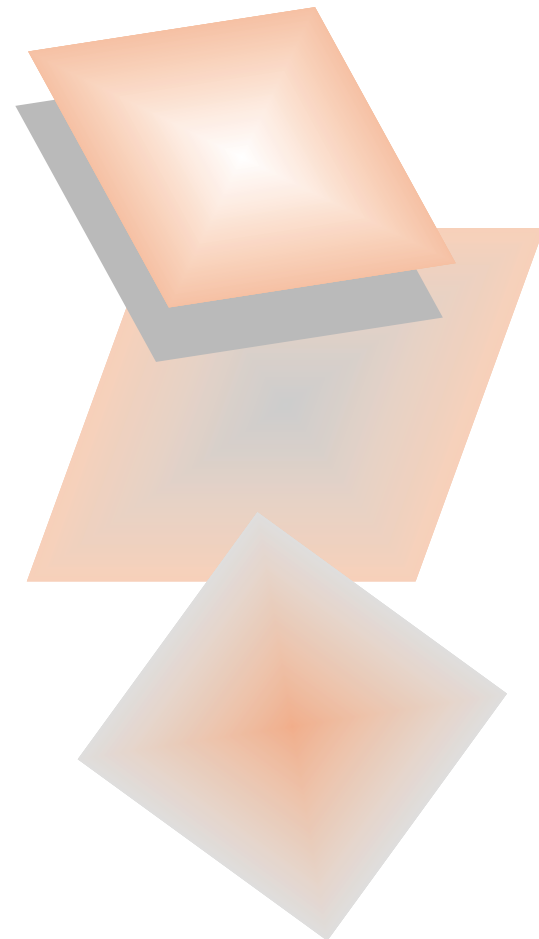
This case study highlights the complexity of teaching procedural skills and conceptual understandings. To sustain the discussion, it was important for all three students to know the formula for finding the area of the parallelogram. They also needed to understand how to apply the formula for special triangles. At a minimum, students should be able to recall these formulas whenever they take a standardized test. It is also important for students to apply their knowledge of geometric concepts beyond what the standardized tests demand—to think through each new problem or even to pose new problems. The debate over basic skills and reform mathematics

overlooks the complicated nature of the interaction between teaching concepts and teaching procedures. The students' inquiry into the transformation of a rectangle illustrates the importance of integrating both types of knowledge in the learning and teaching of mathematics. ✨

Teresa Lara-Meloy is a research associate on the Urban Calculus Initiative. teresa_lara-meloy@terc.edu

Apolinario Barros is a teacher-researcher at Jeremiah E. Burke High School in Boston. He is participating in the Urban Calculus Initiative and is developing the case study on which this article is based.

The Urban Calculus Initiative is funded by the U.S. Department of Education #5B97023005.



Astrobiology

The Final Frontier
of Science Education

By Jodi Asbell-Clarke
and Jeff Lockwood

Astrobiology seems to be all the buzz these days. It was the focus of the Astronomical Society of the Pacific science symposium; the University of Washington is offering it as a new Ph.D. program, and TERC is developing a high school integrated science course based on it. So what is astrobiology?

The NASA Astrobiology Institute defines this new discipline as the study of the origin, evolution, distribution, and destiny of life in the Universe. What this means for scientists is finding the means to blend research fields such as microbiology, geoscience, and astrophysics to collectively answer the largest looming questions of humankind. What it means for educators is an engaging and exciting discipline that is ripe for an integrated approach to science education. Virtually every topic that one deals with in high school science is embedded in astrobiology.

What (or Whom) Are We Looking For?

Movies and television shows such as *Contact* and *Star Trek* have teased viewers with the idea of life on other planets and even in other galaxies. These fictional accounts almost always deal with intelligent beings that have evolved to a point of being able to

communicate with humans. This is very appealing and makes for a great storyline, but in reality, it is much more

likely that the Universe may be teeming with life on a much more basic level. Even on Earth, an overwhelming majority of the biomass with which we share our planet is in the form of microorganisms. So the first thing we have to do is understand what we mean by “life on other worlds” and figure out how to search for it.

Earth is the only known case study, and we must take from it any lessons we can. Apparently, as soon as Earth was mature enough for life to form here, it did. We have evidence of microbial life dating back 3.9 billion years, over 80 percent of the entire lifetime of the planet. This is helpful since it means that someone searching for life on Earth would have had a long timeframe within which to find it. Searching for microbial life elsewhere may not be as easy as finding an alien knocking on our back door, but it certainly seems a more likely prospect.

Because we are not going to be able to observe microbes, or even human-sized creatures, on other planets, we have to look for secondary evidence of life, called “biomarkers.” These include the trace gases and elements given off as byproducts of microbial life. For example, oxygen, detected in

a planetary atmosphere or in an auroral discharge, would be indicative of plant life. Detecting methane or sulfur compounds might indicate energy processes of microbial life such as bacteria. By using spectroscopy and other remote sensing devices, we can search for these elements on bodies in our solar system and perhaps in the future we will be able to detect these elements on the planets being discovered around other stars.

Where Do We Look?

One may be tempted to rule out various places in our solar system as sites that harbor life because of their extreme conditions. Planets too far from the Sun seem far too cold and dark to host life, right? Not necessarily. We only have to look as far as our own terrestrial backyard to find contradictions to this intuition about life. Extremophiles are creatures living at what are considered extreme conditions with respect to human life. Different life forms have

been found on Earth at temperatures greater than water’s boiling point and below its freezing point, in high acid and base conditions, at 4 km below the land surface and at 6 km below sea level. Microbes have lived in space for years, unprotected from extreme radiation.

A crucial example of life under extreme conditions resides in deep-sea vents first discovered in 1977. At depths of 2,100 meters on the floors of the Atlantic and Pacific Oceans, these chimney-like vents spew water heated

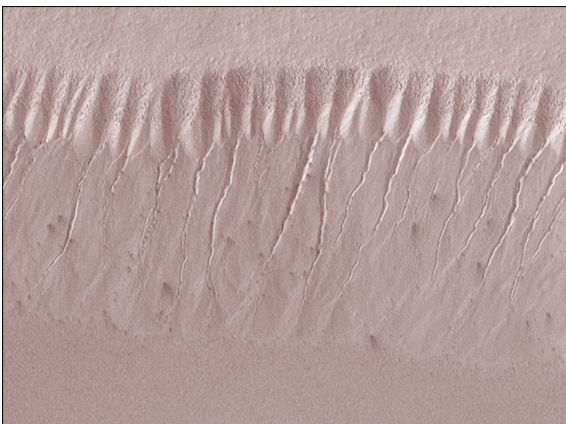
Virtually every
topic in high school
science is embedded
in astrobiology

by a geothermal energy source along with minerals that help support life forms such as tubeworms, clams, and shrimp. The water temperature reaches 750° F but does not boil because it is under tremendous pressure on the ocean floor.

At the other extreme, Lake Vostok sits 4,000 meters under the ice about 1,000 km from the South Pole. This lake provides an Earth-based laboratory that may provide great insight into what is occurring elsewhere in the solar system. It is thought to have conditions similar to one of Jupiter's moons, Europa. Lake Vostok is a unique and precious resource, and scientists must collect samples and pursue investigations without contaminating it. The introduction of any kind of evolved life form into Lake Vostok could perturb this ecosystem so that it no longer serves a purpose for astrobiology.

Lessons from Our Past

By understanding how life formed on Earth, astrobiologists hope to find clues on how to find life elsewhere. Biologists have long believed that Earth formed with only simple inorganic molecules such as hydrogen, methane, and ammonia in its atmosphere and crust. It was thought



Observations by the Mars Global Surveyor indicate areas of liquid water run-off—perhaps even in the very recent past. In this image, it appears that water has seeped from beneath the Martian surface and run down the steep gully walls. Image courtesy of NASA/JPL/Malin Space Science Systems.

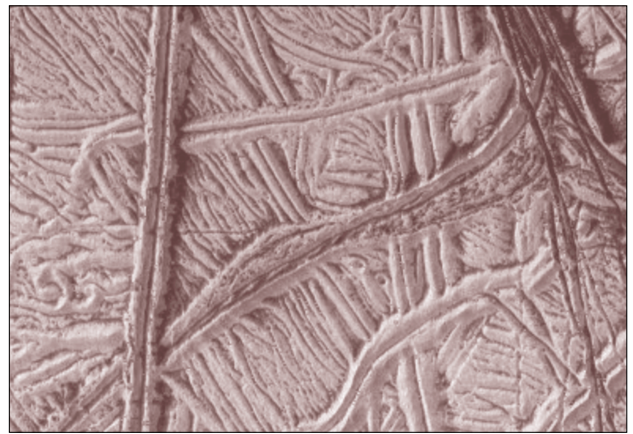
that energy from lightning storms instigated the creation of the complex organic molecules containing carbon, hydrogen, oxygen, nitrogen, potassium, and sulfur (CHONPS) that are attributed to life on Earth. But recent discoveries are opening minds to other possibilities.

It has previously been believed that our solar system began from a cloud of simple molecular gas, and only as the Earth evolved did complex organic molecules form. However, recent observations of the atmospheres around old carbon stars show the existence of organic molecules. As these stars die, they spew organic molecules out into the interstellar medium where new stars form. The formation of the new star may include a planetary system with Earth-like planets that in turn will contain organic molecules right from the start.

Another theory points to a Martian meteorite, such as ALH84001, discovered in an ice field in Antarctica. Although this 4.2 pound piece of rock is thought to have landed on Earth about 13,000 years ago, it was ejected from Mars 16 million years ago and radioactive dating shows that it formed about 4 billion years ago at a time when Mars was much warmer and wetter.

The Search Is On

To find life elsewhere, we must first find homes for life on Earth. Mars has long been a place of study, originally because of it being our neighbor and thus the fodder for many a science fiction story, but also when the surface of Mars was photographed and



Europa's complicated surface appears to betray the presence of an ocean of water beneath the ice. In this image from the Galileo spacecraft, the ridged plains are likely evidence of cracking and then refreezing of the Jovian moon's icy surface. If there is, indeed, a deep ocean under the ice, do conditions for at least unicellular life obtain on Europa? Image courtesy of NASA.

mapped by spacecraft beginning with Mariner, those stories became more than fantasy. Channels on the surface of Mars seem to give clear evidence that water once flowed there and that the planet was once much warmer than it is now.

The Galileo spacecraft sent to explore Jupiter has rekindled great interest about the possibility of life on its satellite, Europa. A large ocean of liquid water is thought to exist under the moon's icy surface as evidenced by the recently discovered periodic fluctuations of Europa's magnetic field. Regions of "chaotic" terrain may represent periodic episodes of crustal melting, which could allow for the exchange of nutrients and gases necessary for the propagation of simple life forms. There is also evidence that the ice layer covering the ocean may be fairly thin, only one or two kilometers thick. This can be inferred from the cycloidal crack patterns that scientists have determined are caused by Jupiter's intense tidal pull. Microbial life is known to exist in European-type conditions on Earth, and studies of Lake Vostok will enlighten future explorations for life in our solar system. In addition, the Cassini spacecraft is hurtling toward Saturn where in 2004

it will be able to examine the ringed-planet's large moon Titan, long a prime site for scientists' speculation about life.

But we are no longer limited to the nine planets around our Sun for future investigations. In the past few years, about 50 planets (and counting) have been discovered around other stars in our Galaxy. These planets were first discovered by detecting the "wobbling" motion of the central star as it was drawn to and fro by the gravitational pull of the orbiting planet. For this reason, the detection mechanism is biased toward massive planets; so not surprisingly, many planets of roughly Jupiter's mass have been found.

Astrobiologists are spreading their wings and searching in many different modes, for many different possible types of life. One of the most exciting is the Search for Extraterrestrial Intelligence (SETI). Since the early 1960s, American and Russian astronomers have been searching the skies for a signal from another civilization. In 1994, Congress cut the government funding for this research, and a new project, Project Phoenix, rose from the ashes with support from private funding. Currently, Project Phoenix is monitoring Sun-like stars over a range of radio frequencies and looking for a signal that is limited to one very narrow-band frequency. This type of signal would almost certainly have to be sent deliberately as opposed to being caused by a natural phenomenon.

What Does the Public Have to Learn from All This?

The research scientists aren't the only ones getting excited about astrobiology. This new discipline has tremendous potential for revolutionizing science education. It is rich with exciting content to engage those who generally don't consider themselves scientifically oriented, and also for opening the ears and minds of adults who may want a new reason to visit their local science center.

High school courses have traditionally been compartmentalized into biology, chemistry, physical or earth science, and perhaps physics or an elective such as astronomy or oceanography. This may, in the best of cases, prepare students for the "almighty test," but does it really prepare students for scientific literacy and logical decision-making? In many cases, the current educational system is failing to prepare students even for its own tests because students' interest and engagement in science is waning. They see no connection between what is taught in textbooks and what they value in their own lives.

Science in the real world is integrated and problem-based. We need to "hook" students. We need to offer a course so inherently interesting, and, yes, even mysterious, that students will open their minds and let us insert a gentle wedge to begin the learning process. Astrobiology is such a subject, a portal to understanding broad scientific concepts in a context that is

immediately exciting and intriguing for students.

Full-year astrobiology courses in the works include the integrated high school science curriculum "Astrobiology: The Search for Life" being developed by TERC and NASA (astrobio.terc.edu) and another, written around the theme of evolution by the SETI Institute and NASA, "Voyages Through Time" (www.seti-inst.edu/education/vtt-bg.html). In addition, the Center for Educational Technologies at Wheeling Jesuit University, in conjunction with the NASA Classroom of the Future, is producing a software program called "Exoquest" for grades 7-9 that will create a link between students and scientists to pursue investigations in different areas of astrobiology research. A new Ph.D. program has also been created at University of Washington, Seattle, specializing in astrobiology (depts.washington.edu/astrobio).

These are just a few of what will be a wave of exciting educational opportunities. The courses and programs meet the challenge of preparing young people for new types of research, those that require multiple perspectives and integrated problem-solving skills. They are also just in time to prepare the next generation to use the rapidly advancing technology that will allow us to unravel the many puzzles the Universe offers us. It is only a matter of time until one of these well-prepared students discovers the first evidence that we are not alone. ✨

*Jodi Asbell-Clarke is a scientist and senior curriculum developer at TERC.
jodi_asbell-clarke@terc.edu*

*Jeff Lockwood is the director of TERC's Astrobiology Curriculum project.
jeff_lockwood@terc.edu*

The Astrobiology Curriculum project is funded by the National Science Foundation #ESI-9730728.

We are no longer limited to the nine planets around our Sun for future investigations of extraterrestrial life

Construct a

Catapult

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Science by Design

Science by Design, developed by TERC and published by National Science Teachers Association, is a series of four curriculum supplements that presents design challenges to students in grades 9–12. These unit activities offer a hands-on method for students to successfully formulate and carry out product design, applying skills and concepts from science and technology. Each unit introduces the design process and sharpens student abilities to investigate, build, test, and evaluate a familiar product.

The activity presented here is adapted from the Quick-Build Catapult activity in *Construct-A-Catapult*. Students read about the design history of the catapult, from tension bows developed by the ancient Greeks through trebuchets used by European fleets well into the 18th century. Students conduct individual research to discover modern elastic propulsion systems, such as pole vaulting, which are related to catapults. Small groups of students form “product design teams” and engage in an iterative

Quick-Build Catapult

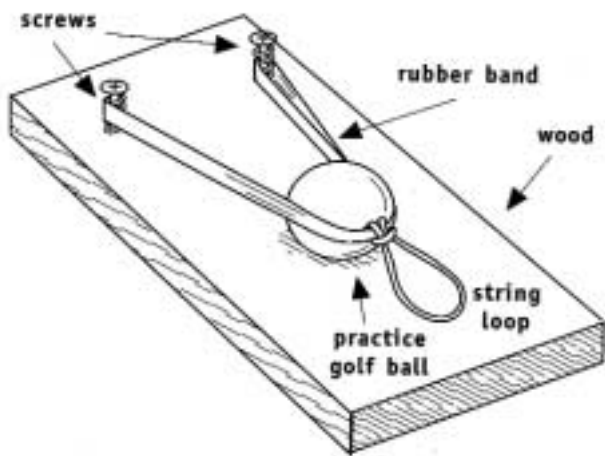
In this activity, students work in teams to construct materials-constrained Quick-Build catapults. The teams use their Quick-Builds to launch uniform projectiles at a pie tin target. They record notes on the adjustments they make to their design and launching process and on the performance they achieve. During homework and class discussion, students identify and organize important variables in the effectiveness of their launching systems. Focusing on variables most critical and controllable for building an accurate and reliable catapult, they begin to plan improvements to their designs.

What’s Next?

Following this activity, product development teams conduct hands-on investigations of elasticity, force, projectile motion, and more. They design and build different components of catapult systems, assemble and rigorously test their new designs, and create user manuals detailing the construction, operating instructions, and science involved in the designs. In the final challenge activity, teams trade catapults and follow each other’s user manuals to evaluate the effectiveness of each catapult and how well the teams communicate about their designs.

The *Science by Design* series also includes *Construct-A-Glove*, *Construct-A-Boat*, and *Construct-A-Greenhouse*. All four supplemental volumes are keyed to the National Science Education Standards, the Benchmarks for Science Literacy, and the International Technology Education Standards.

design process to construct their own catapults—mechanical launching systems that can deliver a small object predictably and repeatedly over a specified range of distance. Students learn and apply the concepts of elasticity, energy, force, and calibration and practice important inquiry science skills such as identifying questions and challenges, conducting experiments, evaluating their own work, and communicating their findings.



- A Quick-Build Catapult

Design Challenge

As a member of a product development team, you are challenged to design, build, and document a mechanical launching system that can deliver a small object predictably and repeatedly over a specified range of distance.

Building

Allow students only one class session to build and test a Quick-Build launcher. This needs to be an active, fast-paced class. Your students will be limited in time and materials to construct their Quick-Build. Remind them that the idea is to build this experimental launcher as quickly as possible and try it out to get a sense for what is important in building future catapults. You can leave the design wide open or suggest a very simple design such as that shown above.

Divide students to work in groups of three or four—refer to these groups as product development teams. Hand out student activity sheets and remind students to keep sheets together with other notes to serve as a record and reference. Remind them to take notes on their building process.

Testing

Once the teams have discussed and constructed their catapults together, direct them to a designated testing area to try launching small projectiles. Each team partner should do some launching and take a turn at observing, making notes, and retrieving projectiles. The goal is to find ways to predict and control where the projectile goes. Have students write down their observations so that they can refer to them later.

Safety Alert: Remind all students to wear safety glasses or goggles, particularly in the launching and landing zones.

Suggestions for Teams During Testing Phase

- ☆ Put the pie tin target somewhere in the launching area and try hitting it repeatedly.
- ☆ Move the target to find a minimum and maximum distance (range) over which you can achieve some measure of control.
- ☆ Use books or boxes to elevate one end of the catapult.
- ☆ Experiment with different ways of hitting the target, such as low and direct vs. a high lob.

Using their trial launch observations, students can begin to identify variables that must be controlled in order to meet the challenge of predictable and repeatable (accurate and reliable) performance. Have each product team discuss:

- ☆ What did they see happening?
- ☆ What did they change?
- ☆ What happened as a function of the change?

Time

2 class periods

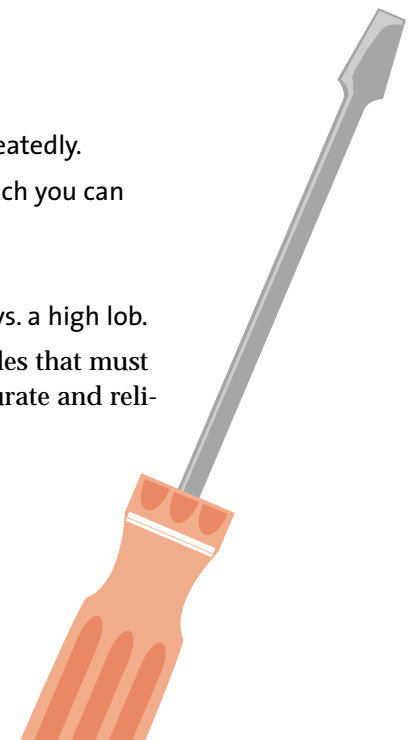
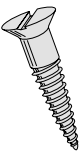
Materials & Tools

For each student:

- ☆ Activity Sheet 1, Identify
- ☆ Activity Sheet 2, Beyond Build

For each team:

- ☆ scrap board or peg board
- ☆ 2–4 screws, nails, or bolts long
- ☆ rubber bands of various
- ☆ short pieces of string or
- ☆ projectiles (small bean cushions, practice golf ball)
- ☆ pie tins
- ☆ awl, punch, nail, or drill pilot hole
- ☆ screwdriver or hammer
- ☆ ruler (mm)
- ☆ pencil
- ☆ safety glasses or goggles



Identifying Variables

Set the stage for design improvement analysis with the Identifying Variables Activity Sheet 1. Students list all the variables they observed as they built and tested their Quick-Builds and specify for each the range of possible variation. On the activity sheet, students are asked to classify the variables in two categories: those that are part of the device itself and those more associated with the user. Some variables you might expect students to identify include:

Parts of the Catapult System

- ☆ Kind of rubber band
- ☆ Tightness of the rubber band
- ☆ Angle at which the catapult is positioned
- ☆ Stability of the catapult's base
- ☆ How far back the rubber band is pulled
- ☆ How far apart the nails are positioned

User Operating Controls

- ☆ How the user handles the projectile
- ☆ How the user positions the rubber band on the nails
- ☆ Where the rubber band is held
- ☆ Consistency of operator stance, steadiness, and concentration
- ☆ Smoothness of release

Activity Sheet 1

Parts of the Catapult System	
VARIABLE	RANGE OF VARIATION
Example: <i>Angle of the catapult</i>	<i>flat, between 0° and 45°, between 45° and 90°</i>
User Operating Procedures	
VARIABLE	RANGE OF VARIATION
Example: <i>How you position the rubber band</i>	<i>high on the nails, in the middle of the nails, low on the nails</i>

Homework

You might have the students complete the Identifying Variables activity sheet for homework. The list of variables they come up with will be part of a class compilation and discussion on the second day of this activity. For additional homework, ask each team to make a rough sketch of its Quick-Build and have students label all the parts.

Planning Modifications

Back in the classroom, compile a list of the variables and ranges of variation students identified in their homework. You may want to make a large chart on the board and jot down students' ideas so that all students have access to the complete list. Use a class discussion to set the stage and level the playing field for their work to improve their designs.

After class discussion, product development teams should complete the Beyond the Quick-Build Activity Sheet 2. Teams discuss and select those variables deemed most critical and controllable for success in meeting the challenge. They record, in words or sketches, their plans to modify or redesign a launcher to address the problems.

Activity Sheet 2

Most Significant Variables	Suggested Variables

See page 2 for a special offer on the Science by Design series.



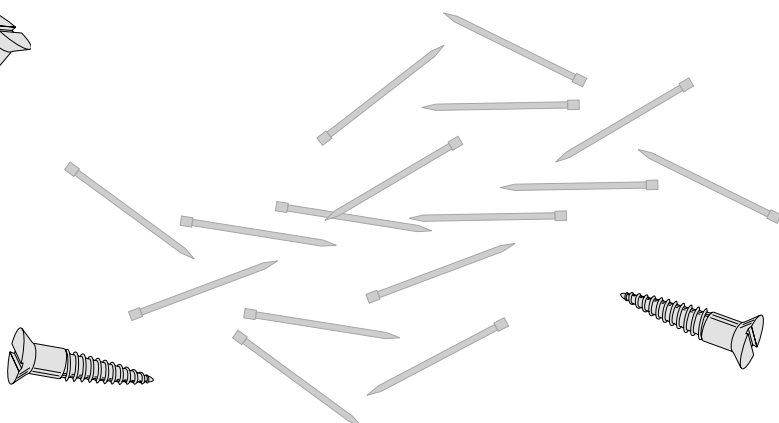
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Assessment + Educate or Audit? |

By June Foster

The challenge

Design and build a scale model of a portable, battery-operated defibrillator, proportionally powered, with proper wiring and working circuits. Justify your choices for every component in the circuit, relating these choices to the function and operation of the model defibrillator, and to the physics concepts involved.

A robust learning experience in high school physics? Assuredly. Motivating to high school students? Yes. An effective means for assessing student understanding of electricity and simple circuits? Indeed.

Building a model defibrillator¹ is the culminating challenge in an extended project that threads throughout “Restoring a Heartbeat,” one of four units developed for the high school physics curriculum, Science that Counts in the Workplace (SCW). The project consists of a series of challenges—“Milestones” in the parlance of SCW. Milestones are actually activities integral to the curriculum. They are not add-ons, projects to be completed after “covering the material.” Rather, these Milestones drive the curriculum. They are learning opportunities that support consolidation and application of conceptual understanding at key junctures throughout the curriculum. Each Milestone progressively builds capacity to undertake the subsequent one and to achieve the culminating Milestone. They are embedded assessments as well, allowing a teacher to evaluate students’ understanding as they build their knowledge.

¹A defibrillator is a device used to correct malfunctioning heart rhythms.

We have developed the embedded assessment system and the curriculum in which it resides in a spirit that reflects the highest hopes of the standards movement. Assessment and learning are fused. The Milestones probe for understanding, problem-solving skills, and application of knowledge in authentic work-related contexts. They are something that students *do*, not something that is done to them. We have designed assessments that, to borrow the words of Grant Wiggins (1998), “educate and improve, not audit.”

The Milestones

In “Restoring a Heartbeat,” students are introduced to electricity and simple direct current circuits, set in the context of work done by hospital clinical engineers and technicians. Throughout the unit, students assume the role of medical equipment technicians undergoing training. They are given the major task of designing and building a prototype of a defibrillator, which provides a need-to-know motivation for delving into physics concepts.

To prepare for their first Milestone, students explore their own ideas about circuits and electricity. Visiting a clinical engineer or biomedical equipment technician at a local hospital, they learn about the function and operation of the defibrillator. They build and diagram different circuits. And they study “The American National Standard for Cardiac Defibrillator Devices.” Students then tackle their first Milestone. They write about the uses, safety features, and main components of the defibrillator and identify the complex systems of its inputs and outputs.

To achieve the second Milestone, students begin to investigate the function of different components in a circuit. For example, to examine the role of the battery, students experiment with electron transfer between metals, build

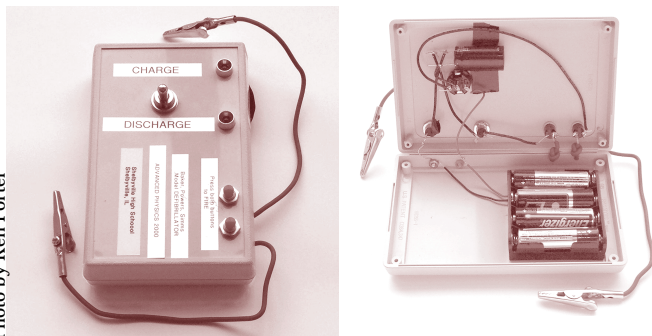
cells with different pairs of metals, and measure how voltage varies with different batteries over time. Milestone Two presents a motivating opportunity for consolidation, application, and assessment. Students establish criteria for choosing the most appropriate battery for their defibrillator model—weighing variables such as voltage, cost, and rate of discharge. They choose a battery and justify their choice.

Students move on to investigate how current varies with changes to voltage or resistance. While looking for patterns in the data, they attempt to form an algebraic equation that represents the relationship between voltage, current, and resistance. This is their introduction to Ohm’s law and a critical step to tackling the third Milestone:

Determine a scale for your defibrillator that is safe to experiment with and determine the associated voltage output. Design a first version of the schematic diagram of your circuit and build a rough model of the circuit. As you’re working, identify questions the answers to which will help you improve your design.

Students then address questions emerging from their first try. They augment their knowledge base—building and experimenting with circuits that use capacitors differently, learning more about how capacitors are charged and discharged in a circuit. In preparation for the final Milestone, students discuss the criteria by which the Milestone will be assessed. Drawing upon their learning throughout the unit, students create a complete circuit diagram, build and test the circuit, justify the choice of each component, and demonstrate their circuit to an audience, explaining why it is an appropriate model for the defibrillator.

The SCW embedded assessments are often complex, calling upon students to structure, integrate, and apply a growing body of conceptual knowledge. The assessments also require a hefty degree of self-management skills. Given such demands, the



Model defibrillator circuitry, designed and built by SCW students.

curriculum provides extensive scaffolding. Teachers can choose to give students “Job Sheets” that provide support as they tackle the assessments: logs for keeping track of work, questions to ponder, and suggestions for reviewing previous work relevant to the new learning taking place.

Support for teachers to use the assessments is provided as well. The Teacher Guides present techniques for readying students for the Milestones, criteria for evaluating student performance on Milestones, and actual samples of student work.

Recognizing the need for multiple forms of evidence when assessing students, all of the SCW units include short answer items. Here students are called upon to solve problems, create and interpret graphical representations, and write about their reasoning. These short answer items allow students to exhibit what they have learned in the context of the workplace problem framing the unit and to demonstrate the transfer of learning to new contexts. The curriculum provides short answer items keyed to each chapter within the unit as well as a pre-unit and post-unit assessment instrument.

Assessment that educates

It is the SCW embedded assessment system, however, that puts the emphasis on learning. The Milestones demand mastery of the concepts through application. Both teachers and students get immediate feedback on what has been learned, what bears revisiting, and what may be a barrier to

developing understanding. Situating the Milestones in a work-related challenge promotes students’ recognition that the physics concepts they are studying have direct applications to relevant problems and to careers. The Mile-

stones seek to draw in students and foster a sense of accomplishment.

Some parents and educators may question how students who engage in such curriculum and assessment will fare on standardized measures of achievement. During the field test of the SCW curriculum, students were given a 20-item equivalency test drawn from the National Assessment of Educational Progress (NAEP). All items were in multiple choice format and are purported by the National Center for Educational Statistics to assess students’ knowledge of important facts and concepts and to probe their analytical reasoning skills. On these items the SCW students in grades 11 and 12 consistently outperformed students in the national NAEP sample.

Nonetheless, the types of assessment and pedagogical approaches embodied in SCW are facing serious challenges across America today. In many states and in many school districts we are seeing the principles of the standards movement being dashed by the aggressive growth of a testing movement where “auditing” predominates. While it is indeed appropriate for parents and citizens to demand accountability from their education systems, many of the tests now being used as instruments of accountability are driving teachers back into a “drill and practice” mentality. If simplistic tests remain the dominant method of determining student achievement, there will be little motivation for teachers to undertake rigorous and authentic educative assessment

approaches such as those in *Science that Counts in the Workplace*. Students may be hard-pressed to recognize the value of their education in the world beyond school. And there may be little motivation for students to engage with the challenges and opportunities of science. ✨

Reference

Wiggins, G. (1998). *Educative assessment: Designing assessments to inform and improve student performance*. San Francisco, CA: Jossey-Bass.

June Foster is Principal Investigator of *Science that Counts in the Workplace*. june_foster@terc.edu

SCW is funded by the National Science Foundation #ESI-9618149.

Science that Counts in the Workplace Curriculum

On the Road Again:
Kinematics/Forces & Motion

Restoring a Heartbeat:
Electricity & Simple Circuits

Building a Better Bike Light:
Generators & Diodes

Hot Sound: Energy

The SCW curriculum was field tested in 14 schools with 475 students.

If you would like to be notified when the units are commercially available, contact Kate Blanchard, kate_blanchard@terc.edu.

Cultivating a Culture of Inquiry (continued from page 1)

level. Despite the specificity of these standards and accompanying recommendations, great latitude exists in how a teacher implements the standards in the classroom.

The PALMS vision, and the state frameworks, fit with the National Research Council's view of teaching and learning, as embodied in the NRC standards for learning and teaching published in 1996, and in *Inquiry and the National Science Education Standards* (NRC 2000), which is the most comprehensive presentation to date of a vision of a standards- and inquiry-based classroom.

In 1998 state educational policy added a new complication for teachers and districts already struggling to reconcile new standards for pedagogy, curriculum, and assessment with the structure and economy of schools. In that year the Massachusetts Comprehensive Assessment System (MCAS) was introduced. This high-stakes test measures content at grades 4, 8, and 10. The eighth grade test covers material on earth science, life science, and physical science. Besides asking students to write clearly on scientific topics, students are expected to retain a wealth of facts that they have learned during the past several years.

The urgent call for rapid improvements in test scores began to affect classroom practice in significant ways. Investigations involving data collection and analysis were squeezed out to make room for more factual material, "fire drill" practices to keep facts current, and testing. Thus, a reform that was never quite clearly articulated to teachers in the first place is now under pressure from a high-stakes exam that seems primarily to mandate a particular scope and sequence of material.

The move towards an inquiry-based classroom is a difficult one; the focus is shifted away from merely "learning about" science to "doing it."

It often entails a change from a frontal teaching approach towards a more student-oriented classroom. Short- and long-term investigations are important contexts for learning, with time set aside for the collection, discussion and analysis of data. Students often work in pairs or teams. Such a classroom requires a teacher who is comfortable with this pedagogy and has the content base to guide student investigations that may go in unanticipated directions. In the six districts we studied, teachers spoke of how these challenges were exacerbated or ameliorated by school or system-wide structures, and by other competing or complementary reforms.

Allenville had established structures that supported teachers in changing the pedagogy, content, and assessment to meet the challenges of inquiry-based science reform. We observed that students were more likely to participate in hands-on activities, to revisit their work, to work in pairs or small groups, and to share strategies. Students were more likely to collect and discuss data. Teachers were less likely to give content lectures, to offer demonstrations, and to have students take notes either on the text or on their lecture.

In what follows, we describe 10 features of Allenville's practice that contribute to a culture of inquiry. It is not our intent to suggest that all of the following must be present to develop such a culture, or that this school had the perfect "recipe" for inquiry in the classroom. Even in Allenville, teachers struggled to varying degrees with implementing the reform. Yet despite the challenges, the discourse in Allenville was about how and to what extent to implement inquiry rather than on whether to implement it. The district had built a coherent foundation which included pedagogy, curriculum, and assessment, and was now positioned to speak about places where they could improve and balance their program, building on that foundation.

District practices that enable a culture of inquiry

1. District leadership has a clear, expressed, vision

We have found that "inquiry-based science" is often poorly defined, resulting in a lack of clarity of what a good science classroom should look like. In fact, in some schools the words "inquiry-based science" have been used to foster separate agendas such as incorporating technology or changing the scope and sequence of the curriculum. In contrast, Allenville had a clearly articulated, shared vision of what inquiry-based science means. Even the few teachers who were resistant to an inquiry-based science approach knew the prevailing viewpoint.

In Allenville, from the superintendent through the building leadership, to the individual teachers, there was no ambiguity about the district's goals for the science classroom. The superintendent had made the implementation of inquiry-based science a consistent goal. He maintained a strong focus on student-centered, question-centered pedagogy. It was expected that this pedagogical stance would permeate the curriculum as well as assessment practices. The superintendent articulated his vision:

It's a classroom where kids are doing real science, and that is, they're investigating in a hands-on way. They're working collaboratively with other students. It's interdisciplinary in that they're using their math, they're using their writing skills, they're using reflection. The teacher is not up there lecturing, but the teacher has presented things for kids to investigate, and things that have a connection to their lives now, and future lives. And kids see a reason for doing it. They're interested in doing it. And we have plenty of supplies. And the teachers know the process, so they're not interfering with kids and giving kids answers too soon or ever...Kids are investigating and trying to solve a problem that either they have posed, or teachers

pose for them. And, they're using the scientific method to come to some kind of theory that they can then prove through inquiry.

Because of this long-standing, consistent vision at the district level, hiring practices over the last several years have favored teachers who share this vision to some degree. In describing hiring practices the superintendent said:

The priorities for me, and I think for a lot of the other people who do the hiring and recommending, is pedagogy first with some content strength, at least in one area.

Once hired, teachers can attend workshops that provide opportunities to address pedagogical as well as content concerns related to inquiry-based science. Beyond the implications for hiring and professional development, the commitment to inquiry in this district even affected design plans for a new school building. Further, this view of science pedagogy was seen as being supported by, and supportive of, consonant practices in other disciplines. Such a foundation enhances the climate for an integrated, inquiry approach across the curriculum.

2. Persistence of pedagogical vision in the face of high-stakes tests

A vision for inquiry can be derailed by competing pressures and concerns. Not infrequently, parents and school committee members question whether a shift away from the lecture, teacher-centered classroom will result in less content being covered. State testing that anticipates broad coverage of material has intensified these concerns.

In some districts the introduction of the state exam has had the effect of putting "inquiry on hold." Teachers dissect the last year's test, hoping to anticipate the topic areas to be emphasized in the coming year's exam. In these schools, teachers add bits of curriculum and drop favorite units to

prepare students for subject matter that may be tested by the MCAS.

By contrast, Allenville has maintained its vision, despite the pressures of the high-stakes exam. In this pressured environment of "accountability," the superintendent's views reflect Allenville's tenacity in holding to their vision.

With the MCAS, there's the content pressure...and I think a lot of people figure, 'If I cover all this stuff...the kids are going to do better on this test.' And I think, maybe the answer is not to have a whole widespread coverage of content, but to do some things well. To look in the frameworks for the important area and do those well. And then enough of the other stuff will probably come into it, because if a kid is really focused and interested in something, he's going to get into some of these areas, because he's going to need that information. And things connect.

[In Allenville] often our open-ended questions are much higher than the state average, and yet some of our content stuff in math and science, spelling, is lower by comparison. And the school committee says well, how can they do complex things if they can't do the basics? And it's hard to explain that. But, it's because they've had more experience doing complex things, and it's going to take them awhile, but those basic skills, if they're using them in the context of solving real problems, eventually they're going to get better at them.

3. Effective curriculum coordinator who carries the vision to the individual schools

Even when school districts have a clear vision statement on paper, teachers are often left on their own if there are no policies, curriculum, or support systems to enable implementation. Teachers in some districts are borrowing and piecing together

inquiry-based lessons from the Internet or from a friend's classroom. The lesson is often unsupported by their pedagogy or assessment strategies, which are still drawn largely from a traditional textbook. In such cases inquiry-based science becomes a sporadic treat thrown into a traditional curriculum.

In Allenville, the superintendent and other district personnel sought ways to align the curriculum and assessment practices with their pedagogical vision. A district curriculum coordinator was charged with the task of alignment, and she led a district-wide effort to create a district curriculum for each grade and to identify and critique materials that support this sequence. This resulted in the creation of three units per grade that have both short and long investiga-

In some districts the state exam has had the effect of putting inquiry "on hold."



tions, accompanying materials, and performance assessments.

In every school, teachers struggle between the desire to create their own curriculum and agenda and the realization that there is not enough time to do so. In Allenville, teachers have received the curriculum with varying degrees of enthusiasm. In many cases the teachers have used the curriculum but adapted it to fit with their own style and approach.

A teacher commented:

We've pretty much been told that we can't throw it out, so that's not an option, which is fine because there are a lot of good quality activities in there. My approach is look at each component and see how relevant it is to my students and

to what I want to do...A couple of the kits I followed pretty much to the letter because I liked what they did. And within that too, even if I am following it, there are times when I'll pull out and do something more or change things around depending on my students.

Some teachers thought that the students often lacked background knowledge assumed by the curriculum kits and investigations being used. One teacher felt that the kits did not contain enough background material and required teachers to fill in the gaps.

We had a parallax activity. Great activity, you make the little instruments, find a parallax...They didn't know what parallax was. I could have done the activity with them, and they still would have said "What?" It wouldn't have made sense. So I gave them background information on it first, we talked about parallax, how they used it in ancient times and all this stuff, and we did the activity, and I just think they walked away with a much clearer knowledge.

Yet despite some teachers' concerns that the curriculum is not perfect, it is a place of departure. It provides a common forum for teachers to talk across grades about curriculum. The curriculum supports teachers who formerly had to transform their classroom towards inquiry with little more than a traditional textbook.

4. Availability of materials, kits, resources, and space

The materials, resources, and space to make the curriculum work are as important as curriculum itself. Some teachers run weekly scavenger hunts to collect materials or make trips to central resource rooms to browse and borrow. In Allenville, kits designed to accompany each unit include print materials, activity guides, manipulables, and teacher background information. The three units are done in rotation in each grade, so when one teacher finishes with a kit, it is passed on to the next

class. The disadvantage of this system is that teachers often do not have lead time to "play with" the materials and resources before starting a unit. This is, of course, a greater obstacle during the first few years of implementation.

5. Teacher-teacher support is established to increase ownership of materials and to share concerns, strategies, and tips concerning implementation

In all the schools that we visited, teachers spoke of insufficient time to speak to their colleagues about the curriculum. This problem is accentuated now that many middle schools have abandoned science departments completely in favor of interdisciplinary teams of teachers. While there are many benefits to this approach, it limits opportunities for science teachers to consult with each other while adopting a new curriculum.

Allenville has implemented district-wide "articulation meetings," in which teachers can discuss the units that they have just finished and share tips and strategies. While some teachers mentioned that these meetings were not well attended, at least the district has built a structure and allocated time for this type of discourse.

6. Creating a culture of trust between teacher and students

Inquiry-based science involves a restructuring of the classroom, which may entail students working collaboratively, students investigating a research question in a small group, and students working beyond the walls of the classroom. This requires a trust between teacher and student that needs to be cultivated over time. Teachers must feel comfortable that groups of students will indeed work on their project rather than just socialize, and students need to feel high teacher expectations for what independent or group work entails.

Allenville has succeeded in building a culture of inquiry. We observed one class where groups of students went unescorted to the stream several hundred feet from the building to collect samples and return. This scene contrasts with districts where teachers will never let students out of their sight. The assistant principal explained that a culture of independent and group research is fostered throughout the building. The school-wide practice of looping (where teachers have the same students for two consecutive years) contributes to this culture of trust.

In the two-year assignments...you have an opportunity to develop certain skills, and a certain set of expectations, with the group of students that you're working with. [The students conducting research at the stream] have spent a year and a half working with and setting expectations, where they build within that two-year cycle, opportunities to go out and do research, and they develop a trust. Now this was a prime example of where you want to get kids to.

7. Heterogeneous grouping

Heterogeneous grouping at the middle school level was widely adopted in all schools that we visited. This reform was problematic in districts that had either not adopted a pedagogical shift toward inquiry, or that had retreated from inquiry in favor of stressing coverage for the state exam. In such schools teachers felt that heterogeneous grouping slowed the pace and often forced them to "teach to the middle." In Allenville, most teachers had shifted their classrooms away from a frontal, lecture style. They felt that a varied mix of abilities and strengths helped in cooperative groups, with some students being more abstract, others being more facile in art, writing, or manipulation and understanding of materials.

The kinds of things that we do are more open ended. It allows kids to go to their own levels...If someone is done,

understands the concept, there's always something else for them to move on to. It's not like they have to sit there and wait till everybody gets it.

8. Flexible scheduling

In addition to looping, flexible scheduling in Allenville fosters inquiry-based science. One of the greatest obstacles to implementing inquiry is making the time for investigations, data collection, and analysis within rigid 45-minute schedules. Allenville has implemented flexible scheduling where small teams of teachers determine how the day will be structured. The teachers in Allenville expressed how important this has been as they implement a vision of inquiry-based science.

It allows me to do a lot more with the science because I'm able to have the kids more spread out, have them working on different things...It gives me longer blocks of time for each day. We usually go between an hour and an hour-and-a-half a day. Whereas if I didn't have the support of my teammates it would be a 45-minute block every day and having to set things up, take things down and start for the next group. So this way I can do it with all of my kids and spend longer periods of time. And my teammates are very supportive in terms of if I need a little more time to finish.

9. Small interdisciplinary teams

Every district that we visited has implemented cross-discipline teacher teams, most often composed of four to five staff members. Even in the districts which support flexible scheduling, it is logistically difficult to arrange a change of schedule involving four teachers.

By contrast, Allenville has moved towards two- to three-person teams.

Often one teacher will teach two subject areas. These smaller teams make flexible scheduling a reality. One teacher explained:

Being only the two of us, it's very flexible. We don't have to switch groups at certain times, we can do a whole day activity, which we've done before.

10. Valuing problem-solving and investigative skills within the system

It is too often the case that educators speak of valuing inquiry, but assess students using multiple-choice exams. Students are often promoted and placed in high school honor classes because of test performance rather than because they have developed a sophisticated ability to conduct science investigations, to collect and analyze data, and to relay their experiences to others. The superintendent of Allenville stressed that students and teachers know that inquiry-based science counts from elementary school all the way through high school:

We expect kids to have this curiosity about science, an understanding of problem solving approaches and how to go about getting answers. So, when [the high school science department head] has testing for honors courses and so on it's not about content, it's about these processes that kids should have. It's more general.

Summary

It could be said that Allenville is dealing with *how*, not *whether*, to implement inquiry. The concerns voiced—how much, to what degree should it be student centered, how to do it under the pressures for coverage and the limits of time—all are mentioned in the context of a general approach that is accepted, but needs some fine-tuning. Perhaps the most

urgent concern is how to balance science rigor and factual information while preserving student exploration and ownership of questions.

The formulation of inquiry-based science will continue to evolve in national and state policy frameworks and documents. Its implementation will ultimately depend on the interplay between teachers' interpretations of inquiry and coherent visions of reform articulated at the school and district level. Allenville provides evidence that a strong, pedagogical vision elaborated through the creation of coordinated materials, opportunities for teacher-teacher communication, and the careful alignment of reforms such as teaming, looping and heterogeneous grouping, support teachers as they refine their understanding of inquiry-based science. ✨

Reference

National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. Washington, DC: National Academy Press.

Brian Drayton and Joni Falk are Principal Investigators for The Inquiry-Based Classroom in Context project.
brian_drayton@terc.edu,
joni_falk@terc.edu

The authors acknowledge the contributions of the project team: Brian Conroy, Craig Altobell, and Liza Applebee.

The Inquiry-Based Classroom in Context is funded by the National Science Foundation # REC-9804929.

NEW Projects

Accessible Mathematics

This project aims to explore ways that students with disabilities can improve their mathematical learning. TERC researchers will work with an action research group of mainstream classroom teachers and special education teachers to examine how these students learn mathematics best and what is needed to develop their mathematical thinking. Successful strategies will be documented and disseminated widely to other practitioners. Funded by the National Science Foundation.

Building Literate Networks for Haitian Students

The Chèche Konnen Center and the Bilingual Literacy Program of the Boston Public Schools will use science and math to improve learning for Haitian literacy students—immigrants older than ten who have had little or no previous schooling. TERC will offer professional development activities for bilingual and ESL literacy teachers and coordinate a network of teachers and students. Through this effort, teachers exchange and enhance each other's resources, as students build literacy skills through written communication while learning math and science. Funded by the Boston Annenberg Challenge Fund.

Council of Chief State School Officers (CCSSO) Study of Data

CCSSO is conducting a longitudinal study of the effects of using enacted curriculum data to improve curriculum and teaching. CCSSO will survey teachers in 20 randomly selected schools. After the survey, schools will receive feedback on analyzing and using data to examine their practices. TERC will

provide technical assistance and professional development on using data to improve curriculum and teaching. A follow-up survey will investigate change. Funded by CCSSO through a grant from the National Science Foundation.

Earth System Scientist Network for Student and Scientist Partnerships

TERC is creating an Earth System Scientist Network to promote the development of student and scientist partnerships. TERC works with scientists to define research projects for student participation, determines the students' role, and maps out the scientific protocols, background, and support materials that facilitate students' successful participation. With scientists, TERC is also identifying issues in Earth system science relevant to the scientists' data which students and teachers can use to help develop investigative skills and content knowledge in the geosciences. The program will be available to teachers through the Digital Library for Earth System Education. Funded by the National Science Foundation.

Eisenhower Regional Alliance for Mathematics and Science Education

The Regional Alliance is one of 10 members of the national network of Eisenhower Mathematics and Science Consortia working to improve K–12 mathematics and science education. Serving the northeast and islands region (New England, New York, Puerto Rico, and the U. S. Virgin Islands) the Regional Alliance provides professional development opportunities and technical assistance, disseminates information, and promotes collaboration. Through initiatives focused on curriculum implementation, leadership development,

and equity, the Alliance seeks to increase the use of instructional materials, teaching practices, and assessment tools that are aligned with state and national standards. To ensure that efforts reach those with the greatest need, the Alliance has also created a program to provide intensive assistance to a group of schools that have high concentrations of underrepresented and underserved students. At TERC since 1995, the Regional Alliance continues to leverage the structures it has created to inform and assist educators in the region with the new award from the U.S. Department of Education.

Extending Mathematical Power

EMPower is developing curriculum materials for out-of-school youth and adult learners of mathematics enrolled in pre-GED, GED/high school equivalency, and transitional courses to college. The curriculum units will be adapted from three standards-based math curricula: *Investigations in Number Data and Space*, *Connected Mathematics*, and *Interactive Mathematics Program*. EMPower seeks to extend school mathematics reform to underserved populations and their teachers so that they may more effectively engage with the mathematical demands of American society—whether that be at work, at home, in the community, or in further education. A collaborative group of teachers and researchers will disseminate the curriculum nationally and provide professional development for teachers. Funded by the National Science Foundation.

Extending GLOBE Community in Massachusetts

TERC supports school-wide implementation of the Global Learning and Observations to Benefit the Environment (GLOBE) program in central Massachusetts. Through this grant TERC continues to support four schools in their efforts to implement GLOBE, while

arranging for three additional schools to join the program. TERC is also launching a planning process with the Ecotarium to establish a GLOBE Program Center in central Massachusetts. TERC staff members are helping each school integrate GLOBE activities into their curriculum through school-wide planning, cross-school conversations, technology support, and access to external expertise and resources. TERC shares information and insights gained about implementing GLOBE locally with the national program. Funded by the Intel Foundation.

Hamilton, Tennessee, Urban Systemic Initiative

TERC is the evaluator for this Urban Systemic Initiative project to improve student achievement in math and science in Chattanooga, Tennessee, and the surrounding metropolitan area. The Hamilton County Department of Education is developing a cadre of math and science lead teachers and, through these teachers, creating professional development activities in support of good math and science teaching practices. The Department not only offers professional development assistance to classroom teachers, but also to a variety of stakeholders, including guidance counselors, administrators, and community members. Funded by the Hamilton County (TN) Department of Education through a grant from the National Science Foundation.

Math in Motion

This project is investigating new approaches to cultivate the mathematical imagination of all students by exploring the relationship between formal mathematics and body action. Researchers will conduct a series of studies with high school students and pre-service teachers that involve three content areas: trajectories in space and over time; force and acceleration; and motion in 3D space and planar projections. The

project is a collaboration between TERC and a research team at the University of Massachusetts-Dartmouth. Funded by the National Science Foundation.

NEIRTEC

The Northeast and the Islands Regional Technology in Education Consortium (NEIRTEC) helps educational leaders at the state, district, and school levels address the challenges involved in putting technology to effective use, particularly in schools in underserved urban and rural communities. NEIRTEC offers educational leaders a mix of face-to-face institutes and online “any time, any place” professional development workshops. Online resources include interactive guides to planning and evaluation, online communities of learners, and analyses of critical issues. NEIRTEC works directly with state and local education authorities to provide technical assistance that addresses the specific needs of underserved communities. TERC is one of four partners in NEIRTEC. Funded by the Education Development Center through a grant from the U.S. Department of Education.

Preliminary Exploration of Tomographic Microscopy

In collaboration with the Radiology Department at the Boston Medical Center, this project is developing a prototype for a new microscope based on MRI technology but using visible light. The microscope reconstructs 3D images on a computer screen out of plane projections of a semi-transparent sample, such as an insect or tissue. The sample is rotated and by processing the projections the software enables the user to “navigate” the object in space. Science teachers at the City on a Hill Public Charter School in Boston will participate by conducting classroom activities and involving students in the development and assessment of a new scientific instrument. Funded by the National Science Foundation.

Polar Studies

TERC is applying the lessons learned from the Leveraging Learning project to develop a Polar Studies module for grades 6–8. The instructional materials take advantage of information from the National Science Foundation’s Office of Polar Programs (OPP) to explore topics focusing on standards-based science content and process. The work involves: 1) identifying a central question that lends itself to a hands-on component, online research, and the analysis of student-generated and scientific data; 2) creating a set of teaching and learning activities, which contain assessment opportunities, for implementation in multiple settings; and 3) building a web site for the module. Funded by the National Science Foundation.

Online Science-athon

The Online Science-athon is a series of challenges that are designed to be engaging and fun, easy for teachers to integrate into their teaching, and instructive. As they evolve, some challenges will be seasonal, others keyed to events such as Earth Day, and some will be generic in nature. Yet common to all of them is that they will be delivered from the Science-athon web site and result in data that are posted and displayed as tables, maps, and graphs. The Online Science-athon is sponsored by TERC’s Cluster for Learning, Teaching, and School Partnerships.

Statewide Systemic Initiatives (SSI) Implementation & Dissemination

With coordination from the Regional Alliance at TERC, eight State Systemic Initiatives (SSI’s) seek to demonstrate the effectiveness of a systemic support network. The SSI’s in Connecticut, Louisiana, Massachusetts, New Jersey, Puerto Rico, South Carolina, Texas, and Vermont are forming a Systemic Practices Resource Network to increase the effectiveness and efficiency of existing

and newly funded programs. The Regional Alliance will also bring together the SSI States to develop a Protocol Rating for Systemic Reforms. This unified model will allow all NSF-supported Systemic Initiatives to measure their success and show their role in improving student performance. The States plan to network with other systemic initiatives and develop a set of common system and student performance indicators for school and district decisionmakers. Funded by the National Science Foundation.

A Study of Place

TERC is developing instructional materials to bridge Earth and physical science with social studies for middle grades students. The modules (polar exploration and ocean exploration) connect hands-on classroom activities and satellite images, advanced geographic visualizations, and maps via the Web. Using these materials, students grasp the inter-relationships among land, oceans, and atmosphere and develop an understanding of the inter-connectedness of our world. This project offers a unique learning opportunity for students who have diverse types of cognitive strengths, such as visual-spatial skills, which are rarely tapped in traditional curricula. Funded by the National Science Foundation.

Supporting and Understanding Sustainability in Local Systemic Change

This project is building on and complementing TERC's LSC-Net which connects 70 Local Systemic Change projects in an interactive, electronic community of practice. The grant enables TERC to continue to provide support and participation to projects after their funding ends, and to conduct collaborative research on what "sustainability" means for LSC projects working within a larger systemic context. TERC will study

factors that promote and inhibit sustainability, and what elements of projects are most likely to be sustained. In addition, the grant includes funds to develop new technology for web-based interactive communities and a "virtual poster conference hall" as part of a virtual conference on issues related to sustainability. Funded by the National Science Foundation.

Technology Leadership Consortium

Massachusetts Technology Leadership Consortium is initiating a comprehensive professional development program for Massachusetts school leaders. These leaders include district superintendents, public and charter school principals, independent school heads, and heads of parochial and other religiously affiliated schools. This program will help participants increase their abilities to lead systemic educational improvement efforts that include high standards for all students, data-driven decision-making, multiple forms of assessment, and effective uses of technology. TERC is assisting in planning and staffing the core institutes and also will evaluate the project. Funded by the Massachusetts Elementary School Principals Association through a grant from the Bill and Melinda Gates Foundation.

Toward the Development of Practitioner Research

The Chèche Konnen Center convened a conference for practitioner-researchers, December 1–2, 2000. This conference focused on the ways teachers understand and use their students' ideas in science and mathematics, especially those ideas they find confusing or puzzling. Approximately thirty practitioner-researchers and ten classroom researchers from around the country participated. Practitioner-researchers discussed their current research, the value they see in conducting research for themselves and

their students, and ways they can share what they are learning with others. Funded by the Spencer Foundation.

Triana Education Outreach

TERC is developing materials for the Educational Outreach Program that accompanies the Triana mission. The Triana spacecraft will orbit between Earth and the Sun, providing continuous views of the entire sunlit side of Earth. The data collected will help scientists understand and model Earth's climate and answer key Earth Science questions. The same data will be available to schools for student investigations of Earth. Funded by the Scripps Institution of Oceanography at the University of California, San Diego, through a grant from NASA.



Exploring Earth from Space Lithograph Set and Instructional Materials has been recommended for Broad Distribution by the 2000 NASA Earth Science Enterprise (ESE) Education Products Review! The lithographs showcase color images of Earth taken from the Space Shuttle by astronauts and by middle school students participating in NASA EarthKAM, a collaborative project in which TERC is involved.

Reviewers commented, "This is an excellent educational resource.... The teacher's manual allows for easy integration into labs, while the map and explanations...provide information that is easy to understand." The set is available free of charge from the NASA EarthKAM web site, www.earthkamucsd.edu.

Resources by TERC

VideoPaper Builder

NEW Created by the Bridging Research and Practice project, VideoPaper Builder, version 1.0 beta, is a software environment designed to quickly and easily create videopapers—multimedia documents that link and synchronize video, text, and slides. It has been designed for users without technical expertise.

With funding from the National Science Foundation, the project is investigating ways to use digital video technologies to increase collaboration

between researchers and practitioners. Videopaper technology creates an alternative genre for the production, use, and dissemination of educational research. Videotaped episodes can not only be displayed but also synchronized with interpretations, transcriptions, closed captions, images of student work, clarifying diagrams, and other information that expand the events, thus portraying their full complexity. Teachers, researchers, and other educational communities can use videopapers to make their conversations grounded in actual

events, more insightful, and more resistant to oversimplifications. Contact BRP@terc.edu or visit www.terc.edu/mathofchange/BRP/VPB.html.

Astrobiology Institute Educator Resource Guide

NEW In affiliation with NASA's Astrobiology Institute, TERC developed the Astrobiology Institute Educator Resource Guide, a series of five hands-on activities to introduce core ideas in astrobiology. Students (grades 5–10) examine five key questions: What is life? What does life need to live? What makes a world habitable? What can life tolerate? Is there life on other worlds? The guide is available from the Institute's web site, nai.arc.nasa.gov/teachers.cfm.

For more Resources see page 2.

For complete updated information about **Resources by TERC**, use the form below to order your copy of the **By TERC** catalog or visit our web site, www.terc.edu.

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Leveraging Learning

Teachers are needed for the pre-publication test run of Are We Getting Enough Oxygen? (circulatory and respiratory systems, for grades 6–8) and Weather in Action (grades 3–5). Each unit requires 6–8 weeks of class time and can be done at any time between January and June, 2001. Students conduct hands-on/minds-on experiments, exchange data and letters with other students, and conduct web-based activities that use reading, writing, and communicating to gain in-depth understanding of the science in the unit. Contact judy_vesel@terc.edu.

Online Science-athon

Teachers needed for Online Science-athon activities. Designed to be engaging and fun, easy to integrate into teaching, and instructive, the challenges include: The Marble Roll (force and motion), How Tall Am I? (heredity), and Catching Sunshine (solar energy). Each challenge takes 10–12 hours of class time; involves data collection, sharing, display, and analysis; and can be done in grades 2–8. Contact judy_vesel@terc.edu.

NSIP

NASA Student Involvement Program's five national competitions reward student research on NASA's mission of exploration and discovery, and support national education standards. Each competition features Educator's Resource Guides, including assessment rubrics designed to help teachers and students as they conduct research and prepare projects for submission. If students have been working on research projects, they have probably met most entry requirements: check competition entry guidelines at education.nasa.gov/nsip (Submission deadline: Feb. 1, 2001).

EarthKAM

NASA EarthKAM education program enables students, teachers, and the public to learn about Earth from the unique perspective of space. At the core of the program is a spectacular (and growing) collection of remotely sensed images of Earth. The images were (and continue to be) taken by middle school students involved in EarthKAM! Everyone is invited to access these images and the exploration resources available at

the EarthKAM web site: www.earthkam.ucsd.edu. Middle school (grades 5–8) educators are invited to join the EarthKAM Community.

Hands-On Universe (HOU)

HOU seeks teachers to participate in a study of the effectiveness of professional development strategies used to support the implementation of the HOU program. During the research study, teachers will be giving their high school students access to the same tools that professional astronomers use: image processing software and images from large observatory telescopes. Students learn science, mathematics, and technology in the context of astronomical explorations. A stipend and academic credits are available. Contact mihorahm@uclink4.berkeley.edu or visit hou.lbl.gov.

Investigations

Education Research Collaborative at TERC offers three types of intensive professional development opportunities across the country for elementary school teachers, math specialists, and administrators implementing the *Investigations in Number, Data, and Space* curriculum. For details, visit projects.terc.edu/investigations-workshops, or call Peter Swanson at TERC.



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