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THIS ISSUE’S FOCUS
Systems
Understanding systems is crucial to fields of science, math and technology. Thinking in terms of systems also breaks down traditional barriers between subjects and opens up new ways to approach learning.

The *National Science Education Standards* define a system as, “...[A]n organized group of related objects or components that form a whole. Systems can consist, for example, of organisms, machines, fundamental particles, galaxies, ideas, numbers, transportation and education. Systems have boundaries, components, resources flow (input and output) and feedback.” (National Research Council, 1996)

The use of systems as an organizing and thinking tool has greatly expanded because of the work of Professor Jay Forrester at MIT. He largely developed the modern field of system dynamics and has applied this thinking to education as well. His work is apparent in the first article in this issue on woolly mammoth populations.

Forrester believes that, “System dynamics offers a framework for giving cohesion, meaning and motivation to education at all levels from kindergarten upward.” He writes that students working with system dynamics, “...have the opportunity to explore, gather information, and create unity out of their educational experiences. Such synthesis can be based on facts that even elementary school students already have gleaned from life.” (Forrester, 1992)

The articles in this issue of *Connect* bring varied examples from classrooms that may provoke your own thinking about systems in teaching and learning.
What happened to the woolly mammoths? Why did their population decline to extinction? What can we learn from them? Our students in grade three and older play a game to find out what might have happened.

Using dice to represent mammoths, teams of students record and graph the changes in the populations of their herds, applying various birth and death rate rules. While students are engrossed in playing the game, they are also practicing data-gathering, graphing and analysis, pattern recognition, probability and fractions, teamwork and inquiry. In the process, they learn that the mammoths’ extinction occurred because their death rate exceeded their birth rate over many years.

In social studies, the kids explore current theories of mammoth extinction as well as the idea of a theory. This game simulates the effect of the arrival of hunters, but there could be many causes for increased deaths or fewer births (or both). Another theory has to do with a change in the mammoths’ food supply. Whatever tipped the scales, the basic population dynamics hold: the size of any population depends on the flows of births and deaths over time.

Modeling the population

We start by giving each team of four students twenty dice to represent twenty mammoths in each herd. The four students roll all the dice at once and sort them according to these rules for Game 1:

If the die reads
1 a calf is born;
2 the mammoth is killed by a saber-toothed cat;
3 the mammoth dies of starvation;
4 the mammoth lives another year;
5 the mammoth lives another year;
6 the mammoth lives another year.

For every birth, players add another die to the herd; they remove a die for every “dead” mammoth. (Sometimes young children want to fix the dice to save their mammoths from dying. This is a good opportunity to explain a simulation and that a scientific investigation requires careful, objective observation without interference!)

Students roll the dice for twenty simulated years, count the remaining dice and record their annual populations. Finally, they plot their results on line graphs and post all the team graphs on the wall for discussion. These kinds of questions stimulate good thinking:

- What do the graphs tell us about what happened to the mammoths in our game? Why is it likely that they all became extinct?
- If some baby mammoths were born each year, why did the populations still decline?
- What is similar about the graphs? What is different? Why? In real-life, would different herds experience different conditions?
- What is the general pattern of all the graphs? For older students, what is the rate of change, the slope?
- Why is the line curved? (Surprisingly, even third graders can explain the death rate applied to a smaller and smaller population, the concept of exponential decay.)
- Would it matter if we started with 100 mammoths in each herd? (Again, the students will surprise you: If two out of six die every year, it doesn’t matter how many you have
to start; they still will become extinct in the same time!)

• How does the game relate to what we have learned about the Ice Ages and theories of mammoth extinction?

• Does this apply only to mammoths? What about other populations?

We adapted this game from a PBS Newton’s Apple segment with third-grade teacher Gene Stamell. We were serving as Systems Mentors in the Carlisle (Massachusetts) Public Schools, a project funded by the Waters Foundation. As Systems Mentors, we worked with our K-8 colleagues to develop and implement curriculum using system dynamics to enhance current instruction. System dynamics is a field founded by MIT Professor Jay Forrester about fifty years ago to understand the causes of change over time in areas as diverse as business management, environmental studies, psychology, economics, public policy and medicine.

In all cases, the causes of change arise from within the system as a result of positive and negative feedback loops. If you can begin to understand these underlying structures, you can use computer simulations to test policies and solve problems.

In recent years, Forrester has devoted much of his attention to introducing system dynamics into K–12 education because its inquiry approach makes education more learner-centered and relevant for students. More importantly however, students will need these skills to address the dynamically complex social, environmental and economic problems facing all of us.

Thinking skills

The Mammoth Game lays the groundwork for deeper systems thinking. With younger students, we can discuss how the size of the herd affected the number of new mammoths born each year. More mammoths in the herd caused more births, which further increased the herd—an example of positive, or reinforcing, feedback. (Our students are familiar with this concept in other applications.)

Students compare the results of Games 1 and 2.
Students can also see that the more mammoths there were, the greater the number of deaths, which decreased the herd, thereby causing fewer deaths—an example of negative, or balancing, feedback.

But in our game, both were happening at the same time, with the two loops tugging against one another. Because we had more deaths than births, the balancing loop took over and the population declined. Births would continue in this model, but not enough to overcome the pattern of decay.

By fourth grade and older, our students are able to make this general causal loop idea more specific. Now we use the basic tools of system dynamics to explain more precisely possibilities of how and why the mammoth population changed over time. (More details on this and other lessons are free online.)

**Water in the bathtub**

In the Mammoth Game, the population of mammoths can be viewed as an accumulation. At the end of each year, the number of mammoths in the herd was an accumulation resulting from mammoths that had flowed in (births) and out (deaths) over time. We call the accumulated population a “stock” and represent it with a rectangle; we call births and deaths “flows” and represent them with “pipes” flowing into and out of the stock.

It’s just like water in a bathtub. The level of water in the tub depends on how much water has flowed in through the faucet and flowed out through the drain over time, a concrete analogy that students grasp easily. The “clouds” represent the boundaries of the system. We take these symbols directly from the field of system dynamics. The “clouds” are the sources and sinks for the flows, beyond the boundaries of our investigation this time (but we don’t use those terms with kids). We usually explain the symbols with the more concrete bathtub analogy. The flows in the faucet and out the drain over time determine how much water is in the tub. Just like the mammoths flowing in and out.

**The challenge of generalizing**

Next, we think again about our experience in the game, our graphs, and the questions we have been asking. Using what we have learned about feedback loops, we know that not only did the size of the herd depend on births and deaths, but the number of births and deaths also depended on the size of the herd. We also saw that more births would cause the population to spiral in a reinforcing loop, and that increasing deaths would cause the population to approach zero in a balancing loop.

Furthermore, we know from Game 1 that, on average, 1/6 of the mammoths gave birth and 2/6 of them died each year, the birth and death fractions.

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**Mammoths in Herd Deaths**

Deaths decrease the number of mammoths in the herd; the decreased number of mammoths in the herd means the number of deaths also decreases.

**Mammoths in Herd Deaths Births**

**Mammoths in Herd Reinforcing Feedback Loop Balancing Feedback Loop**

**Birth Fraction Death Fraction**

**Mammoths in Herd**

**Births Deaths**

**Births Deaths**

**Mammoths in Herd**

**Birth Fraction Death Fraction**

**Mammoths in Herd**

**Births Deaths**

**The symbol \( \sum \) represents time.**
This structure applies to any population. It is also just like a bank balance where an interest rate determines the inflow of deposits and a spending rate determines the outflow of withdrawals. It could also represent the level of greenhouse gases in the atmosphere, or the amount of pollution in a lake. These are all simplifications, of course, but once students can understand the basic structure of one system, they can begin to examine the causes of change in other similar systems as well.

![Diagram of a stock/flow model]

Our middle school students go on to build a system dynamics computer simulation model of this stock/flow map and play with it to see what happens with various birth, death, and initial population values. Students could play several dice games, and thereby relate the abstract computer model to the concrete activity, but it is soon apparent that you can easily conduct many more experiments on the computer model.

Implications across the curriculum

We have used this game as an introduction to basic population dynamics in science or social studies. We also use it as an introduction to the principles of system dynamics and computer simulation. In Carlisle, sixth graders went on to do individual projects on endangered species and gathered their data, learning about carrying capacities. In social studies, the students use the basic model to think about other populations. In literature, they think about what would happen if people could live forever as in the novel, *Tuck Everlasting*, by Natalie Babbit. Math becomes relevant to all of these topics. We hope that the game is basic and appealing enough to suggest lots of interdisciplinary applications for kids.

We have been impressed and encouraged with our students’ enthusiasm and depth of inquiry using the systems approach. We have described this and related lessons in, *The Shape of Change* or as separate free downloads, all available from The Creative Learning Exchange at http://www.clexchange.org. We welcome your feedback.

Rob Quaden teaches eighth-grade math and Alan Ticotsky teaches sixth-grade science and social studies in the Carlisle, Massachusetts, public schools. Alan writes science books for teachers. For many years, Rob and Al were K–8 Systems Mentors supported by the Waters Foundation. Together they have developed many lessons using system dynamics to enhance the current curriculum across all K–8 grade levels and subject areas. They have also conducted workshops for teachers. rquaden@carlisle.mec.edu, aticotsky@carlisle.mec.edu.

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The Creative Learning Exchange is a non-profit organization in Acton, Massachusetts dedicated to promoting learner-centered education and system dynamics in K–12 education. Visit the CLE at http://www.clexchange.org.

Resources

The idea of interrelated systems, with some nested inside others, is not new to science. Ecologists have used such terms for several decades. But when these complex systems were first studied they were called chaotic because they were so hard to understand or predict. Chaos theories began to appear in articles over twenty years ago, confounding many typical textbook explanations. But chaos, as it was termed then, is now referred to as complex systems, a concept that is easier to understand and to research.

One place to look at the complexity of systems and the links between them is in a forest, where at least some of the systems may be visible. In his book, *Reading the Forested Landscape*, Tom Wessels contributed to an understanding of forests as multiple, linked systems. Now Wessels has gone further in explaining the value of thinking about systems in his new book, *The Myth of Progress*.

The book has two great assets for educators. One is the very clear explanation that exponential growth of economies is not possible over the long term. Other forces, beyond standard economic models, will come into play, affecting growth and change in our world. The conventional model of exponential, linear growth is, for Wessels, “the myth of progress.”

To examine this vast topic, Tom Wessels provides the second asset: he explores complex systems and the fact that they tend to be, “nested,” one within another and to have, “fuzzy boundaries . . . that allow for the flow of energy, materials and information between larger- and smaller-scale systems, but maintain each system’s integrity.”

Complex systems may very well find a point of dynamic equilibrium, but this is bound to change as these interactions vary or as an outside event changes the situation. A natural event might be a hurricane or fire. Or the change could be something brought on by humans: a war or the release of vast amounts of a chemical such as carbon dioxide. Large-scale change can occur very abruptly and with little warning.

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**Controlling these systems**

The laws of thermodynamics come into play here, especially the second one: heat cannot be transferred from a colder body to a hotter body without work being done by an outside agent. Tom Wessels uses language that is clear and relates to our modern world. He provides multiple examples of the second law and how it impacts specific systems. He also explores the first law, which states that energy cannot be created or destroyed. One system may appear to give up energy to a related, larger system, but the energy is not lost overall. It may, however, become much less useful to humans.

The book provides a warning about anticipating on-going, expansive progress, and it also helps us to understand this issue and the complexity of systems in terms that the non-scientist can understand and appreciate. In its breadth and clarity, it is a valuable resource for educators.


—EDITOR
Most schools emphasize the importance of caring for the environment. Recycling is taught, perhaps even practiced on site. Endangered species are studied, and funds may be raised to save the rainforest. While these efforts are valuable, they often leave students disconnected from their own close association with nature. Students are left with the sense that the environment is something far away that needs to be saved for the cheetahs. The reality is the environment is as near as the air we breathe, the water we drink, and the neighborhoods in which we live.

Lee Barnes, former editor of Permaculture Connections writes, “Permaculture is the use of ecology as the basis for designing integrated systems of food production, housing, appropriate technology, and community development. Permaculture is built upon an ethic of caring for the earth and interacting with the environment in mutually beneficial ways.” The study of permaculture empowers students with the knowledge and thinking skills to put the care of the environment on the front burner of their lives.

Oak Grove School in Ojai, California has attempted to take the principles of permaculture and apply them to the design and implementation of their school’s garden. Everything—from the greenhouse to the pond—serves the goal of a sustainable natural system that has minimal environmental impact, both now and in the future. What follows is a description of several principles of permaculture and how the school implemented those principles in the design and development of its greenhouse and garden.

Principle 1:

**Work with nature, not against it**

Nature is often subtle, and to understand it takes careful observation. Through observation we can come to know what our environment will support in terms of plant growth. Rather than deciding what is wanted, then altering the environment to make it possible, look at what the existing environment will support, and choose plants that are suited to it. This saves a great deal of energy—physical labor, fertilizer, and so on, because it takes advantage of the natural system that already exists.

Observation is the cornerstone of science and is a skill that needs to be fostered in students from the earliest ages. At Oak Grove, students made observations of the local environment guided by the need to understand what it would support. Observation led to questions: What is the weather like? How much sunlight do we get? What is the condition of the soil? What will grow here? This led to purposeful research—another key aspect of science.
Principle 2:
EVERYTHING IS CONNECTED
AND, WHEN IN BALANCE, SELF-
REGULATING

So much of our modern world is designed and constructed separately. Cars, stores, buildings, parks and so many things all serve specific functions and create the notion that everything is separate. Nature actually operates on the opposite principle. Soil, plant life, animal life, climate, and sunlight all operate together. However, this connectedness can be difficult for children to see because of their constant exposure to a world built on seemingly separate things performing separate functions.

A permaculture garden demonstrates the connectedness of nature by fostering natural connections between interdependent parts. With this in mind, Oak Grove is creating a forest garden. The forest garden consists of a variety of plants: trees, annuals, perennials, vines, and small shrubs, grown together so that they serve the needs and accept the products of each other. In selecting plants, it is important to consider what species are best suited for the climate and soil of the area.

The school used native species as much as possible, not only because they grow more easily, but also because they contribute to the natural self-regulation of the environment. Trees create shade and microclimates for plants that enjoy partial shade. Annuals can grow between rows of fruit trees, fixing nitrogen and helping the soil. Vines can be trained to grow up fruit trees, attracting bees for pollination. And perennials can be used to create natural borders and pathways, as well as grow food.

Composting food scraps and plant trimmings is another way to take advantage of nature’s connectedness. Layer the materials (green for nitrogen and brown for carbon). Each layer is its own micro-biome, supporting different kinds of decomposers. Also, layering, rather than mixing, allows for better air circulation, which is a key part of a successful composting process. Ideally, the compost should be kept moist and airy. Red (brattling) worms can be added. Unlike earthworms, they thrive in the acidic environment and really improve the speed and quality of the composting. By composting, students observe the relationship between life and death in a natural system.

Principle 3:
PLAN FOR EFFICIENCY; USE BIOLOGICAL RESOURCES

To create something in a way that is ecologically beneficial to humans and the environment takes knowledge and planning. It also requires a willingness to do things differently. Oak Grove School decided that a greenhouse would be useful for propagating plants as well as an excellent educational tool. Rather than head off to a building supply company for materials, the school researched ecological construction practices and decided to build a straw bale greenhouse.

The design and construction of the greenhouse was an educational experience in itself. Students created designs that were later used in construction. Students also helped in the construction of the greenhouse, learning concepts like load bearing and joinery. The greenhouse was built with straw bale construction on three
sides and glass with sliding glass doors on
the south-facing wall. It was built at the
top of the garden so that water draining off
the roof could be diverted downhill for
irrigation or to fill the pond.

Principle 4:
MAKE USE OF THE EDGE EFFECT

One of the most exciting principles of per-
maculture states that where two biomes or
environments meet, diversity of life
increases. Making use of the edge effect in
designing natural areas promotes the bio-
diversity that is necessary for a self-sus-
taining system.

One way to take advantage of the edge
effect in a schoolyard is to create a pond.
A pond invites an abundance of life, from
the smallest microbes and insects, to fish,
amphibians, and birds. All of these organ-
isms contribute to the garden, whether by
reducing pests, nourishing the soil through
their waste, or pollinating plants. Encour-
aging such diversity is thus a means of
ensuring that elements in the garden make
functional connections that are mutually
beneficial.

A pond with an irregular shape, includ-
ing small coves and little points of land,
creates a more hospitable environment in
which life may flourish. Similarly, the
variety of depths in a pond helps a diver-
sity of plant and animal species co-exist.
The pond is also a great outdoor science
project. It provides a living demonstration
of several different natural processes: pho-
tosynthesis, the food chain, and the water
cycle. Students are fascinated by the
microbial life of the pond.

Principle 5:
EXERT THE LEAST EFFORT FOR
THE MOST GAIN

The importance of this principle lies in the
saving of energy—an important life value
we all can learn. Through research and
planning, any activity or endeavor can be
done more wisely in terms of resources
needed and energy spent.

For example, we knew we wanted to
build a straw-bale greenhouse because it is
made from all natural materials and is nat-
urally insulated from the cold. We also
wanted a pond that would serve as a wel-
come mat for frogs and other bug-eating
critters as well as a natural repository for rainwater. We placed the pond about five meters (15 feet) below the greenhouse, so that while digging the hole for the pond, we were also collecting mud for the greenhouse walls. As well, when rain fell on the greenhouse, the gutters would divert rainwater into the pond. These simple design choices exemplify the principle and help students see the connection between design and efficiency.

Principle 6:

Caring for People

Our needs for food, shelter, education, work, play, and social interactions must be met if we are to be healthy. Therefore, a permaculture garden should be more than a food production area. It is a welcoming place where people can gather to talk, play, observe, meditate, and work in a pleasant environment. Since Oak Grove is a school, we felt it was important to create an outdoor classroom that would fit into the natural surroundings and be an inviting space.

We chose a spot under a tree on one end of the garden with a good view. Rather than building up, we went down. We dug out an area that is about 60 cm (2 feet) deep at the back end, but, since it is on a slope, levels out to about 20 cm (8 inches) at the front, creating a horseshoe shape. The back end is lined with dirt-filled grain bags covered with plaster. These are layered like the coils of a clay pot to create a circular seating area for resting and instruction. The front end opens to the garden. This outdoor classroom illustrates several principles of permaculture. First, by building into the ground, we worked with nature, not against it, in the sense that we created a smaller visual impact on the landscape. Second, we used natural materials, thereby limiting the environmental impact of the project in both the production and eventual disposal of those materials. Third, by taking advantage of the natural slope, we got the most gain from the least effort. In essence, half the work was done for us.

The principles of permaculture are closely interrelated and all are based on the idea that we human beings need to change how we interact with our environment. Our ecological footprint grows bigger every day, and much of what we call progress is harmful to the environment. When we use the principles of permaculture as the basis for design decisions, we act and progress with nature. Doing so reminds us that we, too, are part of nature’s complex systems. We cannot survive outside of nature; it behooves us to act in harmony with it.

Patrick Praetorius is an educator, writer, and permaculture enthusiast living in Ojai, California. He particularly wishes to thank Oak Grove teachers Teph Dobbie, Onah Helgesson and Theresa Bulla-Richards for their contributions to this project.

Resources

When looking at systems education, a number of topics come to mind: There are solar systems, human body systems like respiratory or circulatory, there are water cycles and number systems like ancient Greek or binary code. One example that might not come to mind initially is systems of organisms.

The Portuguese Man O’ War, for example, is actually not a single organism, but a colony of four kinds of hydrazoan polyps, each with a specific function. Insect colonies such as honeybees, ants and termites, provide simultaneous examples of many kinds of systems.

On a very basic level, the individual insect is completely dependent upon the colony to survive. In gathering food, termites employ a swarming technique and gain access to food sources that individually they could not achieve.

The anthill and the hive

The social structure of the hive or colony is also a system. Clearly defined roles and tasks ensure that there will be enough food, a healthy queen, and plenty of offspring to sustain the colony. A highly organized system, which scientists are still studying, is at work.

There is the system of foraging, storing food and feeding, which meets the immediate needs of the adults and larvae as well as provides enough food for the winter. Within that is also a surprising system of communication, whereby a worker can communicate to others the location of food sources. In bees, this is shown through the waggle or wag-tail dance; in ants, via pheromone trails.

Another interesting system to observe is the architecture of the homes of these creatures. From the golden mean regularity of tension and compression in the layered, hexagonal cells of bees, to the many-chambered tunnels of ants, to the elaborate castings of termites, one has plenty to wonder about. How do these compare to human systems of engineering? Tunnels, bridges and housing construction would be interesting to investigate alongside of these natural forms.

Lastly, one can consider the systems at work when these insects encounter human beings. What niche is filled by ants, by termites? What would happen if bees no longer pollinated the flowers of fruit trees and vegetables? How is it possible for humans to harvest honey in such a way that the beehive can sustain itself, and what methods must we use to harvest the honey?

When a teacher learns alongside children or shares an area of prime interest, there is often more potential for exciting learning. Students perceive the enthusiasm of their teacher and respond to that greater interest and energy. On the next page, author John Fisher of Life Lab Science Program in Santa Cruz, California, describes bee-keeping activities developed for classrooms by staff as they eagerly learned about their new bees.

—Editor
Life Lab’s Bees and Honey

by John Fisher

When the bees for our observational beehive first arrived and got busy, so did Life Lab staff. We wondered what these bees were doing? As we learned more about the bees, we were amazed at how incredible, complex, and specialized the life within a honeybee hive is.

For example, bees have special “eyes” that can see the sun on cloudy days to aid in foraging navigation. A queen bee starts as the same egg and sperm as a worker bee but grows to be a queen based on consuming a higher proportion of royal jelly (a substance excreted by a young worker nurse bee).

Most people know that bees “dance” to “tell” their sisters where to forage for good sources of nectar and pollen using the relative angle of the sun as reference point. But in addition, the dancing bees will also alter the angle of their dance to compensate for movement of the sun. And did you know that worker bees, in the absence of their queen, will start to lay eggs as a last ditch effort to pass on genetic material? We shared our fascination with visiting students and eventually developed a classroom-based program, “Bees and Honey,” for first through third graders.

Introducing “Bees and Honey”

First, we explain the main reasons why people keep European honeybees.

Use a grab bag and have children take turns to pull out a jar of honey, a piece of fruit and a beeswax candle to represent the following:

- Honey, which is a substance secreted by worker bees at a certain age and used to build their comb. Beeswax is still used today for many items such as candles, cosmetics and wood finishes.

- Wax, which is a substance secreted by worker bees at a certain age and used to build their comb. Beeswax is still used today for many items such as candles, cosmetics and wood finishes.

The three types of bees

Workers make up close to 99 percent of the hive. These female bees take on all of the “jobs” to keep the hive running and live only an average of four to six weeks during the spring and summer.

The Queen has only one job, reproduction. She can lay up to 1,500 eggs a day. She’ll mix an egg with sperm to create a worker and an egg alone will become a drone.

Drones are the big-eyed boys of the hive. Not much on their daily agenda but to see if any neighboring queens need to be inseminated. When a new queen has hatched they will chase her high in the sky and only the fittest drones will catch her to mate. After their job is done they die, but they have completed their task of passing on their genetic material.

The life of a worker bee

During this section of the program volunteers are called to the front of the class to represent worker bees of different ages, and
Students wear signs stating the age of the bee and role they serve. Students also hold props that relate to the bee's role.

1- and 2-day-old bees work as housekeepers. "After a baby bee crawls out of its cell, its first job is to clean the hive. Were you doing a job like this right after you were born?" The student holds a hand broom and dustpan.

3- to 5-day-old bees work as nurses. The proboscis is pointed out on an anatomy picture of worker bee to show how bees feed each other. "When the worker bee is three days old, her job changes to be a nurse bee. She feeds the baby bees that are still developing in their cells." The student is given a baby bottle to hold.

6- to 11-day-old bees work as royal nurses. "At the age of six days, a worker becomes a royal nurse, taking care of the queen and feeding some royal jelly to the baby bees." It is the royal jelly, fed in higher proportions to the queen larva, which makes a normal larva develop into a queen. We give the student a fancy-looking jar labeled Royal Jelly.

12- to 17-day-old bees are wax makers. At twelve days old, the bee’s job changes to wax maker. Special glands on her abdomen begin producing wax, and she helps to build the cells that make up the bees’ hive. We hand the student beeswax.

18- to 21-day-old bees work as guard bees. Guard bees are stationed at the hive entrance to make sure no intruders come to steal honey. Guard bee volunteers wear a badge and photo of a bee’s stinger is displayed.

3- to 6-week-old bees are foragers. The word “forage” is defined and we explain that worker bees spend the rest of their short lives collecting pollen and nectar as food sources for the hive.

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**Communication skills**

Honeybees have a complex communication system that is not thoroughly understood by humans. Bees use pheromones to communicate and will dance to demonstrate the location of food sites. A great way to demonstrate the bees’ dance in action is to show the bee dancing portion of the video, *Discover Magazine: Secrets of Science*, Volume 4, “Life Around Us.” Depending on the energy level of the class, students may be asked to get up and dance like a bee. The longer bees shake, the further away a food source is. The harder they shake tells the quality of the food.

The program concludes with an explanation of how different plant nectars create different types of honey. *Life Cycle of the Honey Bee*, a Reading Rainbow video, shows a beekeeper extracting honey from a hive. Beekeepers cut the comb open with a heated knife and spin the comb in a big centrifuge to extract the honey.

Honey flavors and colors vary greatly. The honey taste test is set up by putting drops of three different types of honey on a “tasting palate” (a small piece of card stock). Students can easily compare the different colors of the honey and then taste the three types. Students vote on their favorite. Orange Blossom is a continual winner. Purchasing honey from a farmer’s market or directly from local producers are ways to include more unique types of honey.

After voting on the taste of honey, children get the chance to wear the protective clothing a beekeeper uses and to handle beekeeping tools. This visiting program is a successful addition to classroom studies, for it combines multiple methods of instruction and addresses a variety of learning styles while focusing on an interesting topic that may have many local connections.

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**Resources**

- [http://www.lifelab.org](http://www.lifelab.org): Life Lab Science Program is committed to environmental stewardship by promoting science and garden-based education for all learners.
Watch Out! Systems Change!

In elementary science, the word “system” perhaps is applied most often to the Solar System, which we all learned is a group of nine planets that revolve around our sun. Incredibly old and fixed in number, this has been a system that we have been confident to teach about, imparting knowledge that should not change during our students’ lives and generations beyond. Until the Pluto problem.

Although portrayed as a decision to include or exclude Pluto from the list of the Sun’s planets, this was really a complex debate among astronomers (concluding with a vote by the International Astronomical Union). A competing proposal would have kept Pluto on the list and added Pluto’s large moon, Charon; the largest asteroid, Ceres; and recently discovered Xena. Another plan could have raised the number of planets to fifty-three, many of them in the Kuiper Belt beyond Neptune, where we find Pluto.

The astronomers created a definition of “planet” that excludes Pluto and many reports about this have also made us aware that the system of nine planets (now eight) is really far more complicated, with dozens of large objects (but smaller than planets) to be found within the space occupied by this system.

What do we mean by system?

The very word, system, may suggest permanence: something has been so well figured out that it is a system that can then be explained to others. Yet, in science, systems are changing all the time—or we are learning more about them so that the data and our information changes significantly.

So, now what is a planet?

The Astronomical Union now defines it this way:
A planet is a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and (c) has cleared the neighborhood around its orbit.
The concept of a system also runs the risk of being arbitrary. Professor Mike Brown at the California Institute of Technology discovered 2003 UB313 (now nicknamed Xena). He recently wrote about the planet argument in the New York Times (8/16/06):

Think of it this way. The term “planet” is similar to “continent.” The word helps us organize our world, but the division between continents and subcontinents is thoroughly arbitrary.

Professor Brown is referring to our creation of a system out of the best data available at the time. All these terms are conventions that make it easier for us to think about and discuss continental landmasses, or the solar system, or many other systems.

Solar system / school system

The solar system, now down to eight planets but up every year in the complexity of other masses to be found within it, provides an example of another challenge for schools. Education Week (9/6/2006) reports that changes in textbooks will take roughly three years and some states will not adopt new texts for several years after that. Several states are planning revisions in their tests, however. This will mean that some states will have approved texts that say one thing about the planets and tests that have a different correct answer. For teachers and students, this is not too important in this well-known case where much current information is available in print and online. But it does point to how long it takes our system of education to adapt and change in a world where new knowledge brings about changes at high rates of speed.

—EDITOR

From the earliest recorded times, vast amounts of human research and invention have related to fascination with planets and their moons. See Resource Reviews on page 20 of this issue for a review of Exploring the Solar System, complete with a detailed timeline and narrative.
In 2003, Connect reported on a model of the solar system built to scale along US Route 1 in northern Maine. The idea, which was developed by Professor Kevin McCartney at the University of Maine at Presque Isle, was to create a model that was accurate as to the diameters of the planets and to the distance between them. This is something none of us can do within a school because of the vast distances that are involved.

For the model in Maine, the sun is almost fifty feet in diameter and is painted on a wall of the Northern Maine Museum of Science. The Earth is five and a half inches in diameter, one mile from the museum (the sun). Pluto is one inch in diameter and forty miles from the sun, located on the wall of an information center in Houlton. Route 1 in that region is relatively straight as it runs through Aroostook County, making it possible to create such a model.

The change in labeling of Pluto has caused the designers to plan for inclusion of several dwarf planets on new outdoor bases. To put a model outdoors the scale must result in a size that is about as big as a marble. Smaller objects (at the standard scale) may be located in schools or other public buildings.

In the case of the Maine model, the new designation for Pluto will result in a more complete solar system presentation, illustrating the system as a much more complex phenomenon than just eight planets. Instead of seeing Pluto as something to remove (the solar system has only eight planets), the change brought about a review and improvement of the whole system as presented in this vast model.

The scale of the model in miles is 1:93,000,000, or one mile to one astronomical unit. The distance from the Earth to the Sun is defined as an astronomical unit, or 93 million miles. For the record book: this is said to be the world’s largest solar system model.


• Diameter: 5.5 inches (14 cm)
• Location: Percy’s Auto Sales (1.0 mile or 1.6 km from Sun)
• Construction: Styrofoam ball with fiberglass cover
• Constructed by: Caribou Tech Center (Caribou High School)
• Painted by: Jeane McGowan, Curator of Collections at the Northern Maine Museum of Science and student at the University of Maine at Presque Isle
• Posts constructed by: Northern Maine Technical College, Sonny Michaud and students
• Base constructed by: David Tarlale and his students, Living Job Corps, Cement Mason Program
• Moon (diameter: 1.5 inches or 3.8 cm, 10 feet or 4.9 m from Earth axis)
One of the ongoing challenges teachers face is helping students to forge connections. Beyond memorizing names, dates, and other isolated facts, we want students to see how things are organized and the ways in which they are linked. When everything is separate, each item needs to be accessed and recalled as a discrete entity.

Just as we help students develop the ability to organize their papers and books, we need to help them to organize what is on those papers and in those books. At the very least, stuffing everything into the great bookbag of life makes it hard to locate what you’re looking for. More important, however, is the lack of conceptual connections when everything remains separate. To shift the analogy a bit, are we helping students pile up more and more building blocks, or are we helping them to build elegant structures?

Unfortunately, traditional schooling and much of popular culture work against this structure-building. Most textbooks and efforts at mass assessment favor isolated facts over substance, but the problem goes much deeper. The controversy that erupted this summer over whether Pluto is a planet presents a great opportunity to engage science students in issues of operational definitions and categories, instead of just memorizing planets.

Immediate responses focused on how soon textbooks (as the repositories of all things wise) could be updated, and how the MVEMJSUNP (“My Very Excellent Mother Just Served Us Nine Pies”) memorization tool for the order of planets was being upset. Clearly an American icon useful in helping generations of students pass their astronomy test was at risk. While some of this press-posturing was decidedly tongue-in-cheek, the fact that the discussion is even an issue is indicative of how far schooling can stray from being an intellectual endeavor if we leave the curriculum to being a collection of loose pieces.

Helping our students to view the world through organized systems offers one powerful means to combine their loose blocks and build up elegant cognitive structures. As a means to that end, concept-mapping software offers a flexible tool for building, sharing, and critiquing models. Over time, many find that having access to such a tool becomes an indispensable part of their thinking repertoire. Once you start thinking in terms of systems it’s hard to stop!

To start, two examples are provided here of how concept mapping can advance typical elementary school science investigations. These examples use Kidspiration, the kid-friendly version of Inspiration (http://www.inspiration.com), since these programs are commonly used in schools. A wide range of other programs is available. A web search for concept-mapping software reveals a plethora of options for different computer platforms, some of which can be downloaded for free.

**Cause and effect**

Perhaps the simplest use of concept-mapping software is to show cause and effect. Under what conditions do plants grow well? Among other considerations, they need water, light, and good soil. A simple diagram can be constructed showing how these factors lead to good plant growth.

Going further, a common elementary grade experiment investigates what happens when a plant has most of these conditions but one is removed. For example, how well does a plant grow when it has no access to light? An experiment I did with my students once tested this with sunflower seeds, with the resulting plant...
being reasonably well developed, but a pale milky white instead of green. Without the light to “feed” photosynthesis, the normal coloration doesn’t appear.

Using Kidspiration, the students could show the results of their experiment, comparing the different outcomes realized by having or not having access to light. One possible representation of this is included here.

Students could then add digital photographs to their project, showing the causal link and the results. One could argue that the photographs by themselves show the outcomes, but a concept map can show the full scope of the project, helping students to document the thinking behind the experimental design, the inputs, and the outcomes. In all, this leads to a more comprehensive view of the project that ideally can become recursive, promoting thought about what else could be changed in a second round of testing.

Displaying local food webs

In the ecology field labs we run for students at the Litzsinger Road Ecology Center (a division of the Missouri Botanical Garden), we start with careful observation of attributes and behaviors of the organisms found on site. One of the common extensions past this initial phase of observation is a consideration of where the organism fits in the ecosystem. From where does it get its energy? Which animals are likely to prey upon it? This avenue of inquiry, of course, can lead to a very engaging look at adaptations: What features allow an animal to eat and not be eaten?

Students can use concept-mapping software to capture these relationships, showing what sources provide energy to the plant or animal in question, and which animals in turn rely on it for energy. This multi-layer thinking is an essential part of developing ecological literacy, promoting understanding that everything is connected to something else.

Systems thinkers

As your students mature, the complexity of these models can grow to reflect ever more interconnections, but even simple webs in the elementary grades are a great start. In terms of ecosystem thinking, creating a model of your local food web helps students to visualize what might happen if there were a shortage of a particular prey species or an abundance of a particular predator.

As these examples show, adding concept mapping to your curriculum can help students to integrate their metaphorical blocks into larger conceptual structures, showing how one factor affects others. Paper and pencil concept mapping is extremely valuable, but the benefit of software-based models is the ability to quickly revise or expand a model based on new insights or critical feedback. Whether your students build their models with software or with quick sketches, they are on their way to becoming systems thinkers.
**Mammoths on the Move**, by Lisa Wheeler (Harcourt, 2006), is a stunning book that uses rhyme and repetition to convey theories about the lives of woolly mammoths. Dynamic scratchboard and watercolor illustrations by Kurt Cyrus convey the magnificence of these beasts. The simple text for ages four through nine relates issues of migration, predation and changes in population, as well as outlines the roles of males and females in herds. An interesting note from the author explains that this information is based on the latest available research, or lacking that, developed by studying the closest living relative of mammoths, the elephant.

**The Big Rivers**, by Bruce Hiscock (Atheneum, 1997), is an interesting book to use, particularly after the flooding and broken levees as a result of Hurricane Katrina in 2005. The author provides a look at the big picture of three great rivers: the Missouri, the Mississippi, and the Ohio, and the “giant saucer” that holds these rivers between the Rockies and the Appalachians. Although dated, this book for ages eight through thirteen gives a great explanation of the larger systems of weather, water cycle and watersheds. This book could serve as a historical piece to compare to more recent weather patterns and speculation on the impact of global warming, as it refers to the flood of 1993 as an event that happens only, “once every few hundred years.”

**The Woods Scientist**, by Stephen R. Swinburne (Houghton Mifflin, 2002), tells the story of naturalist Susan Morse. Using photographs and a conversational tone, the book describes Susan’s job, her way of life, history, and the terrain and animals she encounters on the job. Much information is shared here about specific animals, tracking, documenting observations, also general information about ecology and the interconnectedness of species. This is part of the **Scientists in the Field Series** and is particularly suited for students in second to fifth grade.

**The Glass Ark: The Story of Biosphere 2**, by Linnea Gentry and Karen Liptak (Puffin, 1991), is a fascinating book about developing a prototype for colonies in space. It was written just as the “biospherans” were about to seal the air lock doors and commence their two-year trial of living without resources or wastes coming in or going out of the giant greenhouse-like structure. With optimism and excitement, the authors describe the many facets of the attempt at a closed system. This experiment pushed scientists to consider the systems at work on Earth that sustain us. The story of Biosphere 2 provokes many questions for older students. What would it take to simulate life on Earth? What would you include in a Biosphere 3? What are some of the problems that biospherans encountered and how might we address those now? (The facility is now privately owned by a corporation that conducts tours and manages a hotel and conference center.)
The Pebble in My Pocket, by Meredith Hooper (Viking, 1996), is an exciting chronicle of a 480 million-year-old pebble. A young girl observes a rock she holds and asks, “Where did you come from?” Volcanic eruptions, mudslides, tides, glaciers, and winds all play a part in the formation of the rock. Chris Coady’s illustrations, painted and drawn on a textured background, add even more drama to the story. A geological timeline with further information is included at the end of the story. This is a great book for first through fifth graders to accompany studies of geology, rocks and minerals, prehistoric animals, cycles, and systems.

The Magic School Bus at the Waterworks, by Joanna Cole (Scholastic, 1986), is but one of many titles in the Magic School Bus series. Although at times simplistic in the information she includes, Joanna Cole creates an engaging format for young readers. Combining non-fiction and fantasy in a comic book sort of format, she conveys important ideas, facts and questions in an engaging manner. Follow students and their fearless Ms. Frizzle as they don scuba suits and transform through the water cycle, into a reservoir, and into their city’s water supply.

 Millions to Measure, by David M. Schwartz (Harper Collins, 2003), is a whimsical book that explores systems of measurement. Although quite silly, it gives comprehensive descriptions of equivalencies, how standard measurement came to be, the metric system, and an example of what can happen when things go wrong: two NASA teams used different systems (standard and metric) to calculate the trajectory of a space probe, each thinking the other was using the same system. The result was that the probe headed off into the great vast space rather than head toward Mars, its target. This fun book can reinforce concepts of measurement systems for students in second through fifth grade.

The Honey Makers, by Gail Gibbons (Morrow Junior Books, 1997), provides a colorful guide for young readers to the world of honeybees. First, the life cycle of the bee and structure of the hive is described. Then, the history, techniques and tools of honey gathering are explained. The simple language of the text and friendly drawings make this a very good resource and an interesting picture book. The author includes monthly entries from a beekeeper’s yearbook at the end of the story, which helps to convey the cyclical nature of beekeeping and a more agrarian awareness of the calendar. Bee facts and cautions conclude the book.
Resource Reviews

**Engineering the City**, by Matthys Levy and Richard Panchyk, looks at complex systems, encouraging students to ask questions in order to understand how one might design such systems. Each chapter begins with a broad concept (i.e., water, transportation), and leads readers to consider a simple, early application of technology. Some activities are included. Then step by step, through additional questions and facts, progressively complex ideas are introduced. Students are asked to consider the infrastructure with which they currently live. What is necessary? What could we live without? Water, waste management, transportation, power, and construction (of highways, bridges, etc) are some of the topics covered in this excellent resource for students aged nine and up. 129 pages. **Engineering the City** ($14.95) is available from Independent Publishers Group, Order Department, 814 North Franklin Street, Chicago, IL 60610. Call 800-888-4741, fax (312) 337-5985, online at http://www.ipgbook.com.

**Exploring the Solar System: a History with 22 Activities**, by Mary Kay Carson, tells the story of how we discovered and learned what we know about our solar system. It is structured as a timeline, beginning with prehistoric peoples’ observations and beliefs, continuing through Eratosthenes, Galileo, detailing pivotal moments in the space race between the Soviet and US space programs, and concluding with the most recent explorations at the time of publication. Many sensible and fun activities appear throughout this comprehensive text. Glossaries, timelines, biographical information, and a field guide to the solar system make this a valuable resource for teachers of students aged nine and up. 168 pages. **Exploring the Solar System** ($17.95) is available from Independent Publishers Group, Order Department, 814 North Franklin Street, Chicago, IL 60610. Call 800-888-4741, fax (312) 337-5985, online at http://www.ipgbook.com.

**Environmental Detectives**, from the Lawrence Hall of Science, is a GEMS (Great Explorations in Math and Science) guide that presents a mystery for fifth-through eighth-grade students to solve. A significant fish die-off began five years ago in the “Gray Area,” a fictional watershed that includes forests, a city and town, a coast, and several bodies of water. Students collect data, learn about potential contributors to the problem, and realize the complexity and interwoven nature of environmental problems. GEMS guides in general are excellent and this one is typically well thought out and incredibly thorough. Not
only is the content excellent, the supporting ideas such as managing groups and materials, asking leading questions, scaffolding learning, and assessing student progress are outstanding. Correlations to national standards and resources are included. 256 pages.

**Environmental Detectives** ($25.50) is available from Lawrence Hall of Science, University of California #5200, Berkeley, CA 94720-5200. Call 510-642-7771, fax 510-643-0309, online at http://lawrencehalloffscience.stores.yahoo.net/.

**Ecosystems**, from the National Science Resources Center, is both a teacher’s guide and a kit. This comprehensive guide walks a class through making first terraria, then aquaria, and then connecting the two in a human-made ecosystem, complete with live organisms. The guide is very well researched, with expert advice on managing students and materials. It succeeds in sequentially building upon previous activities to arrive at a complex yet understandable result. **Ecosystems** was recently revised and includes lots of information tying learning to national standards. One point to consider before engaging in this study is figuring out what to do with the organisms once the unit is over—in some states release of the organisms into the surrounding environment is illegal. **Ecosystems** is available as a guide alone ($99.95) or as a complete kit ($795.00) from Carolina Biological Supply. Call 800-334-5551, fax 800-222-7112, online at http://www.carolina.com.

**Plate Tectonics** and **The Greenhouse Effect**, by Darlene R. Stille, are two titles in the Earth Science series for accelerated readers. These books for ten- through thirteen-year-olds are filled with information and images that will engage readers eager for non-fiction material. Because the author presents material in such an age appropriate manner, these books are particularly useful for teachers who are organizing resources for students’ research. The amount of text on the page, exciting images, and comfortable size make these attractive to students. 48 pages.


**Science is Elementary** is the four-issue annual volume published by MITS, Museum Institute for Teaching Science. Titles of issues this year are **Climate Change**, **Earth’s Atmosphere**, **The Shape of the Land**, and **Our Oceans**, all good topics for systems. This journal, free of advertising and packed with background information, activities and resources, is a great value for teachers. To further its mission of, “the teaching of participatory, inquiry-based science, mathematics, and technology/engineering in elementary and middle schools,” MITS also offers summer institutes, workshops and conferences. Their Web site lists back issues and other publications. 48 pages per issue. **Science is Elementary** ($26.00) is available from MITS, Inc., 308 Congress Ste, Suite 5D, Boston MA 02210-1027. Call 617-695-9771, online at: http://www.mits.org.

**Bullfrog Films** has a large collection of videos and DVDs related to science and social science topics. Topics such as Globalization, Global Warming, Ecological Design, Sustainability, Biodiversity, Ecosystems, Conservation, Pollution and Physical Science can be considered in studies of systems and system dynamics. They offer resources for students in pre-school through college. **Bullfrog Films** can be contacted by writing Bullfrog Films, Inc., PO Box 149, Oley, PA 19547. Call 800-543-3764, fax 610-370-1978, online at http://www.bullfrogfilms.com.
The study of water teaches students that if they look carefully at familiar things, there is more to learn and deeper understanding to be gained. Further, it is a rich topic for developing basic skills. In the Water Works curriculum, students predict, experiment, observe and draw conclusions. They read, calculate, and communicate. Activities address many Learning Standards set forth by the Massachusetts Curriculum Frameworks as well as national standards. Water Works, the Massachusetts Water Resources Authority’s elementary curriculum guide, is intended to lay the foundation of responsible water use for elementary students, leading them to look beyond the faucet to the natural and human-made systems which support that stream of clean, reliable water.

Water systems are instructive examples of technology for elementary students. Technology, these days, conjures up “high tech,” wires carrying electrical charges that no one can see. Low-tech water pipes carry water, with which students are entirely familiar. Water systems are science and technology in service to families, businesses and the community. The technology is in their homes and under their streets, bringing them essential services.

Finally, water systems can help students consider distant and local human history. Not many generations have enjoyed the hot water and flush toilets that we take for granted. When and why did people decide to concentrate resources on water supply systems? Though Water Works concentrates more on the science and technology of water supply, other areas of inquiry are readily available. Whether it is town history or the Roman Aqueducts, fruitful connections and extensions abound.

Just as we benefit today from planning done a century ago, today’s young people will soon be responsible for community decisions with far reaching consequences. Water Works is designed to help build a foundation that serves the community today and tomorrow.

Building a model water delivery system

I am invited into hundreds of classrooms each school year. “Building the System” is the activity I conduct most often for grade three classes throughout the Water Resources Authority. I begin each lesson...
by telling the students that the MWRA is responsible for bringing water to all the buildings in their community. “We bring you your water, but where did the MWRA get it from?” I ask.

The faucet and pipes are the most popular answers. I explain that it does travel through pipes to the faucet. “But where was it before it got in the pipes?” Answers range from the ocean to rivers, some mention wells and ground water. Sometimes a student will mention a reservoir.

I then show a picture of the Quabbin Reservoir and give a brief history. The Quabbin Reservoir, located 65 miles west of Boston, is the largest human-made reservoir in the United States. When it is full, it holds 412 billion gallons. The kids are usually fascinated to learn that, years ago, there were four more towns in Massachusetts. Everyone in those four towns was forced to move and all the buildings were demolished. There were 36 cemeteries throughout the towns and all the graves had to be relocated. The reservoir was completed in the year 1939.

It took seven years for the reservoir to fill. How did the reservoir get filled with water? I tell them that there are three main ways that it was filled and all begin with the letter “R.” Rain is the most obvious (and correct) answer. Dams were constructed to divert the flow of rivers into the reservoir. Runoff is the third way. I asked the students what year the reservoir was filled to capacity for the first time. Someone always gives me the correct answer: 1946.

Reservoir to towns and buildings

Now we get into how the water moves from the reservoir to all the buildings in their town. It doesn’t take long for the students to figure out that the water travels through pipes. I tell the students that indeed the water does travel through pipes and I mention that when I was driving through their town I didn’t see any pipes. They all know that the pipes are buried under the ground. I explain that it is the MWRA’s job to fix broken pipes and to replace old pipes with new pipes. I then ask why we bury the pipes under the ground.

Students tell me that if the pipes were on top of the ground, the cars would crash into them and people would be tripping over them. I then tell them that there is another important reason why we bury the pipes under the ground and that it has to do with weather in winter.

“Because the pipes would freeze!” they tell me. “But, is it the pipes that would freeze or is it the water in the pipes that would freeze?” I wonder aloud. We then get into a discussion about what happens to water when it freezes. When water freezes, it expands causing the pipes to break. I explain that by keeping the pipes underground, the ground acts like a blanket, keeping the water warmer, so that it won’t freeze, expand, and break the pipes. In the summer, it has the opposite affect, keeping the water cooler.

It’s time to begin hands-on learning. I explain to the kids that they will have to use their imagination. Everyone’s desk will be a different building in the town and will need water. It doesn’t take long for the students to get the point that every building needs water. The aisles between the desks are the streets that have water pipes running beneath them. We discuss how the water gets to the buildings and I note that the water leaves the reservoir through a tunnel (aqueduct) and that pipes branch off and lead to water mains in different communities. Connector pipes then lead from the water mains, bringing water to each building.

Laying down the pipes

Now the fun (and more learning) begins. To represent the MWRA pipes, we use cardboard tubes. The community’s water mains are slightly smaller diameter cardboard tubes and the connector pipes are straws. After I lay down the MWRA delivery system, each student then lays down a water main. They must connect to either an MWRA pipe or another water
main already on the ground. We talk about the fact that there is only one main water pipe (or water main) running down the middle of each street.

After the local water delivery system is in place, each student must estimate how many connector pipes he or she will need to purchase in order to connect his or her building into the nearest water main. We discuss over- and underestimating and the consequences of each.

I explain to the students that the goal is to use as few connector pipes as possible when connecting into the nearest town water main. Some students will, in an attempt to use the fewest connector pipes possible, connect into an MWRA aqueduct or another student’s connector pipe. This always provides a valuable lesson and much discussion. After every building is connected to the nearest water main, we talk about the many ways each building utilizes water. The kids soon comment on how much we take water for granted.

I then “break” the connector pipe leading into the school and ask who is responsible for fixing and paying for this broken pipe. The most common answer is the principal, followed by the janitor. After a lively discussion, someone realizes that the town owns the school and therefore is responsible. The students are always eager to assist with breaking down the system.

I know the students have fun doing this activity, but I want to make sure that they

Just whose pipe is it?

If time permits, I will sometimes “break” a pipe. We talk about who is responsible to fix the broken pipe—MWRA, the town, or the person who owns the building. I always get a positive response when asking the leading question, “Did anyone choose this school as their building?”

About the MWRA

The Massachusetts Water Resources Authority was established by an act of the legislature in 1984 to provide wholesale water and sewer services to 2.5 million people and more than 5,500 industrial users in 61 metropolitan Boston communities. Its School Education Program includes curriculum guides containing hands-on activities for a range of water related topics and grade levels, in addition to free teacher workshops and classroom presentations in the MWRA communities. These classroom presentations are conducted for grades Pre-K through grade 12. Subjects range from the drinking water supply beginning at the Quabbin Reservoir and the distribution system to wastewater treatment at Deer Island and the transformation of wastewater into effluent.
have actually learned from it as well. I ask the kids to name some of the things they could not do if there was no water in their building. Eventually, we talk about the fact that you would not be able to flush a toilet. At this point, amid giggles and gasps, I pull out a miniature flushing toilet and ask who wants to flush. Each student must answer a question in order to flush! I am always pleasantly surprised at how much the kids learn and retain. This is often the kids’ favorite part of the lesson and mine as well.

That might sound trivial, but teachers always tell me they love this part of the lesson because it makes the students actually think about what they learned, not just focus on the fact that they had fun putting a bunch of “pipes” on the floor. It also teaches some important lessons, such as the fact that the water that fills up toilets is clean drinking water to begin with. One set of pipes brings all the water into a building (Others take the used water away). The water filling up a toilet has the same source as that which comes out of the kitchen faucet, the shower head, or that fills up the dishwasher or their fish tanks.

**Beyond this first experience**

Teachers often comment that students are so eager to answer my questions that you would think I was handing out one-hundred dollar bills. Some teachers tell me that if they put the same questions in front of their students as a quiz, the kids probably wouldn’t be able to answer them.

This ending also leaves the students with a desire to learn more about the MWRA and the sewer system. I explain to the students that bringing clean water to cities and towns is only one of the tasks of a water authority or district. Our other big job is the opposite. If one of our jobs is to bring you your clean drinking water, what would our other job be? “To take away the dirty water!”

“How do you do that?” they want to know. “Down the Drain” is a lesson that explains what wastewater is, where it came from and where it goes. Sometimes, I do “Building the System” with a certain grade level (3-5) and come back the following year (grade 4-6) to do the “Down the Drain” wastewater lesson.

One teacher shared with me that her students were quoting water system statistics for days after my lesson. They read *Letting Swift River Go* and found the Quabbin on a map, since they were in the middle of a mapping unit. Studying the Quabbin and water systems tied the science and social studies curricula together in a sensible way for these students.

Meg Tabacsko is manager of the Massachusetts Water Resources Authority School Education Program. She received the Educator of the Year award in 1994 from the New England Water environment Association, and the Napoleon Bonaparte Award in 2004 from the Massachusetts Marine Educators Association.
The National Standards in science education list machines as being a prime example of systems at work. Teachers have been resourceful and creative in presenting simple machines to students over the years.

One idea for a means of studying simple machines is to put them in the context of Rube Goldberg machines. Goldberg was a cartoonist, sculptor, and author, best known for his drawings of machines he described as being, “symbols of man’s capacity for exerting maximum effort to accomplish minimal results.” Teachers can pose to their students the challenge of designing a comical and complicated way to complete a simple task, employing simple machines in the process. The Theta Tau fraternity of Perdue University holds a Rube Goldberg Machine Contest each year for students in high school and college (http://www.rube-goldberg.com/), but your class could promote a contest in your own school.

Many area science museums work with classrooms as part of studies of energy or inventions. To find a science center near you, visit: http://www.astc.org.

Simple machines can become components of kinetic sculptures, as in the works of artist George Rhoads (http://www.georgerhoads.com/) who constructs sculptures that chime, click and bing as marbles or billiard balls course through a series of tracks and channels.

Sculpture challenges can involve whole communities, as the Kinetic Sculpture Race in Baltimore, Maryland does each year. Contestants maneuver their artworks under human power only, over 15 miles of pavement, mud, sand and water (http://www.kineticbaltimore.com/), in an eight-hour race! Could your students build models of vehicle/sculptures capable of this feat?

Students expand on the standard elements of simple machines to build more and more complex devices, all of which will use some form of energy to do work. In no time at all, they’ll progress from simple to not-so-simple machines!

Wheels and axle take a spin down an inclined plane