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Hands On!

Muscles, Lungs, Blood, and Guts

BY GILLY PUTTICK AND
JUDY STOREYGARD



Week after week, afterschool centers are filled with cries of “There’s the pulmonary artery!” and “I found the gills!” As curriculum developers, we are thrilled by the level of enthusiasm for science learning. These young people are learning to create and conduct their own investigations, and they are thinking and acting like scientists. (CONTINUED ON PAGE 4)

TERC Board Names Frank E. Davis President



“TERC embraces a mission that has been at the center of my professional life.”

— FRANK DAVIS

**Noted Educator and Social Change Advocate
Will Extend the Organization’s Impact in Research,
Classroom Practice, and Public Policy**

Frank E. Davis began his tenure at TERC on February 20, 2007.

On his appointment, Dr. Penny Noyce, trustee and chair of the search committee, said, “We are very fortunate to have Frank join TERC. This is a critical time in education. We wanted a leader who could broaden the organization’s impact. Frank is a scholar, skilled administrator, and gifted teacher, and well grounded in the realities of today’s classroom. He has a real commitment to creating better educational opportunities for the students who need it most and all the qualities to successfully lead TERC into its fifth decade.”

“It is an honor to be chosen to head what I consider a premier R&D education organization,” says Davis. “TERC embraces a mission that has been at the center of my professional life—providing greater access to all, regardless of race, gender, class or age, to the thrill and joy of understanding and doing mathematics and science.”

Davis comes to TERC from Lesley University where he led the Doctoral Program in Education Studies. He has an ongoing relationship with the Algebra Project, leading research and evaluation efforts supported by the National Science Foundation and several well-known philanthropies, including the Boston, GE, Lilly, Soros and MacArthur foundations.

Prior to his appointment at Lesley, Davis was a professor at the University of Massachusetts where he helped develop a mathematics program for adult learners interested in careers in public service. Before that, he was the mathematics curriculum coordinator for a Boston Model Cities project designed to ensure that post-secondary students could make a successful transition into undergraduate programs. Davis holds a doctorate from Harvard University Graduate School of Education and a master’s in physics from the University of Massachusetts, Amherst.

The TERC community welcomes Dr. Davis and his leadership as the organization builds on its tradition of innovation in mathematics and science education.

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THIS IS AN EXCITING TIME in TERC's history. As the organization enters its fifth decade, we welcome a new president with a proven commitment to creating educational opportunities for the students who need it most. We continue to expand our initiatives beyond the classroom by reaching new audiences through online explorations, afterschool programming, and materials for learning at home.

This issue of *Hands On!* features some of these initiatives. The Muscles, Lungs, Blood, and Guts afterschool curriculum, developed by TERC for United Way, is engendering an excitement in science for hundreds of middle school students (cover). Through a group of projects, TERC is collaborating with several afterschool agencies, public libraries, and businesses to make math learning a part of everyday life (page 10). The Earth Exploration Toolkit (page 18) is helping teachers make use of real-life scientific data available online.

As a research and development organization, TERC examines how educational innovations and strategies are implemented in real classrooms. In "What's the Problem?" (page 14), Brian Drayton describes ways that teachers can create true insight in the science classroom. Indeed, TERC continually seeks to bring about deep understanding through quality inquiry.

Zoe Keller,
Editor

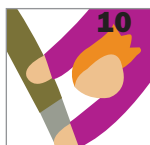
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Muscles, Lungs, Blood, and Guts

By Gilly Puttick and Judy Storeygard

The challenges and rewards of designing a science curriculum for afterschool settings



Math in the Moment

By Marlene Kliman

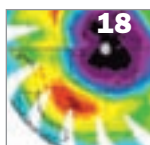
TERC initiatives are making math a part of everyday life



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Muscles, Lungs, Blood, and Guts

BY GILLY PUTTICK AND JUDY STOREYGARD

In the fall of 2004, United Way engaged TERC to develop a curriculum for their “Math, Science, and Technology initiative” (MSTi). The program kicked off when 50 students at three agencies signed up for the *Muscles, Lungs, Blood, and Guts* curriculum. By the next fall, the program had grown to include close to 300 middle school students. Gaining comfort and experience teaching hands-on science, the afterschool staff are helping students see how science is a part of their life and their future.

Beyond the Classroom

Developing an afterschool curriculum poses a unique set of challenges and rewards. As curriculum developers, we keep in mind that our science and math activities are competing with homework, tutoring, and sports. Not surprisingly, the most successful units include hands-on activities.

The program takes kids beyond the walls of the center and introduces them to careers in science through visits to museums and biotech labs, and meetings with science professionals in the community. In developing the curriculum, we wanted students to understand how science is done and to engage them in scientific processes. We designed activities that allow them to create their own hypotheses and investigations, so they begin thinking and acting like scientists.

“Opening hearts and minds to science at a young age makes it more likely that they will continue their learning in the field. We are excited by this partnership with TERC, and we look forward to continuing and expanding this effort. Most of all, we hope to see these young people graduate from college with a science-related degree in hand.”

— CHRIS O’KEEFE, VICE PRESIDENT FOR COMMUNITY IMPACT AT UNITED WAY



{musculoskeletal}

Did you know it takes at least 35 arm muscles to make a fist?

In *Muscles, Lungs, Blood, and Guts*, students explore the four systems of the human body: the musculoskeletal, respiratory, circulatory, and digestive systems. This approach complements several existing programs that focus on health, fitness, and nutrition. The students begin each investigation by discussing what they already know. Using their own physiology gives students the chance to connect the material to their everyday experiences and to hypothesize. They take these brainstorming sessions very seriously. When asked, What do muscles do?, some answer in the form of a metaphor: “Muscles move your hand and your arms. Without muscles we are like sponges.” Others relate to their experiences: “Muscles help your joints move. They grow as you exercise. They help you to frown or smile.” These discussions are a jumping-off point for students’ questions and predictions. Later, they engage in investigations and record their data, and finally share their findings through a group discussion.

Showing What They’ve Learned

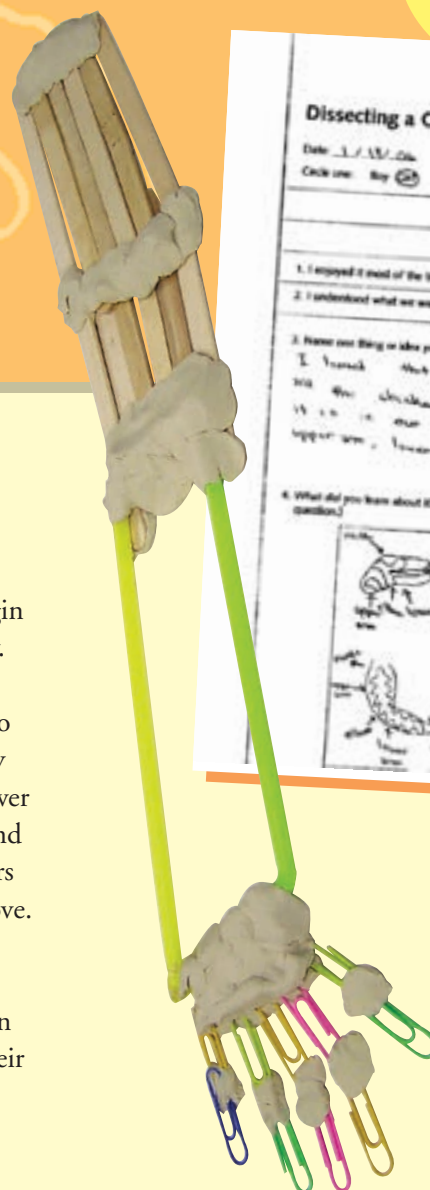
The first activity in the Muscles unit asks students to build a model of the arm from their prior knowledge. This introduces a 10-week unit exploring the structure and function of the arm’s musculoskeletal system.

One of the ways students learn about the arm is by dissecting chicken wings, observing tendons and ligaments. One student reported, “Dissecting the chicken wings was great! We saw the relationship to our own arm.” They discover, for example, that contracting the muscles in the upper arm (simulated by tugging on the biceps) moves the lower arm and hand. They are astonished to find that 35 muscles are

used in gripping, and that those muscles are located not in the hand, but in the forearm (Figure 1).

At the end of the unit, the students repeat the initial model-building activity, pulling together everything they’ve learned through web-based activities, dissections, discussions, and field trips. Using popsicle sticks for fingers, balloons for muscles, and fuzzy pipe cleaners for tendons, students fashion radius and ulna, biceps and triceps.

(photo at left) Students use adapted turkey baster “pumps” to model the action of the heart’s valves.



Students build model arms from popsicle sticks, pipe cleaners, and paper clips.

Figure 1

The staff have noticed that the activity takes much longer the second time because the students want to include so much detail. One staffer pointed to students' models, saying "I'm really surprised to see the difference. They really have the structure and function. Their models show what they've learned."

The arms the students build at the conclusion of the unit include ligaments, veins, and additional joints. When presenting their models and comparing them to their first efforts, teams reported, "We forgot the wrist, all the muscles, and the two bones," "There was only one bone for the top, the bottom and the hand. It failed," and, "The models are more accurate this time. It's easier to build it after all the activities."

Demonstrating Comprehension through Questions

Participating in hands-on activities only adds to the students' curiosity about the functions of the body, and their understanding of the material is apparent in their questions.

How does the spinal cord relate to the gills and heart?



For example, during the Blood unit, students found the dissections of the fish and cow hearts especially compelling. They asked: "How is the fish heart like a frog heart?" "How does the spinal cord relate to the gills and heart?" and "Is the fish heart more hollow than the cow heart because the fish lives in the water?" Through their questions, kids demonstrate that they are developing scientific thinking and a comparative approach to understanding body systems.

Designing Investigations

As fledgling scientists, the students pose questions and then design and conduct investigations. During the Lungs unit, one group studied how long smokers can hold their breath compared to nonsmokers. Another group wanted to know if being upside down would impact lung capacity (Figure 3).

During the Blood unit, students examined changes in heart rate due to sugar consumption or to various exercise machines. Another group investigated whether a person suffering from a headache has an elevated heart rate.

Is the fish heart more hollow than the cow heart because the fish lives in the water?



Afterschool students discover the valves in a cow heart.

{circulatory}

The students found that holding their breath and going out into cold weather raised their pulse rate, while eating hot sauce got mixed results (Figure 2).

Analyzing Data

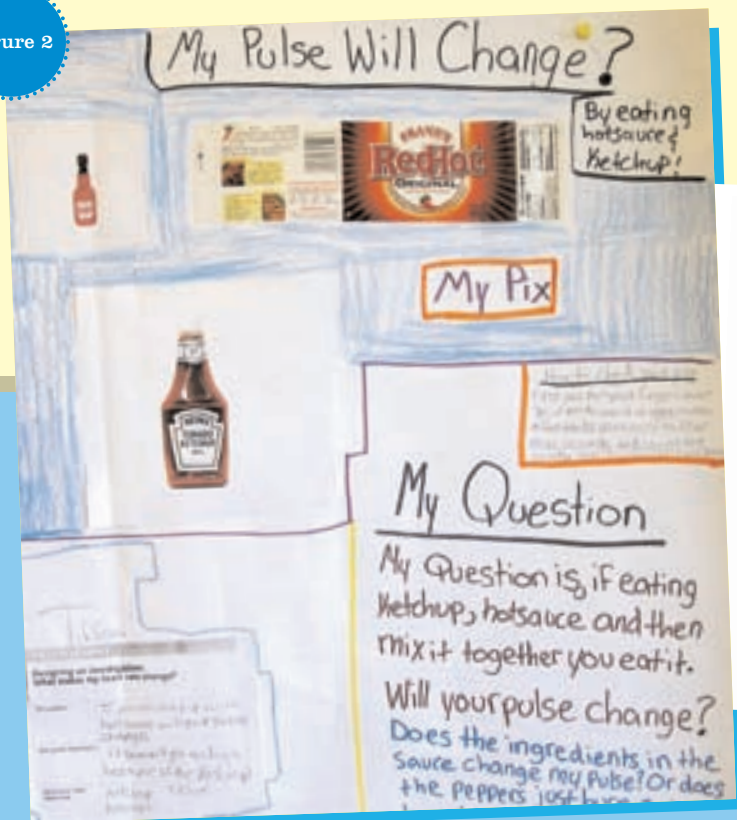
Data analysis skills are necessary for scientific study. The curriculum helps students develop those skills by allowing them to interact physically with the data. For example, during the Guts unit, youth at one center used segments of rope to predict the length of the small intestine. In another classroom, students were graphing their data on lung capacity, so their teacher created an oversized x-y axis on the floor with masking tape. Students wrote their data on paper plates and moved around the room “plotting” their data on the axis—a lively activity that captures their interest. In an activity on lung capacity, students calculated how many miles of lung bags they could fill in a year and plotted the distances on a map. One teacher commented, “Guesses and results were totally different, but that helped the kids see differences between what they thought and the results.”

Teachers as Learners

To prepare afterschool staff to teach the *Muscles, Lungs, Blood, and Guts* units, we engaged them as learners themselves. The curriculum is designed to create opportunities for inquiry, but teaching through hands-on exploration can be daunting, even for trained teachers in the formal classroom. TERC supported 41 teachers from 19 centers through professional development sessions that familiarized teachers with each activity. The teachers had in-depth discussions about the science content as well as some of the difficulties they might encounter during implementation. Like their students, the afterschool teachers found the hands-on activities the most compelling. For example, the staff most enjoyed building a model of the lungs and using lung bags to measure breathing capacity. Also, teachers who were afraid of science were surprised by how much they enjoyed the work and how much they learned.



Figure 2



Students investigated whether eating ketchup or hot sauce would raise their pulse rate.

Does being upside down effect my lung capacity?

Figure 3

2.4 - Upside down 2.2 - Standing up	2.6 - Upside down 4.0 - Standing up
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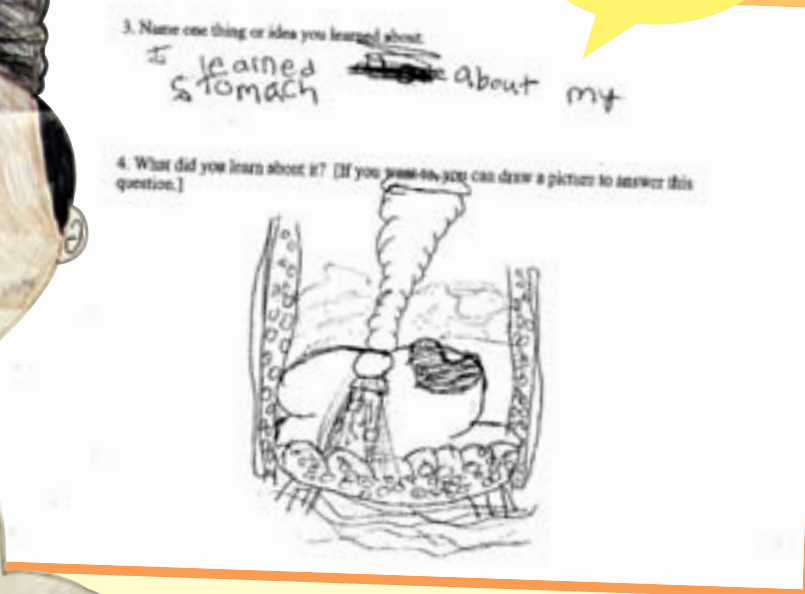
- Melissa actually did better upside down and it's starting to seem like our guess was wrong.
- I did a little bit better standing up so I think that their both good because if Melissa did better ~~upside down~~ then standing up and I did better standing up that wouldn't be any right answer

{respiratory}





What does a stomach look like?



Students showed their prior knowledge before learning about the digestive system. They created a poster that explained, "We think it's one huge system with organs to break up the food."

United Way to develop a cost-effective system for delivering fresh dissection materials because many centers do not have cold storage.

Because of the lack of predictability in afterschool settings, we are creating a variety of ways to conduct each activity. This includes detailing alternatives that could take shorter or longer amounts of time and creating substitutes for web-based activities. We are also creating options for structuring whole group discussions—a difficult format for inexperienced teachers to manage. We encourage teachers to have students share their ideas and opinions as a way to end each activity. The teacher then has the opportunity to summarize what the group has learned, while these young people feel their thoughts are valued.

We saw our own goals realized through the words of LaCasha Wilburn, a participating teacher. She reflected on her time with the curriculum by saying, "When I first got introduced I was apprehensive. Because I hated science in

Meeting the Needs of Afterschool

While the informal structure of afterschool programs provides unique learning opportunities, it also poses some challenges. Staff turnover is a common problem, and many centers lack dedicated space. Using shared space can mean a shortage of computer access and the distraction of multiple activities in a single room. To facilitate the program's hands-on activities, we have supplied kits that include inexpensive, but durable, materials. We are working with

{digestion}

Students outlined their own bodies to create models of the human body's systems.

“You can tell by looking at the posters... that they learned. They may not be able to verbalize it, but... they are enthused. They say, ‘I can’t wait until science every week.’ That’s all you can ask for.”



school, I thought I would hate it. [Then] I got the hang of it.” She found that her students also developed more confidence and understanding through the course of the program. “You can tell by looking at the posters... that they learned. They may not be able to verbalize it, but... they are enthused. They say, ‘I can’t wait until science every week.’ That’s all you can ask for.”

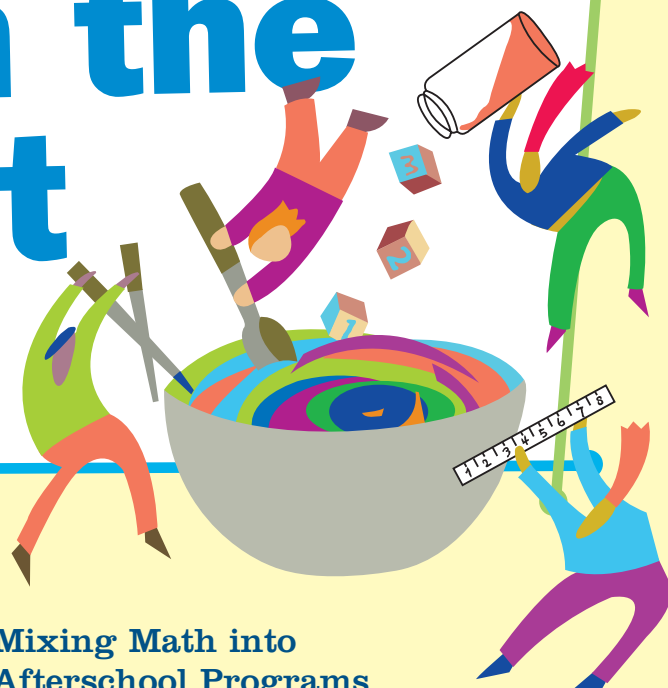
Funding for the Muscles, Lungs, Blood, and Guts curriculum provided by the Math Science and Technology Initiative at United Way Massachusetts Bay and Merrimack Valley. Find more information at www.uwmb.org/mst

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Math in the Moment

By Marlene Kliman



How many days until my birthday? ... How long can we make this paper chain in half an hour? ... How far can you hop in a minute? ... Where are the sports books, call number 796?

TERC is leading a group of projects that make math a meaningful and significant part of children's lives. These projects focus on simple ways for caregivers to build math into what they already do with children in afterschool programs, day care centers, homes, and libraries.

Activities such as arts and crafts, cooking, and gym games involve estimation, measurement, timing, counting, and other "common sense" math. TERC projects aim to make this math visible and fun for caregivers and kids alike.



Mixing Math into Afterschool Programs

Mixing in Math (MiM) project, funded by the National Science Foundation, is producing research-based interdisciplinary math activities and supporting implementation in afterschool programs. Educators from the YMCA, Girls Inc., BELL, and community programs associated with the St. Louis Science Center are working with TERC to shape and implement these materials for the diverse populations they serve. MiM will ultimately reach 50,000 to 100,000 children nationwide, most of them low-income, along with tens of thousands of afterschool educators.

Currently in its third year, MiM has already made a substantial impact nationwide, as afterschool networks build math into all aspects of their programming. As one afterschool educator noted: "Now everything I think about teaching, I think about how to mix math into it." Afterschool staff report that the great majority of children are quickly gaining enthusiasm for math, along with skills and confidence.

Math Begins at Home

One of TERC's math-for-families projects, Recipe for Math, is funded by the **AT&T Family and Work Development Fund**. TERC developed a "recipe box" of ideas that help parents incorporate math into family activities such as story time, conversations, and car trips. While many families view math homework as fraught with stress and conflict, math activities that fit into a family's own ways of spending time together can be fun for everyone (see below).

Math off the Book Shelf

Librarians are enthusiastically using TERC's informal math materials. For instance, the youth services librarian at the **Boston Public Library** Egleston Branch is able to help some children with homework while she engages others in "How Many in a Minute?," an activity that involves estimating and telling time, gathering and comparing data, and counting (see pages 12-13). Children's librarians from the suburban **Newton (MA) Public Library** regularly offer hour-long programs combining informal math with stories.

Diane Miller, Vice President of Public and Community Programs at the **St. Louis Science Center**, is developing

curriculum and training for AmeriCorps. She is using TERC's informal math in crafting a program that integrates literacy, math, and science. Says Miller: "Sometimes we work with kids who have never touched dirt, never played in water, never drawn a picture, never sung a song. Mixing in Math gets kids to measure ingredients, draw as many stars as they can in a minute, clap a rhythm, organize and categorize objects. Much of what we do is brand new to them. Embedded in these activities are science, math, literacy, and also the process skills you have to develop just to be successful in an academic environment."

Math on the Horizon

Recently, TERC forged a partnership with the **IBM Global Life Fund** to develop "I Believe in Math!," hands-on activity kits for children of IBM employees. As TERC continues to build its out-of-school math work, we are forming new collaborations with libraries, day care and afterschool programs, and businesses. Through these partnerships, we seek to create a generation whose enthusiasm and skills in math serve them both in and out of school.

Marlene Kliman is principal investigator for the Mixing in Math project at TERC, marlene_kliman@terc.edu.

RESOURCE

Math Out of School: Families' Math Game Playing at Home

by **Marlene Kliman**

A study published in *The School Community Journal* was conducted as part of the NSF-funded "Math Packs for Families" project. Thirty parents received games integrating math and geography and were asked to play with their children as little or as much as they wished. The extent and nature of family game play was followed over four months.

Parents described the game playing as a rich educational experience that their families shaped to meet their own interests and styles of interaction. Children took a substantial role in deciding when, how, and how much to play. Although all parents believed the games promoted learning, several drew sharp contrast between

playing educational games and doing homework with children. One parent of a 12-year-old explained:

It's different than doing homework or a project, where it can get stressful. We have a deadline [for homework] when I'm helping my daughter, and we're fitting it into my schedule, which isn't always her schedule. She wants to watch a TV program, she wants to go somewhere.... [With the games] I'd try to help her...learn to ask more logical, better questions. It's relaxed, it's fun, no stress, which I'm sure is the point of the game, to make learning fun.

While engaging parents in children's school math is undeniably worthwhile, this study suggests that engaging families in math unrelated to homework can promote positive experiences with math and shared learning between parents and their elementary school-age children.

The School Community Journal, Volume 16, Number 2, pages 69-90.

How Many in a Minute?



Grades: K-7

Group size: any

Time: 10 minutes or less

Math Spotlight: Timing a minute



Materials: Clock or watch that shows seconds, paper and pencils

Prerequisites: Some familiarity with clocks or watches

Activity

1. Choose an activity to do for a minute

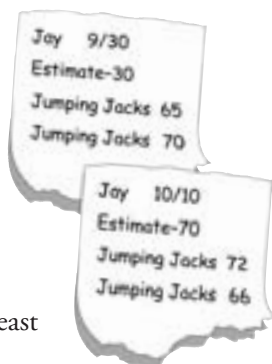
Each child picks an activity, such as throwing and catching a ball, doing jumping jacks, or shooting baskets. They predict how many they'll be able to do in a minute. If needed, review how to time a minute.

2. Find how many in a minute

Select a volunteer to time the group for one minute while the others do their activities. Children work alone and keep count themselves, or they pair up: one child does the activity for a minute while the other counts; then they switch.

3. How close were your estimates?

After comparing the actual count to their estimates, children write down the activity, the date, and how many they did in a minute. They put the records in a safe place so they can keep track over time.



4. Repeat!

If possible, do this activity at least twice in a row, so children can compare their times on different trials.

Variations

How Many Stars?

Children find how many times in a minute they can draw a star, write their names, or write a letter of the alphabet (good practice for younger children). Ask them to organize their work so items are easy to count—for instance, in rows of 5 or 10.



Estimate a Minute

Explain the procedure, and then try it:
Everyone shut your eyes. I'll say "Start!" when I'm going to start timing. Raise your hand when you think one minute is up.

Note who raises hands before one minute is up, who at about one minute, and who after one minute. Once all hands are up, tell them the results.

Sing It Again

Children find how many times they can sing a rhyme, call out names of everyone in the group, or do a sequence of dance moves in a minute.



Math Spotlight

Timing a minute

Children may find it easiest to start timing a minute just when the second hand passes 12 (or, with a digital clock, when the seconds read 00). As they gain skill and confidence, they should practice timing when the second hand passes another number (or, when the seconds reads some other number.)



Start when the seconds read zero.



Start when the seconds are between 0 and 60.

Resources

How Long? (Grade: K)

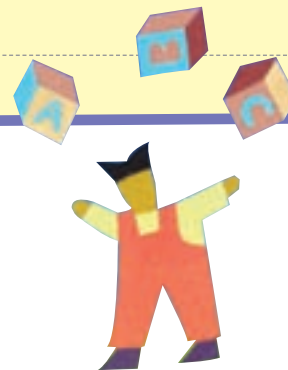
Dale, Elizabeth. (NY: Scholastic. 1998)

Me Counting Time: From Seconds to Centuries (Grades: K-2)

Sweeney, Joan. (NY: Crown Publishers. 2000)

On Time: From Seasons to Split Seconds. (Grades 3-7)

Skurzynski, Gloria. (Washington D.C.: National Geographic Society. 2000).



Everyday Connections

When a minute matters

Sometimes an extra minute can make a big difference. Hairdressers need to know how long to leave in dyes, permanents, and straighteners for different hair types—leave them in for too long and the results could be disastrous. Bakers and pastry chefs need to watch time in the oven carefully, or dough may not rise properly. Health care workers taking your pulse are measuring beats per minute, so it's important that they time carefully.

Minutes also matter when it comes to public transportation. If you're a minute early for the bus, you'll have a short wait; if you're a minute late, you miss the bus.

Download all Mixing in Math materials for free at <http://mixinginmath.terc.edu>.



What's the Problem?

BY BRIAN DRAYTON

One key to more meaningful classroom inquiry

“Scientists are often thought of as problem-solvers. But they are more than that, they are problem-seeking creatures, too.” — DAVID PYKE

It often happens that “inquiry” activities in the classroom fail to offer the depth of learning that we hope for. Data collection is fun, active, and often requires enough attention and care to make it a challenging task in its own right. Yet when the time comes to make sense of the data collected, the hope that something valuable will be learned about science practice, or about the specific topic of the inquiry, is often not fully realized. Supporting productive inquiry is subtle work, and often the way we talk about the process increases the mystery for students. For instance, a common approach to student-centered inquiry is to invite students to propose a hypothesis and to design an experiment to test it. But when they come to make sense of their data, they seem to lack enough raw material to enable an evaluation of the data that can render fruitful insights.

In this article, I'd like to think about how this common task—the search for a good student-designed investigation—is derailed by certain misinterpretations of “scientific method” and of “inquiry cycles.” Then I will suggest one ingredient in an inquiry that can enhance the search for, and understanding of, problems for investigation. This can yield both good science learning and an improved understanding of the fundamentals of inquiry.

In the classroom vignette on page 15 (top), the teacher had carefully guided her 8th grade students in the development of possible investigations based on things that interested them about the ecology of their school yard and its adjacent field, woods, and stream-side. The content of the unit (energy flow, food chains, nutrient cycles, and photosynthesis) was used to filter out questions that would not relate to the teacher's learning goals, but the students were encouraged to find questions that intrigued them.

The teacher guided the refinement of questions by relating them to data collection methods. She created information packets on 18 different basic methods of study used for elements of an ecosystem—elements such as water quality, soils, flora, and fauna. She then asked the teams to select their research topic from their “short list” of favorite questions, according to available methods of investigation. Each packet provided background on the use of the method, including the science behind it, examples of how it is performed, and suggestions for analyzing the sorts of data produced.

A boy and girl are sitting quietly at a desk. They have three princess pine (*Lycopodium*) specimens on the desk, each in its own container. From time to time, the girl writes something, and she and her teammate talk quietly, but mostly they just kind of hang out looking at the pines. When asked, the students explain their experiment: “It’s to see the effect pollution has on plants. One plant has trash around it. One is watered with polluted water. One is surrounded with polluted air (smoke).” They intend to carry out their experiment for 2 weeks.

— OBSERVER’S NOTES FROM AN 8TH GRADE CLASSROOM



Princess Pine (*Lycopodium*)

The team in our vignette above had chosen to conduct a comparative, experimental study. Their question was, “What is the effect of pollution on plants?” They went out and found some specimens, and set up their comparison. At the time we observed, the team was starting to feel that the investigation was not promising; not much was happening. Moreover, they had chosen a rather general condition—pollution—to examine. But in order to compare the effects of three kinds of pollution with an unpolluted system, they had made some unproductive decisions about how to pollute their plant containers. They were looking for changes in the plants, but were not sure what those might look like. As the unit went on, the team came to the conclusion that they had hit a dead end, and started looking for something else to do. There was no evidence, however, that their discouraging experience with the princess pine had equipped them to develop a more satisfying project. Perhaps in their eagerness to find a hypothesis to test, they moved too quickly past the problem itself. It is possible that, paradoxically, the rush to a hypothesis and data can sabotage good inquiry.

Obstacles to Successful Inquiry

The hasty search for hypotheses. We all know that the soul of scientific investigation is the hypothesis. Therefore, it is very tempting to leap from the identification of an area of interest to the formulation of a hypothesis, or something to test by data collection. In our case, “What is the effect of pollution on plants?” was quickly pushed to a conjecture: “Polluted plants won’t do as well as unpolluted plants.” So our students were led to a comparative study.

The problem is that students often have a hard time coming up with a hypothesis that will produce, not only data, but insight. It is a matter of simple care to formulate a conjecture that one can subject to a test. In this instance, the teacher took real care that the students formed their questions carefully enough to be testable by practical means. In this sense, their questions were productive or answerable—no mean feat. However, finding hypotheses that are productive of insight is quite another matter. Even for experienced researchers, hypotheses are hard to formulate on the spot when one is first learning new material.

We may be led astray by the common form of storytelling in science, the journal article, which starts out with a general introduction, and then the hypothesis or question to be tested, then the methods, and so on. But a hypothesis arises from a situation in which we have a question we care about and want to understand better.

As the great biologist Peter Medawar writes:

Every discovery, every enlargement of the understanding begins as an imaginative preconception of what the truth might be. ... a 'hypothesis' arises by a process as easy or as difficult to understand as any other creative act of mind; it is a brain-wave, an inspired guess, the product of a blaze of insight.

It is very challenging to confine the leisurely and somewhat unpredictable experience of inquiry within the constraints of the classroom and the demands of curriculum frameworks. Potentially rich science learning can be squelched by the rush to “get” a hypothesis, or by a focus on data, rather than on meaningful questions.

The rush to data and problem-solving. The National Research Council (NRC) “National Science Education Standards” (1996) advise, quite rightly, that the ability to reason about evidence is a skill critical for everyday life, which can be honed and educated in science class. Data collection and data analysis form a key part of the NRC’s influential inquiry standards (2000). Data collection also tends to be the most active, enjoyable part of an investigation—you run the carts down the ramp, shine the lights through the prism, scoop the crawlies up from the streambed, watch the two liquids bubble and fizz when you mix them. Sometimes the data collection is the moment when students finally get engaged in the situation their teachers have set up for them. (Though, for our team, the fun was in collecting the *Lycopodium* specimens, and polluting the containers with trash or dirty water.)

But all too often, you count up your occurrences, or report your pH measurements, or describe the organism’s behavior when you subjected it to your test, and you don’t have much to say beyond a reporting of the results.

Interpretation can become an exercise in guesswork, rather than in sense-making. In our vignette, the students were not seeing any change in behavior, so they had no data to report. Yet the students were so aware that something was missing that they had begun to discuss other possible investigations which would perhaps provide more action.

Maybe if they had stuck with their question of how pollution affects plants a little longer, they might have been able to turn it into a problem from which they could learn something that mattered to them.

Soaking in the Problem

In thinking about how to enrich an inquiry, it is useful to revisit the philosopher John Dewey’s ideas about how we come through inquiry to understand anything reliable about the world. He suggests that inquiry of any kind includes these elements:

- A** a question, problem, or uncertainty about something
- B** intellectualization of the problem (what later authors call “problematization”)
- C** the formulation of a possible solution to the difficulty, and a way to test it
- D** reflecting on your proposed test and its implications
- E** testing your solution, and reflection on the outcome, and what light it casts on the problem that started you off

Among these ingredients, Dewey points out several places in the process where reflection is essential. It is important to reflect upon the results of an investigation, as well as the possible paths toward a solution. But we also need to spend time reflecting on our questions. Our inquiry will be most productive if we resist the temptation to neglect the problem because of our infatuation with solutions and conclusions. For Dewey, the problem is always the guiding beacon for inquiry. Every step along the way is to be considered and evaluated for its relation to your question.

So let us consider this deceptively simple second step of Dewey’s inquiry cycle—the “intellectualization” of the problem—in relation to our vignette. When Dewey talks about this stage of reflection, he clearly has much more in

mind than just identifying a testable hypothesis. Rather, the inquirer should spend time “soaking” in the problem, understanding why it is a problem at all, and what some of its ramifications might be. In the case of our vignette, the students could have been led to reflect on each part of their problem for a while before designing the test they actually would perform. This is an act of scientific imagination.

In figuring out whether they had a hold of an interesting problem, they might have gone down some such paths as these:

- **What does it mean to say that pollution “affects” plants?** How can you tell when a plant is affected by something—say, by browsing, mowing, drought, or pollution?
- **What do you mean by “plants”?** Does *Lycopodium* behave the way a grass does, for example? What does “behave” mean for a plant, anyway? What changes might indicate a response to an experiment?
- **What do you mean by “pollution”?** Maybe putting trash around the base of a plant will be good for it, rather than bad, even if it’s not pleasant for humans to see or smell. Could some kinds of pollution have different effects from others?
- **Can we find plants of the same species in the wild that are in polluted and unpolluted situations?** Can we see any difference, and how would the differences relate to how plants grow?

Of course such questions can be elaborated for a long time. The point is, by examining the problem itself before focusing on formulating a hypothesis or testing the question, we are gathering invaluable raw material for the meaning we may find through our inquiry. The more we know about the situation that intrigues us, the more likely we are to ask questions with answers that mean something as a solution. By creating a more informed question, we can place what we learn in a richer context, building more connections, seeing more clearly the meaning of our question, and becoming more fully aware of some of its implications.

By reflecting on the problem, the students in our vignette could have found a more responsive plant to study, understood what “pollution” might mean for a plant, learned more about plant behavior and physiology, and seen how

all this fits into an understanding of the fields and streams near their school. Spending time on the nature of the problem, and why it is a problem, lays the groundwork for interpreting our findings. As Dewey writes,

“If we knew just what the difficulty was and where it lay, the job of reflection would be much easier than it is. As the saying truly goes, a question well put is half answered....[When we first are confronted with the problem of a ditch, and think of how to cross it to continue our walk] our uneasiness, the shock of disturbed activity, gets started in some degree on the basis of observed conditions...The width of the ditch, the slipperiness of the banks, not the mere presence of the ditch, is the trouble. The difficulty is getting located and defined... We know what the problem exactly is simultaneously with finding a way out and getting it resolved.”

When Medawar called the hypothesis a sort of guesswork or inspiration, he might have added another important part of the picture: we are more likely to make guesses that can lead us to new understandings if our guesses are educated. In science, educated guesses are more likely to arise when we know something—even something apparently irrelevant—about the situation we are asked to inquire about. Taking time to “problematize” the question is essential, if our sense-making is to lead to further learning. Even simple situations can yield rich insight, if we spend solid, high-quality time asking ourselves, “What’s the problem here?”

REFERENCES

- Dewey, J. (1989). How we think. In J. Boydston (Ed.), *The later works of John Dewey, 1925-1953* (8: pp. 105-352). Carbondale and Edwardsville: Southern Illinois University Press.
- Medawar, P. (1979). *Advice to a Young Scientist* (p. 84). New York: Harper and Row.
- National Research Council, *National Science Education Standards* (1996). Washington, DC: National Academy Press.
- National Research Council, *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (2000). Washington, DC: National Academy Press.

Note: Thanks to George Hein and the TERC Dewey group for a continuing series of good conversations.

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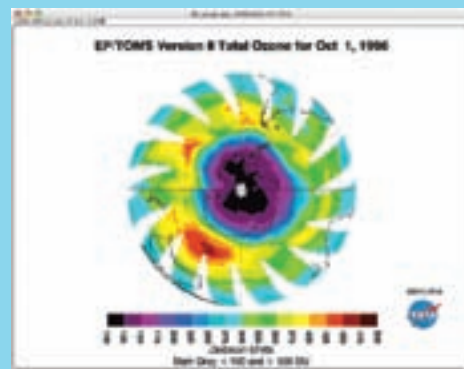
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Earth Exploration Toolbook

ANALYZING THE ANTARCTIC OZONE HOLE This chapter in the Earth Exploration Toolbook (EET) shows users how to download free data images from NASA's web site that indicate the amount of ozone over the southern hemisphere over a span of 10 years. The ozone "hole" that develops each October allows more ultraviolet (UV) energy to reach Earth's surface, causing damage to the eyes and skin of humans and other animals.

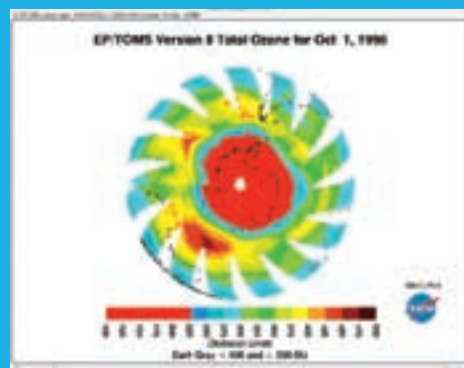
➔ Download images over a span of 10 years

These images from NASA's Total Ozone Mapping Spectrometer show the amount of ozone overhead. If all of the ozone molecules overhead could be concentrated in a layer covering the Earth's surface, the ozone would measure only 3 millimeters thick—about the same height as two stacked pennies. This amount of ozone has a value of 300 Dobson Units (DU). Scientists consider an area where the total amount of ozone is less than 220 DU to be the ozone "hole."



➔ Highlight and measure the ozone hole each year

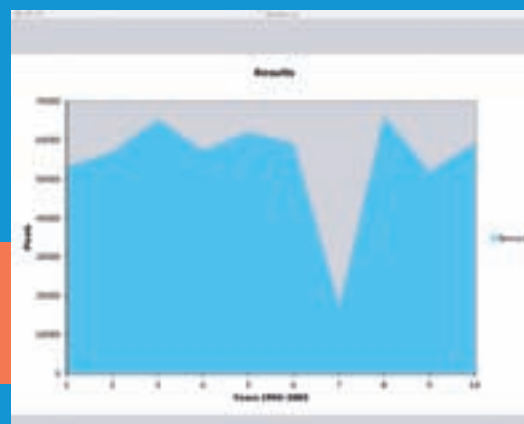
Using the free ImageJ analysis software, highlight in red the pixels (picture elements) with an amount of ozone below the 225 DU contour. ImageJ counts the number of red pixels as an estimate of the size of the hole. This number is not meant to be a precise measure of the area, rather a relative comparison.

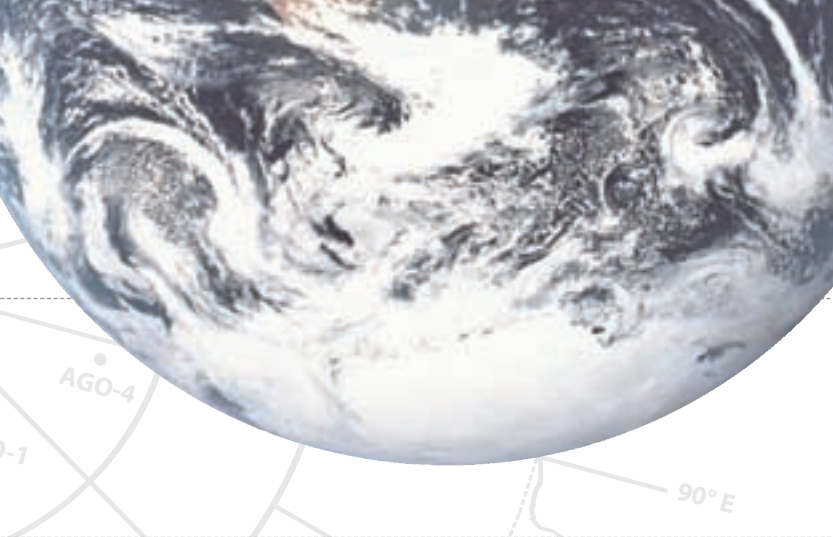


➔ Graph the change over time

Graph the number of red pixels to compare the area of the ozone hole year by year. Why was one year's ozone hole much smaller than the other years'? Outline a plan for finding out why that year might have been different than other years.

➔ See the full chapter for detailed instructions and further explorations at <http://serc.carleton.edu/eet/ozonehole>





ACCESS TO SCIENTIFIC DATA

Teachers and students are gaining access to authentic Earth science data through the Earth Exploration Toolbook (EET). This free online collection of activities, organized into chapters, has step-by-step instructions for making use of real-world data in the context of compelling case studies. The EET uses data compiled and used by scientists and researchers at agencies such as NASA and the U.S. Geological Survey. EET chapters are helping teachers enrich their existing science programs with data analysis and increase the use of technology in their classrooms.

<http://serc.carleton.edu/eet>

SUPPORT FOR TEACHERS

TERC has created two professional development programs for teachers who want to increase the use of data, data analysis, and technology in their classrooms. The EET Workshops project supports teachers from across the country through simultaneous teleconferencing and web-conferencing. Workshop facilitators demonstrate analysis techniques and give step-by-step instructions, and teachers share how they use EET chapters in classroom projects and activities.

<http://serc.carleton.edu/eet/workshops/about.html>

The DataTools program offers a two-week summer workshop for Massachusetts teachers that uses the EET to introduce a set of data analysis tools. Teachers prepare customized activities, which are pilot-tested by a group of their own students. During the following school year, teachers support one another through online discussions.

<http://serc.carleton.edu/eet/msdatatools/>

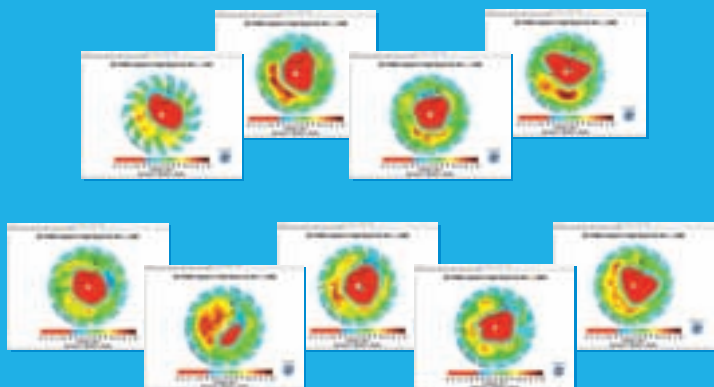
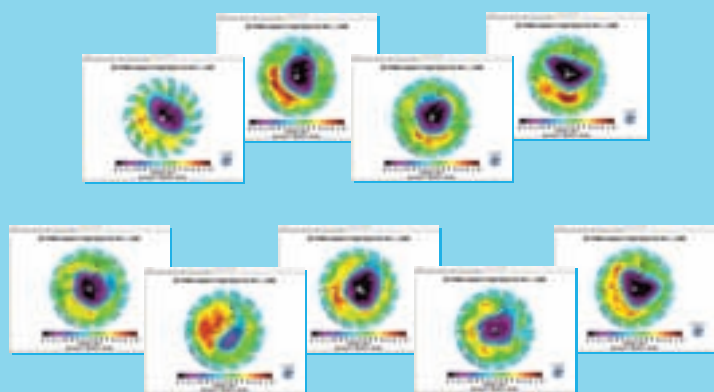
A GROWING COLLECTION

New EET chapters are continually developed through AccessData Workshops. This annual event brings together a range of experts, including data providers, tool specialists, scientists, curriculum developers, and educators. This face-to-face collaboration results in new EET chapters that use relevant examples, making data accessible and useful for teachers and students.

<http://serc.carleton.edu/usingdata/accessdata>

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Results				
	Area	Mean	Min	Max
1	53314	19.254	0	22
2	57125	19.445	0	22
3	65460	19.203	0	35
4	57461	19.220	0	35
5	62145	19.539	0	35
6	59171	19.283	0	22
7	17461	21.292	16	22
8	66293	19.388	0	35
9	51849	19.696	0	22
10	59391	19.109	0	35

New Projects



The Watson Family Solar House is providing data for Project REDI. Find out more at <http://256.com/solar>.

ArtScience

This project, a collaboration between the Chêche Konnen Center at TERC and the King Open School (Cambridge, MA), is examining connections between artistic and scientific literacies and the pedagogical opportunities such connections may create for engaged and equitable learning for all children. This exploratory study aims to generate a new, long-term vision for integrating the sciences, arts, and humanities in public education. *Funded by the Ford Foundation.*

Biocomplexity and the Habitable Planet

TERC and the Institute for Ecosystem Studies are developing an innovative high school curriculum designed around the dynamics of complex and evolving coupled human and natural systems. Materials are drawn from research at the Long-term Ecological Research sites. The inquiry-based curriculum will consist of a series of cases relating to biocomplexity and climate change. See the pilot test opportunity on page 22. *Funded by the National Science Foundation.*

Connecticut MSP Program Evaluation

The Connecticut Math Science Partnership (MSP) program supports relationships between local education agencies and institutions of higher education that will improve professional practice, raise student achievement, and promote a comprehensive pre-K-16 education reform initiative. The evaluation of the 2006-2009 MSP grant projects focuses on the impact of the Leadership Training Academies, which prepare K-12 teachers to act as school-based instructional coaches. *Funded by the Connecticut State Department of Education.*

Cultural Context of Learning: Native American Science Education

Past research shows that rural Menominee children and urban inter-tribal children begin school with advanced understandings of biology and that they reason ecologically, much like practicing expert scientists. However, this conceptual advantage does not translate to school achievement. This project

will test the effectiveness of an approach which builds upon the intellectual resources children develop in their everyday lives to develop critical academic literacies. *Funded by the National Science Foundation through Northwestern University.*

Does Project-Based Learning Matter to Undergraduate Women in Engineering?

This study is exploring how project-based learning pedagogies compare with each other and with traditional pedagogies in fostering women's performance, interest, and participation in lower-division STEM courses in undergraduate engineering programs. The study, involving 600 female and male students and 24 faculty in four institutions, will explore reasons for gender differences and implications for classroom practice, theory development, and policy. *Funded by the National Science Foundation through Franklin W. Olin College of Engineering.*

Excellence in Estuaries Education

TERC will conduct a needs assessment of K-12 teachers and develop curriculum and professional development materials for the National Estuarine Research Reserve System (NERRS) and other affiliates of the National Oceanic and Atmospheric Association (NOAA). The project will help integrate state standards and teacher needs into NERRS programming for informal and classroom settings, and will draw from NERRS real-time water quality and weather monitoring data. *Funded by NOAA.*



TERC is creating a curriculum using data from estuaries such as the Chesapeake Bay Reserve. Photo courtesy NOAA.

Foundations of Algebra

This project is a collaboration of teachers and researchers who will develop a sourcebook consisting of yearlong portraits of classrooms in grades 1-8, showing how teachers and students articulate, represent, and reason about general claims in the context of their work in number and operations. This resource and an online course based on it will help teachers develop this work in their own classrooms. *Funded by the National Science Foundation.*

The Inquiry Project

TERC is partnering with Tufts University to help students in grades 3-5 to develop an understanding of science that will lay a foundation for later comprehension of the atomic-molecular theory of matter in middle and high school. This learning progressions project is focused on important ideas that are challenging for today's students, including measurement, weight, volume, and density. *Funded by the National Science Foundation.*

Inside the Double Bind

This project is compiling research on women of color in science, technology, engineering, and mathematics (STEM) in higher education and careers. Little information exists, since most data are collected by either race or gender. This project will gather and synthesize scattered articles, books, narratives, chapters, and parts of reports about minority women in STEM. It will disseminate findings and identify gaps in the research. *Funded by the National Science Foundation.*

MSPnet Phase II

This new funding will extend MSPnet (<http://mspnet.org>) until 2012 and will result in a comprehensive archive of NSF's Math Science Partnership (MSP) Program, which will inform future large-scale education reform efforts. Through MSPnet, projects share emerging research, tools, and resources with their constituents, with other MSP projects, and with the public at large. TERC will continue its cutting edge research and development on building and studying complex, nested communities for professional development. *Funded by the National Science Foundation.*

Project REDI: Renewable Energy Data Investigations (REDI)

TERC is developing investigations around the urgent topic of renewable energy. Using real local and national data, students understand the science and impact of renewable energy. Participants correlate data on matters such as solar irradiation, wind speed, and energy output. Students understand the factors that affect the efficiency of these energy sources, and realize the potential for use in their communities. *Funded by the Massachusetts Technology Collaborative.*

Scaling Up TRIAD

The goal of the TRIAD (Technology-enhanced, Research-based, Instruction, Assessment, and Professional Development) project is to increase math achievement in preschool children, by means of an implementation of the Building Blocks math curriculum, professional development for teachers, and on-site support by mentors. TERC will assist in the research about the TRIAD intervention's efficacy in improving teaching performance and children's achievement in the Boston Public Schools. *Funded by the U.S. Department of Education and the National Science Foundation through the State University of New York, Buffalo.*

S-CASTS

S-CASTS: System for Collaboration among Students, Teachers and Systems is a collaboration between TERC and Artificial Intelligence researchers at Harvard investigating the use of models of collaboration, especially as embodied in collaborative human-computer interface systems, in the augmentation of existing flexible software tools for mathematics education. The mathematical domain is probability modeling and the educational software being used is TinkerPlots. *Funded by the National Science Foundation.*

Signing Science Dictionary for Young Learners

TERC is collaborating with Vcom3D to extend the SigningAvatar® accessibility software to a younger audience. The project is developing and disseminating an illustrated, interactive 3D dictionary of signed science terms and definitions for children in pre-K through first grade who are deaf or hard of hearing and whose first language is sign. *Funded by the Carl and Ruth Shapiro Family Foundation Disability Initiative.*



Using EarthScope Data in Secondary Classrooms

TERC is improving the educational outreach for EarthScope, a partnership between NASA, the NSF, and the U.S. Geological Survey using modern technology to investigate the geological processes shaping the North American continent. TERC is working with scientists at UNAVCO to develop a new chapter for the Earth Exploration Toolbook (see page 18) to make complex data accessible and useful to educators. *Funded by the National Science Foundation through UNAVCO.*

New projects

ADULT NUMERACY

Through the following work, the Adult Numeracy center at TERC seeks to serve adults and adolescents who have not had the opportunity to achieve in math. Find out more about these programs at adultnumeracy.terc.edu.

EMPower Curriculum for Adult Learners

TERC's adult numeracy work began with a major grant in 2000 from the National Science Foundation (NSF) to found the EMPower (Extending Mathematical Power) project. The project resulted in a comprehensive math curriculum that reaches students in adult and workplace education, alternative high schools, and GED programs. The EMPower curriculum helps adults develop mathematical proficiency to more effectively meet the demands of work, community, family, and continued education.

EMPower Professional Development Workshops

In order to serve adult numeracy teachers, TERC offers EMPower Professional Development Workshops. Teachers will

expand their ideas of what it means to do math, focusing on reasoning, communication, and real-world problem solving.

Project TIAN

TERC is collaborating with the University of Tennessee to expand teacher learning opportunities through TIAN (Teachers Investigating Adult Numeracy), a professional development model for teachers of adult math students. Six states have participated in TIAN, which uses inquiry and reflective learning to engage teachers in creating new approaches to algebra and data.

State and City Initiatives

As part of a its Math and Science Achievement program to ready adults for employment in technical fields, the City of Boston called upon TERC to help develop a math and science program to prepare adults for college level studies.

TERC is also supporting an initiative to provide professional development to all teachers serving students incarcerated in

Massachusetts DYS residential facilities. TERC co-developed a math guide and set of teacher workshops. In addition, TERC staff are teaching a graduate course developed for DYS educators.

Statistics for Action

TERC's latest adult math project steps out of the classroom to help community action groups understand and make use of statistical data. TERC and the University of Tennessee received NSF funding to improve mathematical understanding among adults who are engaged in investigations related to public health and the environment. Project staff are helping these groups make sense of the data they are collecting and find meaningful ways of conveying that information to their neighbors and public officials. Partners include the Blue Ridge Environmental Defense League, Haitian American Public Health Initiative, Rutherford County Citizens, and parent leaders from the Boston Urban Asthma Coalition.

Get Involved

← Biocomplexity and the Habitable Planet

Biocomplexity is seeking grade 11-12 pilot teachers for two units. One focuses on urban ecology and links local to global climate through feedbacks that impact biodiversity; the other focuses on suburban and regional landscape ecology related to agriculture. Students build scientific understanding through field-, lab- and model-based investigations and make decisions about land and other resource use through evidence-based arguments. For more information and to apply contact gilly_puttick@terc.edu.

EMPower Workshops

The EMPower professional development workshops support teachers who want to breathe life into the "remedial math" classes offered in alternative high school programs,

Adult Basic Education and GED programs, and developmental college. These hands-on workshops are accessible to instructors of all "math comfort" levels. See Adult Numeracy above. Visit adultnumeracy.terc.edu or contact empower@terc.edu.

Online Science-athon

Teachers of students in grades 4-8 are needed to test virtual and physical versions of the Marble Roll and Catching Sunshine. For more information, visit the Science-athon web site at scithon.terc.edu or contact judy_vesel@terc.edu.

Signing Science Pictionary

Teachers and parents of children who are deaf or hard of hearing in grades K-3 are needed to pilot test a prototype interactive 3D sign language dictionary of animal terms. For more information, visit the Signing Science web site at signsci.terc.edu or contact judy_vesel@terc.edu.



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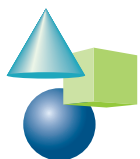


Lee Kilpatrick

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