www.concord.org vol. 9, no. 2 Fall 2005

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REALIZING THE EDUCATIONAL PROMISE OF TECHNOLOGY

Five Lessons: A Taste of the Future, Today

Interactive lessons allow students to learn more science and math, earlier and deeper.

BY ROBERT TINKER

This issue of *@Concord* features five ready-to-use "Lessons" that illustrate how interactive models and tools can fit into real classrooms today. Each of these lessons addresses important content that can be found in all the standards and frameworks, and does it by giving students tools with which to explore and interact. The lessons illustrate how sophisticated math and science content can be taught earlier and how generative the resulting understanding can be.

Why these lessons?

For years, the Concord Consortium included a "Monday's Lesson" feature in our *@Concord* newsletter, which was quite popular. Each was an innovative, classroom-ready learning activity that you could use on Monday morning. We responded last year to this popularity by including five lessons in our fall issue, one for each day of the school week. That was so well received, we are doing it again in this issue. But just writing about this great interactive software fails to convey its educational potential. You have to use it and try it with your students.

To make this as easy as possible, we have included the software on a free CD. Just pop the CD into your Mac, Windows, or Linux computer and you and your students can run all the activities.

The lessons and CD are intended just to whet your appetite. Much more is available at our website. Best of all, it's all free. U.S. taxpayers have already purchased these innovative computer-based learning activities by making it possible for us to win grants, so we invite you to download and use them.

Enhancing inquiry with probeware

Whenever possible, students should interact with part of the real world. That's why we have been on a 25-year campaign to use probes and sensors with computers. What we first named "Microcomputer-Based Labs," and now goes by the more modern "Probeware," gives students unprecedented ability to explore the world, capture and analyze data, and understand fleeting effects.

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Inside

Free CD!
with interactive software included!

More Science for More Americans

BY ROBERT TINKER

American pre-college science, technology, engineering, and mathematics (STEM) education is in crisis. It is not only educators who are alarmed, but also those concerned with the economy, long-term security, and equitable access to education and employment. A confluence of factors will result in irreparable damage to the U.S. in a decade or so.

The factors that are converging include: overemphasis on testing and rote test preparation; the decline of problem solving, laboratories, and inquiry; too many under-prepared teachers; segregation and inadequate funding in many urban schools; and an outmoded curriculum. The results are already evident: poor performance on international comparisons, declining numbers and diversity in STEM college majors and graduate admissions, and increased reliance on foreign-born researchers.

> Educators know what is needed to **improve student achievement** in STEM fields.

This decay of STEM education will adversely impact Americans in the next decade, given the increasingly technological and interconnected world. It will result in poor public understanding of science that is needed for a democracy to function, inadequate technical capacity of the workforce, and too few of the inventors and researchers who drive innovation and change.

Educators know what is needed to improve student achievement in STEM fields. There is no mystery, no need for further academic research, and no "silver bullet" waiting to be found. The prescription is fairly unanimous among experts who understand STEM education. In a nutshell, we can provide more science education for more Americans by focusing on the following:

More projects and exploration. The national content standards in math and science promote inquiry and student exploration, with an emphasis on "extended inquiry" that resembles research as closely as feasible. But as these standards filter through state and local levels, the difficulty of measuring open-ended projects and the emphasis on facts and computation have effectively eliminated these standards.

Greater depth. The TIMSS study found that in 8th grade math, U.S. schools covered 16-18 topics with no single topic receiving more than 8% of the time. Other countries covered much less in far greater depth using texts that were one-third as large. In Japan, four topics received two-thirds of the class time. We need to teach fewer topics much more deeply.

More emphasis on causal explanations. The power of science depends on the way many apparently distinct phenomena are united by a few underlying concepts. Once the interconnections are understood, science can be easy to learn. Similarly, math is built on just a few axioms and operations, but both math and science are taught as disconnected facts, algorithms, and experiences while the connective tissue is ignored.

More diversity. We need to reach more students with quality science and to make it more interesting, meaningful, and accessible. Too many students are repelled by dry content, excessive emphasis on facts and procedures, and the apparent lack of connection to the real world. For others, mathematics requirements rule out the physical sciences and engineering. Using projects, going deeper, and relying more on reasoning and less on memorization will make STEM fields more inclusive and accessible.

If the evidence is so clear and the solution so obvious, why is there a STEM crisis? The fundamental problem is that it takes resources, skill, and content knowledge to teach—and to test—using more projects, digging deeper, and concentrating on cause-and-effect logic. Schools can lack the space, instrumentation, and other resources for student projects. And it is far more difficult to assess student progress in projects and deep understanding than it is to test for facts and procedural skills. In this era of measurable standards and high stakes tests, if something cannot be measured, valuable class time cannot be "wasted" on it.

Technology can enable the needed changes. It can provide an environment for enriching and guiding student exploration of both the real world and models, it can be used to assess student understanding and problem-solving skills, it can provide a medium for collaboration and dissemination, and it can be a powerful tool for teacher professional development to support the needed changes in curriculum and instruction.

Robert Tinker *(bob@concord.org) is President of the Concord Consortium.*

Improving Student Learning with Teacher Professional Development

RAYMOND ROSE AND
ALVARO GALVIS

The No Child Left Behind legislation states that all teachers must be "highly qualified" by 2006. However, current teacher data indicates that a number of teachers do not yet meet that definition. Many professional development programs aimed at helping teachers meet NCLB requirements are available, but they are not all alike.

Technology, and in particular the Internet, supports communication, collaboration, and sharing information—hallmarks of successful learning communities. Computer-based models and simulations help students learn difficult math and science concepts. The Concord Consortium has integrated these technologies into online professional development.

Use technology that excites both students and teachers

Simulations, games, and problem-solving tools allow learners to explore, inquire, construct ideas, and test those ideas. Our *Seeing Math*™ Secondary materials help algebra teachers reflect on their teaching by inviting them to become careful observers of their own learning processes while they explore math concepts with Java-based interactive materials. Teachers build knowledge by sharing their experiences with these materials. After they have experienced such inquiry learning and discussed their different solutions to the same problem, they use the interactive software with their students.

Focus on student gaps in learning

National and state standards, as well as standardized tests have helped to demonstrate the successes —and weaknesses—of each school district in particular content areas. This information provides a starting point for teacher professional development, which can focus on those weaknesses and develop targeted approaches to potential causes and possible solutions. In our *CONGENIA* project, which offers local and online courses for rural teachers in Colombia, the professional development effort is driven by the identification of student weaknesses on standardized tests; content is then aligned to those areas. Our *Modeling Across the Curriculum* project helps teachers see student gaps by capturing large amounts of data as students work with computer models. Analysis of the aggregated data at the classroom, school, and district level allows teachers to make targeted interventions and helps inform the design of appropriate teacher professional development activities.

Understand student thinking

Our *Seeing Math*™ Elementary interactive video cases capture the interaction between students and teacher, making it possible to analyze the learner's thinking. Teachers view videos and transcripts, plus surrounding materials in order to participate in grounded discussions centered on events in the video or in their own classrooms. They learn to analyze student work, as well as the questions and answers students pose.

Teachers practice questioning strategies to uncover student thinking, including misconceptions and a variety of valid ways of solving problems.

Recently, the Department of Education has called for scientifically based research data to demonstrate a professional development program's efficacy. Quantitative and qualitative evaluation of the Seeing Math project shows that teachers gain instructional knowledge after participation in our courses. As teachers incorporate that knowledge into their instruction, their content knowledge also increases, moving them into the "highly qualified" category.

Raymond Rose *(ray@concord.org) is Vice President of the Concord Consortium.* ***Alvaro Galvis*** *(alvaro@concord.org) is Research Director of the Seeing Math project.*

LINKS *Improving Student Learning*

- **Seeing Math** *http://seeingmath.concord.org*
- **CONGENIA** *http://64.76.89.221/fcongenia/home/home_ing.htm*
- **Modeling Across the Curriculum** *http://mac.concord.org*

Lessons–continued from page 1

Adoption of probeware has been slowed because it usually requires special equipment—probes or sensors and some interface electronics. The costs of these, the incompatibility of available systems, and the need to keep all student materials, documentation, software, and equipment together and functioning has proven to be too much trouble for many teachers. So we are developing probe-based learning activities that run on almost any computer, including handhelds, with almost any probe hardware.

Monday's Lesson, "Investigating Sound," is drawn from this project. Rather than requiring special hardware to detect sound, it uses the microphone now built into almost every computer. The software tool is streamlined, with few options, because it is designed for students as early as grade three. But it does not lack sophistication: a tremendous amount of computation is used to deduce the frequencies present in the sound. Students don't need to understand the computations, just how to interpret the results.

Figure 1: An illustration from the TEEMSS Sound activity, which suggests how young students can collaborate to understand the relationship between the sounds they create and the resulting waveform captured on the computer.

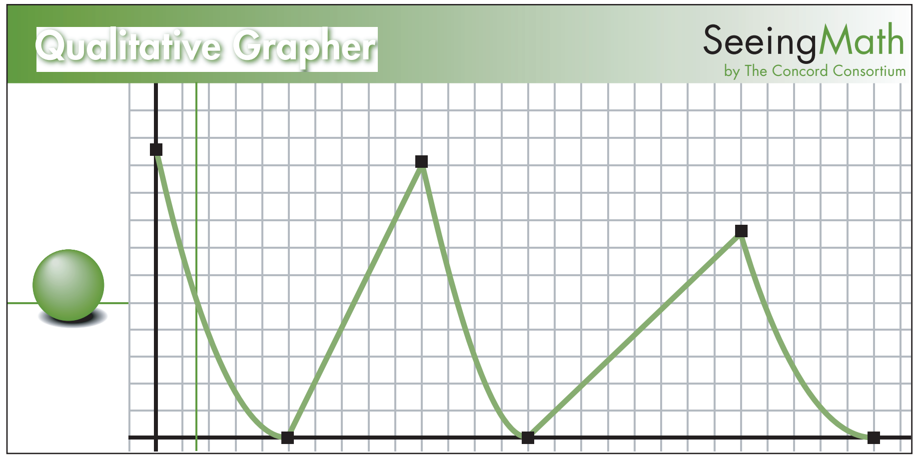


Figure 2: Here is a possible model of the height of a bouncing basketball. When you "run" this, the cursor moves to the right and the ball moves vertically according to the graph. Running this model, you would quickly notice that something is wrong.

Beyond calculation

Too much of mathematics is about learning facts and procedures. One of the reasons calculators are resisted in math education is that calculators already know all the calculation facts and procedures, so students don't have to think about them. But what happens if the calculator fails?

Tuesday's Lesson, "What Can You Do with a Broken Calculator?," shows how a broken calculator can stimulate student thinking. This software simulates a calculator with inoperative buttons and even allows the user to determine which keys do not work. The challenge is to come up with the right answer in spite of these hindrances—to design a work-around.

For instance, one student might solve a multiplication problem without a multiply key by thinking of multiplication as repeated additions. Another student might guess the answer, check by dividing, and then use the result to make a more accurate guess. Both approaches require understanding, not mechanical application of rules. Like most real-world problems, there is more than one right answer. A perceptive teacher will encourage different solutions and stimulate a discussion about why one might be better than another.

Elementary calculus

Calculus is the gateway to much of mathematics and science, but its beauty and utility is often obscured with derivations and proofs. Calculus comes late in the curriculum, not because it is difficult to comprehend, but because its formal derivation is. Few students think calculus is easy and fun.

A better approach is to design a strand of materials that build the concepts early. Students who never take a calculus course will still be able to use calculus ideas, and those who go on to formal calculus will build on a deep conceptual understanding.

Wednesday's Lesson, "The Trickster Squirrel," uses the Qualitative Grapher, which introduces calculus concepts in early grades. Unlike most graphers, it does not have numeric values on its axes, so students have to focus on the shape of curves and their meaning.

Figure 2 shows a graph that is easily constructed and explored. A student has attempted to show how a basketball might bounce, and while the graph does capture some of the general features, it is also wrong in several respects. By running the model, the student would soon notice that the ball should not slow down before hitting and that it will not rise steadily as shown. These are calculus ideas that couple slope and speed as well as curvature and acceleration.

Population experiments

It is almost impossible to do hands-on experiments with genetic drift and evolution, because many generations and large populations are required. The underlying situation involves sophisticated statistics, so a mathematical approach cannot be used with beginning students. This is a perfect case for a computational model.

Thursday's Lesson, "Budgie Populations," gives students hands-on experience with genetics, using our Population Explorer. This model traces the fates of individuals that obey basic genetic rules and react to the environment. Students can create a large population that reproduces according to standard Mendelian genetics. Any individual in this population can be examined to see not only its outward characteristics, but its genes and the molecules in these genes. Genes can be made to mutate. Students can alter the environmental impact on the health and survival of individuals with certain characteristics and see what happens over many generations.

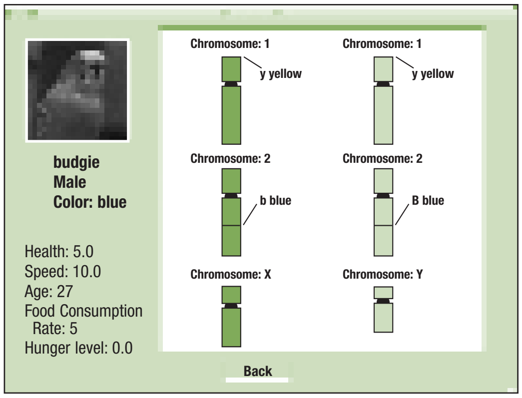


Figure 3: Students can cause mutations to budgerigar birds and witness evolution.

Of course, under the right conditions and over long times, the population can show genetic drift, speciation, and evolution. These are emergent phenomena that do not have to be programmed into the model; they are inherent in the assumptions of genetics, mutations, and environmental pressure. Experiments with such a system establish the basis of evolution.

> There is **a world of difference** between watching how a graph is constructed and **creating it yourself,** watching pre-recorded sound waves and **capturing your own,** or hearing about evolution and **setting up a situation** in which animals will evolve.

Science from the atoms up

Perhaps one of the most important ideas of science is nowhere in any of the standards: atoms stick together because of inter-atomic forces. Without these forces, there would be no liquids or solids; there would be no hemoglobin, viruses, or fingernails; and cloth would fall apart. Many biological molecules are active only when two or more stick together with inter-atomic force. It is almost impossible to understand the world without reference to inter-atomic forces.

Conversely, an understanding of these forces provides a deep unification of physics, chemistry, biology, and engineering. Students who understand the atomic basis of phenomena can apply their understanding to topics that would otherwise seem unrelated. This helps students see the organizing power of an atomic viewpoint and reduces the amount of science students have to memorize.

Self-assembly is a potent idea that dominates biology and is being examined as a potential way to assemble nano-sized particles and machines. If you understand that disorder (or entropy) generally increases, then self-assembly seems impossible.

Friday's Lesson, "Molecular Self-Assembly," is one of almost 200 that use our Molecular Workbench software based on inter-atomic forces. Not only can students observe molecular self-assembly, they can create their own molecules and see how their properties determine the ability to self-assemble and the shape of the resulting structure. Thinking about how the forces they have previously encountered can be used to create a particular shape makes the process feasible and comprehensible.

The future

In the future, computer-based models and tools will transform education by expanding the world that can be experienced and learned. The five examples in this issue give a taste of what that future looks like. Interaction is the key. There is a world of difference between watching how a graph is constructed and creating it yourself, watching pre-recorded sound waves and capturing your own, or hearing about evolution and setting up a situation in which animals will evolve. The lessons in this issue engage students in interactions and explorations.

The lessons also make concepts accessible to much younger learners. No abstract mathematics is required in the science lessons, not even beginning algebra. The only mathematical skill required is graph interpretation, and that skill can be acquired early using the Qualitative Grapher, or even the Sound Grapher. This is the promise of technology: it will allow the creation of lessons that allow students to learn more science and mathematics, more deeply, and far sooner.

Robert Tinker *(bob@concord.org) is President of the Concord Consortium.*

LINKS *Five Lessons*

- **Free model-based learning resources**
  http://www.concord.org/work/software
- **Probeware**
  http://www.concord.org/ccprobeware/probeware_history.pdf
- **TEEMSS**
  http://teemss2.concord.org

Investigating Sound

ED HAZZARD

Teacher Guide

Physical Science: Sound Waves

CD: Sound Grapher

Web: www.concord.org/resources

Grades: 3-8

The world of sound is extraordinarily rich—rich in meaning, emotion, cultural content, and opportunities for scientific investigation. All sounds are mixtures of different frequencies, which the ear hears simultaneously and the brain interprets with exquisite subtlety. On the one hand, our perception blends together the parts of a sound and gives us a single idea, such as which friend is on the other end of the phone, what species of bird is calling, or whose baby is crying. On the other hand, it teases sounds apart so we can comprehend a single conversation at a noisy party or identify each of the instruments in an orchestra.

To investigate sound, it is essential to be able to "see" frequencies and "freeze" snapshots of sound waves. Frequency and waveform displays can pull apart the components of a sound and stop it in time, allowing students to develop a scientific understanding of sound that expands their natural appreciation of the world around them.

The Sound Grapher

Displaying sounds is relatively easy on a computer. Indeed, most laptops have a built-in microphone. With this basic equipment, students have a ready-made sophisticated scientific instrument. All they need is some simple software and ideas about how to use it.

The Concord Consortium has developed a cross-platform Sound Grapher for the Technology Enhanced Elementary and Middle School Science (TEEMSS) project, which creates sensor-based investigations for students in grades 3-8.

You can find the Sound Grapher on the enclosed CD or at our website.

Technical notes: If you need to connect an external microphone, refer to the technical hint at the download site. Although there is a volume control in the Sound Grapher, you should increase the sound input level on your computer for best results.

The Sound Grapher represents a sound in two ways. Waves shows a snapshot of the waveform, like an oscilloscope. The vertical axis is air pressure, and the horizontal axis is time (about 30 milliseconds). Frequencies displays the amplitude (y-axis) of each frequency that is present in the sound (x-axis).

Compare two sounds

The Sound Grapher has two screens so sounds can be compared.

1. Click on either screen to make it active. Press Record and speak into the microphone. Press Stop after a few seconds.
2. Choose the second screen, record a sound, and take another snapshot (by pressing Record, then Stop).

Observe the shapes of the two graphs. Try speaking the vowels—a, e, i, o, u. Do they look different as well as sound different? Try to get pure sounds, and ask yourself what pure means. Try low and high sounds, loud and soft sounds. Also try toneless noises, like "shhh." Is a beautiful sound also a beautiful wave?

You can adjust various parameters, such as amplitude and the time length of the graph by clicking on the settings.

A single frequency appears as a simple sine wave. When more than one frequency is present in the sound, the waveform is a combination of several sine waves and looks more complex. It is difficult to tell what is happen-

The vocabulary of sound

A few common words used to describe a sound may need clarification.

Frequency is the number of cycles per second of the pressure variation. Most sounds have a mix of frequencies. The ear usually perceives one as dominant, and this dominant frequency is called *pitch.*

Amplitude is the size of the pressure variations, seen as the height of the waves.

Loudness is what the ear perceives, and is measured in *decibels.*

LINKS *Monday's Lesson*

TEEMSS
http://teemss2.concord.org

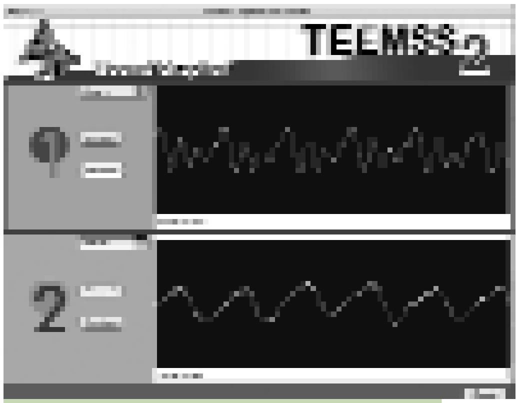


Figure 1: Recordings of two vowels—"ahh" and "eee"—with the same pitch. The graph is amplitude vs. time, over about 30 milliseconds.

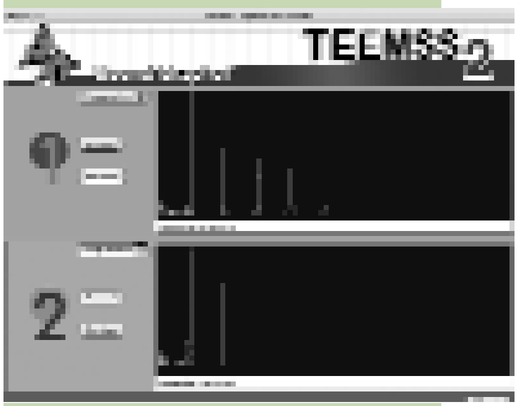


Figure 2: Two vowels—"ahh" and "eee"—using the Frequencies mode.

ing from the waveform alone, so an additional analysis tool is provided. Click on the Waves button, and change the drop-down menu to Frequencies. The screen now displays the distribution of frequencies that are present in the sound.

The "ahh" sound (figure 1, top screen) has a primary frequency and lesser amounts of several higher frequencies, called overtones. The "eee" (figure 1, bottom screen) is a single frequency plus one overtone.

The Frequencies mode (figure 2) also includes a settings button, so you can change the amplitude and the range of frequencies displayed. The default range is 0 – 2000 Hz.

Try whistling, humming, clapping, and making a "shhh" noise. The whistle is a nearly pure note—it will have just one frequency. Humming includes a mixture of several frequencies, with a main pitch and a number of overtones, which are two and three times the frequency of the main pitch. The "shhh" noise, by contrast, has many frequencies mixed together, with little relationship to each other.

Music to my ears

The traditional musical definition of a beautiful sound is one in which the relationships among the frequencies are simple ratios, such as 2:1, 3:2, and so forth. On a stringed instrument, these are the same ratios as the lengths of the string. For instance, if you make a violin string half as long by pressing it in the middle, the frequency is twice as high.

1. Strike a bell very sharply and record it with the Sound Grapher's Frequencies mode. The first sound is jarring and discordant, and the mix of frequencies is chaotic. As the bell sound fades, it becomes more pleasant. Notice that the waveform becomes smoother and overtones appear that are simple multiples of the basic pitch.

2. Play pairs of notes on a piano and record them with the Sound Grapher. The ratio of the two frequencies for an octave is exactly 2:1; the ratio for a fifth is 3:2; the ratio for a fourth is 4:3, and so on. As this ratio becomes a pair of larger whole numbers, such as 17:16, we perceive the interval to be more dissonant.

Another factor in "beautiful" sounds is the quantity of overtones compared to the basic pitch. Many singers and instrumentalists work hard to add overtones, giving their sound greater richness, depth, and carrying power.

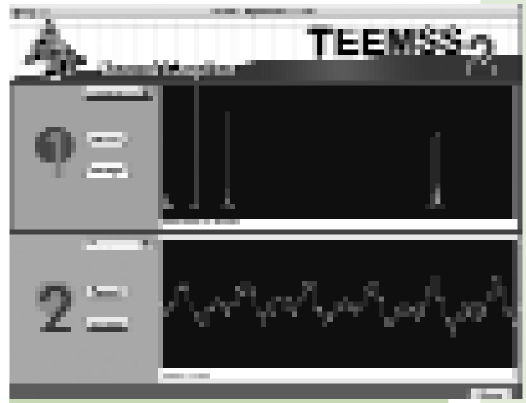


Figure 3: Two superimposed sounds—one person singing "eee" and another whistling— viewed as Frequencies (top) and Waves (bottom).

3. Explore the characteristic overtones of several instruments. A flute is quite pure, an oboe is quite complex with very prominent overtones, and a clarinet has only odd-numbered overtones!

Superimposed sounds

Try recording two simultaneous sounds (figure 3).

The Frequencies mode approximates the way the ear works. Thousands of hairs in the inner ear each respond to a different frequency. The ear sends signals to the brain indicating the intensity of the sound at each frequency. But that is only the simplest description of what happens. What the brain does with this information is truly astonishing.

The Sound Grapher does not begin to reveal the subtleties the ear is capable of recognizing, such as the flow of language, inflections, dialects, and rhythms. Still, with the Sound Grapher, students can begin to delve into the science of sound. Perhaps then they will ponder the question: how can a bird pick out its offspring from a thousand others in a nesting ground only by its tiny peeping voice?

Ed Hazzard *(ehazzard@concord.org) is Curriculum Developer of the TEEMSS Project.*

What Can You Do with a Br

JOANNA LU AND JUDAH SCHWARTZ

Teacher Guide

Math: Number and Operations

CD: Broken Calculator

Web: www.concord.org/resources

Grades: 2-5

Kelly Goorevich teaches fourth grade at the Hosmer public elementary school in Watertown, Massachusetts. The following "letters to Mom" are part of an activity Ms. Goorevich developed to accompany her math lessons using the Broken Calculator.

"Mom! Don't throw away my broken calculator! 'Why?' you ask. Because it can still be used. 'How?' I'm so smart … say I can't use the 5 key and I need to multiply 5 x 27, I know I can add 3 + 2 and then do (3 + 2) x 27 = 135!"

"Why did you throw away my favorite calculator? It helps you think out of the box. That means think of new and interesting ways to learn. It can help me learn more about numbers. It's very fun to find out how to solve it and not to go for the answer."

"Mom, don't throw away my broken calculator! … if your multiplication sign is broken …but the problem you are working with has a multiplication sign in it … BIG WHOOP! You can use addition or you could use division or you could use subtraction. You can sort of fix the broken keys with other keys."

Broken Calculator: a laboratory for exploration

Some critics fear that calculators undermine the teaching of elementary math. With a calculator at hand, why would anyone bother to memorize number facts or learn computation? If students use calculators, what will they do if the calculator, well, breaks?

The ***Seeing Math***™ Elementary teacher professional development course, currently distributed by ***Teachscape,*** turns the technology around and uses this unhappy scenario to develop mathematical skill and insight. The original Broken Calculator program, created by Dr. Judah Schwartz of Tufts University took this simple concept, developed the broken calculator scenario, translated it into a versatile application, and made for students a calculator with selectively disabled keys. (This can be applied in the form of a computer program called "Broken Calculator," which runs in Flash, or one may simply pretend that certain keys on a calculator no longer work.) Students must solve arithmetic problems without using the broken keys. For example, they must solve a division problem in spite of a "broken" or disabled division key.

Consequently, students must be far more inventive in how they solve problems. In standard algorithms, the computational steps are simple. All one needs is knowledge of single-digit addition or multiplication facts. But Broken Calculator requires reasoning beyond the standard mechanics. It challenges stu-

Figure 1: The Broken Calculator, a Flash interactive.

Figure 2: Disabling keys means they're no longer available to the user.

oken Calculator?

dents to explore number relationships and use their mathematical knowledge to invent and test a wide variety of strategies. The intellectual responsibility for finding the answer is shifted from the calculator back to the students.

Broken Calculator is, in effect, an inexpensive, widely available number laboratory for developing and assessing students' computational fluency. As students develop strategies for solving problems, they:

- Learn to reason mathematically
- Explore place value and relationships between operations
- Apply basic math skills, such as "math facts"
- Develop the flexibility to apply their skills to unfamiliar problems

Let's start!

Use the Seeing Math Broken Calculator on the CD or at our website.

The interface is simple, and works much like a standard handheld calculator. The number and operator keys are "pressed" by pointing and clicking with the mouse, or by using the computer keyboard numbers and operators (+, -, *, /).

In several important ways, it may, in fact, be better than a "real" computer (that is, the type cased in plastic, with a keyboard and all!). For instance, in doing

Figure 3: Set a goal as a number or calculation.

LINKS ***Tuesday's Lesson***

- **Seeing Math Video Case Studies**
  http://seeingmath.concord.org/case_studies/
- **Teachscape**
  http://www.teachscape.com

a problem such as 53 + 39, one can see the 53, the + sign, and the 39 before pressing the equals key.

A unique feature of the software allows you to *disable* specific keys. Selecting numbers or operators from this screen disables them, graying them out.

You can also *set a goal* to pose a problem or enter a target number by pressing the "set a goal" button, then "ok."

Finally, another feature of the Broken Calculator software is the *leading digit* mode, accessible by a toggle switch that alternates between leading digit and *normal* modes. In leading digit mode, only 0, the decimal point, and the four operators are active after entering a numeral from 1 to 9.

Familiarize yourself with the software before attempting the following activities.

Place value: Disable 2, 3, 4, 5, 6, 7, 8, 9, x, and /. Now get the calculator to display 4321 (or any other target number). How many steps did it take? The history window on the right will keep track of steps for you. Can you tell in advance how many steps it would take to display any number?

Turn on the leading digit mode, and leave all the keys enabled. Set a goal of 678.9 and see how many steps it takes to display that number. What is the minimum number of steps you can take to reach your target? How do you know?

Understanding addition and subtraction: Try addition problems with the plus (+) key disabled; for example, 53 + 39. How many ways can you do this problem? Try subtraction problems with the minus (-) key disabled.

Understanding multiplication and division: Do several multiplication problems with x disabled. Do division problems with / disabled.

Signed numbers: Keep all keys enabled. Explore problems such as (-m) + (-n) or (-m) - (-n). For example, what is the sum of –7 and –9?, that is (-7) + (-9) = ? What about (-7) – (-9)? Note that there is no way to enter a negative number directly. It must be constructed!

Estimation: Suppose only the 1, 2, 7, 9 keys and all the operation keys function. Get the calculator to display 2059.

Video cases

To see Kelly Goorevich using the Broken Calculator with her students, you may access a public version of the Number & Operations: Broken Calculator teacher professional development course on the Seeing Math website. Our commercial partner, Teachscape, distributes twelve Seeing Math™ Elementary courses developed by the Concord Consortium. Try them out in your district for professional development opportunities where kids can "break" the calculator and still learn math!

Joanna Lu *(jlu@concord.org) is Managing Director of Seeing Math.* ***Judah Schwartz*** *(judah@gse.harvard.edu) is Emeritus Professor of Engineering Science & Education at MIT, Emeritus Professor of Education at Harvard, and Visiting Professor of Education and Research Professor of Physics & Astronomy at Tufts University.*

Wednesday's Lesson

The Trickster Squirrel

GEORGE COLLISON

Teacher Guide

Algebra: Graphing

CD: Qualitative Grapher

Web: www.concord.org/resources

Grades: 6-12

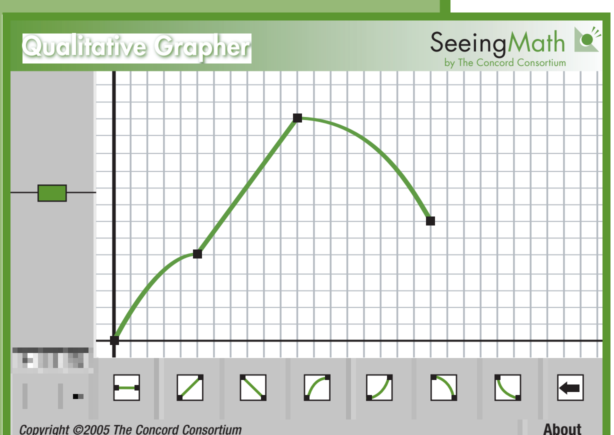
The concept of function, which links a change in one variable to a corresponding change in another, is key to understanding and applying mathematical models to the real world. By studying and comparing functional relationships in different representations, students gain access to some of the deeper ideas of secondary mathematics, including slope as rate of change.

Getting beyond rise over run

The Trickster Squirrel activity focuses on the graphical definition of a function using the rate of change of distance over segments of time. Students shift attention from seeing the graph as a static image, or perhaps a trajectory, to seeing the two variables—time and distance—and rate of change as interconnected.

Democratizing big ideas

Jim Kaput of the University of Massachusetts, Dartmouth, relentlessly argued that what tradition calls pre-calculus and calculus represents a collection of ideas formed by historical accident. One need not wait for the formal symbolic machinery of calculus to approach the mathematics of change. The vast majority of our students are, by this approach, blocked from access to very important ideas for them and for our society. To ensure equity of access, a thread on functions and rates of change should be integrated into the curriculum from early grades.



Getting to know the Seeing Math™ Qualitative Grapher

The Seeing Math Qualitative Grapher, like Kaput's ***SimCalc,*** explores change through graphically defined piecewise functions. Traditional symbolic form may be difficult for many students, but expressing functions graphically is quite easy. Adding linear or curved elements of the graph in the Q-Grapher changes the way a virtual object moves. Units are not specified on either axis. The user defines meaning for either axis or the value of the grid lines. Access the Qualitative Grapher on the CD or at our website. (Note: You need ***Java*** 1.3.1 or higher to run the interactive.)

Using the Q-Grapher

The grapher opens with two line segments on the graph. The x-axis shows time in seconds. The y-axis shows the height of the object (a box) at each second. All graphs are continuous.

- Click (play) and watch the motion of the object on the left. As it goes up or down, a red line moves across the graph.
- To add a straight or curved line to the graph, click the desired icon:
- To change the position or angle of any line, drag its "handles" (■).
- To remove the most recently added line segment, click .
- Use the Change Object button to change the box to a dollar or a billiard ball:

Use these features to become familiar with the software. Try adding a linear or curved segment and pressing the Play button. What happens when you change the angle of a line segment? When you delete a segment?

The Trickster Squirrel

Trickster Squirrel is a mischievous creature that lives in a tree overhanging a spot where students like to play. Trickster has a toolbox of cunning gadgets like springs, parachutes, and pipes that he uses to alter expected paths of balls thrown his way.

Challenge 1: A ball is tossed up vertically. At the top of its path, out of the students' sight, Trickster Squirrel grabs it and holds onto it for

LINKS *Wednesday's Lesson*

Java
http://java.com

SimCalc
http://www.simcalc.com
http://www.simcalc.umassd.edu/

two minutes. Trickster throws the ball up higher; as it comes down, it hits a student on the head. Use the Q-Grapher to animate this motion. Explain your reasons behind selecting each segment of the graph.

Challenge 2: Students are intrigued by the unexpected behavior of the ball. They toss another. This time Trickster catches it, holds it for one minute, attaches a small parachute, and lets it go. The ball floats down slowly. A student catches it, holds on a bit, removes the parachute, then throws it up to a lower height so the squirrel cannot get it. The student catches it again.

Challenge 3: Make up your own Trickster Squirrel activity. Describe the event using speed, not distances, to determine the graph. How does the shape of these graphs compare to the actual trajectories of the ball? List similarities and differences.

Getting beyond distance/time

Challenge 4: Create a narrative about a relationship between two quantities and animate it using the Qualitative Grapher. Do not use time and distance. Consider a "nervousness meter" that measures heart and breathing rates and imagine a student at a school dance. The student is nervous about asking (or being asked) to dance. Make up a narrative of the student's movement around the room, approaching or avoiding situations. Make a graph of the nervousness meter readings vs. time using the Q-Grapher. Explain for each segment the rate of change of values on the nervousness meter.

In the classroom

Students can use the Qualitative Grapher to explore dynamic relationships in linear and non-linear functions. Where are there maxima or minima? Where are rates changing the most rapidly, the least rapidly, or not at all? As students experience graphically defined functions in the Q-Grapher, they will be better equipped to interpret graphs and move more easily to generalized and more formal definitions of mathematical functions.

George Collison *(george@concord.org) is Senior Curriculum Author for the Seeing Math project.*

IN MEMORIAM

Professor James Kaput, Mathematics Educator

by George Collison

July 30, 2005 brought news of the death of James Kaput, Chancellor Professor of Mathematics at the University of Massachusetts, Dartmouth. He was killed while jogging near his home in Dartmouth. Jim was a valued colleague and friend of many at the Concord Consortium. He shared our commitment to creating materials and technology that embody powerful mathematical ideas in dynamic ways to inspire both teachers and students. Jim was a member of the Advisory Board of the Seeing Math Project, and expert commentator on two of the case studies. Seeing Math video cases and software owe a great intellectual debt to Jim's counsel and vision. His commentaries were deep, insightful, and inspiring. One teacher said that initially Jim's comments went right over her head. After the third viewing of the video she realized she had to change the way she thought about and taught equations and equality. She was amazed that she had the capacity to learn something new and surprising about herself and about her teaching. Jim had a way of surprising all of us.

Jim shared a powerful vision: "democratizing access to the mathematics of change." He believed that it was a moral responsibility as well as a social and political necessity to make mathematics accessible to all. At conferences, and in his papers, emails and personal contacts, Jim forged an ongoing virtual symposium, inspiring and connecting ideas and people, often through his puckish sense of humor. He was deeply committed to the toughest problem—how most effectively to teach all students the core ideas of algebra. The central project in Jim's work was SimCalc, an approach, aided by computer-based graphs and animations as well as symbols and tables, that made mathematical rates of change and accumulation—the centerpieces of calculus—conceptually available to elementary and middle school students.

His death is a tragic loss to family, friends, and indeed to all in the mathematics education community. Jim helped people, from the under-prepared students at UMass Dartmouth to colleagues fortunate enough to work with him, including many at the Concord Consortium. We grieve for Jim while working to continue a common vision of democratic access to big ideas in mathematics.

Budgie Populations

PAUL HORWITZ

Teacher Guide

Biology: Population Genetics

CD: Population Explorer

Web: www.concord.org/resources

Grades: 9-10

Budgerigars ("budgies" for short) are complicated birds. They come in four colors—green, blue, yellow, and white—with an interesting genetic background, emerging from the interplay of two sets of genes. One of these genes codes for yellow pigment, the other for blue; when both pigments are present, the resulting color is green. Absence of both pigments gives rise to the white variety. Moreover, each pigment is dominant, in that a single copy of the active form (the "dominant allele") of the gene for that pigment will ensure that it shows up in the color of the offspring. This results in a simple, but surprising pattern: when two budgies mate, the color of their offspring depends not only on the parents' color (their phenotype), but also on their particular genetic makeup (their genotype). Two white parents, lacking any dominant alleles, can only have white babies, but the offspring of a white and either a yellow or a blue budgie can resemble either parent—the exact proportions depend on whether the colored parent bird carries one or two dominant genes. Finally, the mating of a blue and a yellow budgie can result in green, blue, yellow, or even white offspring (see note).

Population over time

What happens when a randomly distributed population of budgies is allowed to interact over many generations? A new Concord Consortium model—Population Explorer—will help you find out.

Access the Population Explorer on the enclosed CD or at our website.

When the model opens, you will see an empty green field denoting a model budgie habitat. (The green represents a generic food source: "grass." It turns paler and paler as the food is consumed.)

1. Place budgies in random positions in the field by clicking the "Add organisms" button. A dialog box will open. For now, we suggest that you keep the default selection, which includes 100 male and 100 female birds with a uniform (random) distribution of genotypes. The small squares represent male budgies, the circles, females.
2. Using the arrow tool, double-click on a square or circle to see what the budgie looks like and also to view its chromosomes (see figure 1).
3. Click "Play" and each organism will cycle through four actions in quick succession: it will move, eat, mate (if a suitable partner is nearby), and possibly die. Whether an organism lives or dies depends on three factors: its age, whether or not it is hungry (these budgies cannot go more than five cycles without food), and its state of health.
4. Let the simulation run for about a minute. What do you observe?

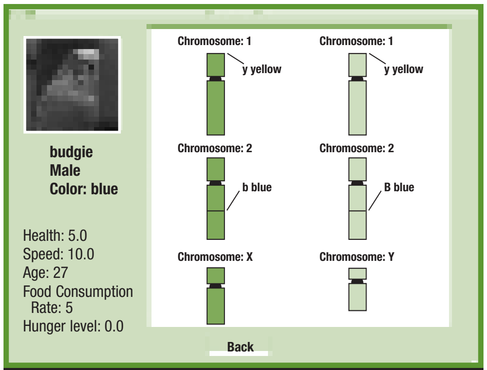


Figure 1: A blue budgie with its chromosomes. Note that this budgie has two recessive yellow alleles (yy), and one dominant and one recessive blue allele (Bb).

As the graph in figure 2 shows, the populations of all four colors of budgies tend to grow rapidly until they outrun their food supply. At that point, the numbers start to decline, finally reaching steady, though fluctuating, values. The green budgies are more numerous simply because a larger fraction of the genetic combinations available lead to green. By the same reasoning, the doubly recessive white budgies are most rare in the population.

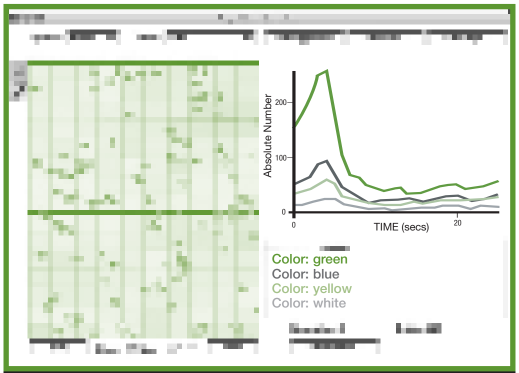


Figure 2: Budgie population after approximately 30 seconds, run on the default settings. Following the initial peaks as budgies mate and produce offspring while food is plentiful, the populations of all four colors decline.

LINKS *Thursday's Lesson*

Note: Our budgie genetic model is a good deal simpler than the real world. To learn more about budgie genetics, visit *http://www.geocities.com/RainForest/3298/*

Variables affect populations

In the simple case outlined above, none of the color groups has any particular survival advantage, or disadvantage, compared to the others. But that is not always the case in nature. What if we introduce a new factor to the environment—a disease, say, that adversely affects the health of the green budgies? Clearly, we expect the numbers of green birds to decline, but what effect will this change have on the genetically related blue and yellow budgies? And what about the white ones, which are entirely unaffected by the disease? Will their numbers increase? Let's find out.

1. Click the "Edit Rules…" button to open a dialog box. Leave the "Terrain" popup in its default ("ANY") state. Choose the only genetic trait these budgies have—color—and select "green."
2. Change the setting for "Health" from its default value of 5 to 4. This is a small change, but it will have dramatic consequences, as you will see!
3. Click "Back" to exit the dialog box and start the simulation. The green budgies will start to die off at a slightly younger age than the yellow, blue, and white ones. At first, it's not very obvious, but observe what happens if you wait a while…

Nine minutes and about 150 generations later, not only have the green budgies died out (that small health disadvantage actually drove them to extinction!), but so have the yellow ones—and the white ones aren't faring too well, either. The demise of the yellow budgies is easy to explain: whenever they mated with a blue budgie, they had a chance of having one of those unfortunate greens—in other words, though they themselves were not affected by the change, they tended to have fewer healthy offspring. So in the presence of blue budgies, the yellow budgies had a selective disadvantage. And vice versa—the blues suffered a loss of fertility in the presence of the yellow. In other words, the presence of blue and yellow together was unstable. Once the yellow budgies were gone, however, the blue population stabilized and now it dominates the population.

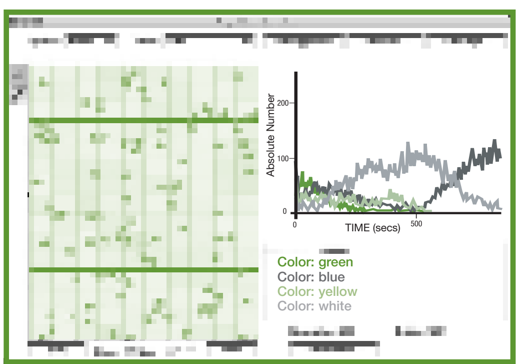


Figure 3: After about 30 seconds, we gave the green budgies a slight health disadvantage, causing them to die at a slightly younger age, and consequently have fewer offspring during their lifetime. Their numbers started to decline shortly thereafter.

So why are the white budgies dying out? (Hint: try running the model many times—it doesn't always do the same thing!)

Models help students explore

Amazing, isn't it, how such a simple model can have such unexpected consequences? The Population Explorer model allows for additional explorations. For instance, you can create multiple terrains and set up different rules for each.

1. Click on the paintbrush tool for a menu of four choices of terrains: grass, water, desert, and mountains.
2. Select a terrain, then click and drag over a section of the screen to fill a rectangular region with that terrain.
3. Create your own rules to govern the health (or the speed, age of maturity, or food consumption) of any color budgie on any terrain. To get you started, you might try giving each color a special advantage when it is on the terrain of its own color (consider why this would be the case). Notice what happens in each terrain.

You can switch to a different species (e.g., dragons). You can also create your own mutations that change one allele into another, either randomly or whenever you click on a button. Just click "Edit Mutation…" and follow directions.

The Population Explorer is an incredibly rich environment to help students explore what happens when genetically related organisms interact over many generations. Stay tuned for Ecologica, which will have multiple species interact, each species adapting its genetic mix in response to challenges from the others.

Paul Horwitz *(paul@concord.org) directs the Modeling Center at the Concord Consortium.*

Molecular Self-Assembly

ERIC ROSENBAUM

Teacher Guide

Biology: Molecular Biology

CD: Molecular Workbench – Self-Assembly

Web: www.concord.org/resources

Grades: 9-14

Imagine this: You dump a pile of Lego pieces on the floor, and they start bouncing around, sometimes snapping together. Gradually, elaborate Lego structures form: bridges, buildings, vehicles, and even little machines that take apart and put together other little machines. All this happens without any human intervention.

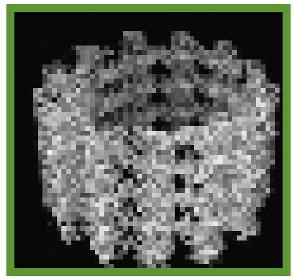


Figure 1: ***A segment of a microtubule. Microtubules are polymers made of many tubulin monomers.***

It sounds like magic, but something very much like this is constantly occurring at the molecular scale in every cell in your body. Called self-assembly, it's the spontaneous formation of ordered structures from smaller parts. Lipid bi-layers form this way, as do many biological macromolecules, such as enzymes made up of multiple polypeptide chains. Protein folding is a type of self-assembly, and so is crystal formation. In these examples, order emerges from disorder, and although the process seems mysterious, a few basic principles of molecular motion and attraction can help explain it.

The ***Molecular Logic*** project has developed an activity for secondary and college-level students to learn about self-assembly. It's one of a sequence of activities developed by the Concord Consortium that uses dynamic models to help students reason about biology at the molecular scale.

Launching the activity

To view the self-assembly activity, open Molecular Workbench – Self-Assembly on the CD, or point your web browser to: ***http://molo.concord.org/database/activities/231.html***

When you click the "launch activity" link, the Molecular Workbench software will automatically download (approximately 4MB), and display the first page of the activity.

Note: Molecular Workbench runs on Windows, OSX, and Linux. If you're having trouble running the activity, you may need to download the latest version of ***Java.***

How does self-assembly work?

The activity begins by introducing the two key factors on which self-assembly depends: motion and stickiness.

Motion is the random jostling of all molecules due to their heat energy. For two molecules to "stick" to each other, they need to be close together and lined up in the right orientation. Thermal motion guarantees this will happen eventually.

"Stickiness" refers to intermolecular attractions, those weak forces that make molecules stick to each other, from the small van der Waal's force to the stronger hydrogen bonds and Coulomb forces. While these forces may be weak individually, together they can add up to a strong attractive force between two molecules that are shaped just right to fit together.

So, with thermal motion jostling molecules around and intermolecular attractions to make them stick, spontaneous structures can start to form.

Molecular Logic Database

The Molecular Logic project seeks to improve the ability of students to understand fundamental biological phenomena in terms of the interactions of atoms and molecules. To view the Molecular Logic Database of over 100 activities, go to:

http://molo.concord.org/database/browse/stepping-stones/

Here you will find, among others, activities that cover life's macromolecules, intermolecular attractions, protein synthesis, and protein folding.

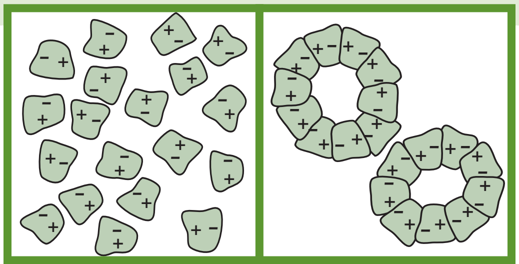


Figure 2: Self-assembling rings: before (left). Wedge-shaped monomers, with positive and negative charges, start out in disarray.

Figure 3: Self-assembling rings: after (right). Opposite charges attract, and the wedges assemble into a stable configuration.

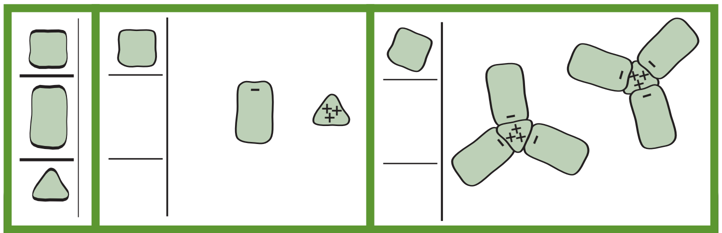


Figure 4: Three different monomer shapes (left).

Figure 5: Applying charges to the surface (center).

Figure 6: After making copies, students run the model to see new structures assemble (right).

Microtubules and self-assembling rings

This activity introduces students to three examples of self-assembling biomolecules: dimers, fibers, and microtubules. An image or interactive 3D model shows the structure of the biomolecule in each case, and is followed by a simplified 2D dynamic model that demonstrates how the structure can self-assemble. Finally, students are challenged to modify the model so that it assembles differently.

Microtubules are long molecular-scale tubes made up of thousands of tubulin monomers (figure 1). They play several important roles in the cell, such as providing structure to the cytoskeleton and acting as molecular conveyor belts. The 2D dynamic model shows the self-assembly of a ring structure, representing a cross-section through a cylindrical microtubule. The model starts with a random array of wedge-shaped monomers, each with a positive charge on one side and a negative charge on the other (figure 2). When students run the model, the wedges gradually assemble into a stable ring formation (figure 3). The challenge asks students to modify the charges on some monomers, and then run the model to see the effect of their changes.

Make your own molecule

On the final page of the activity, students are presented with a more open-ended challenge. They are given a set of three different monomer shapes with which to work (figure 4). They choose from these, apply positive and negative charges around their edges (figure 5), and make several copies. Next they run the model and watch how their monomers assemble (figure 6). Students can attempt to create one of several example shapes shown on the page or invent their own. When they are finished, Molecular Workbench creates a printable activity report containing students' answers to the embedded assessment questions, along with any snapshots of models students may have taken.

Self-assembly and beyond

Self-assembly is not part of the traditional biology curriculum, but it is a powerful idea related to many concepts that are taught. For example, this activity can serve as an engaging introduction to protein folding. With a teacher's guidance, students should be able to generalize from these simple examples to the formation of more complex molecular structures.

LINKS *Friday's Lesson*

Molecular Logic
http://molo.concord.org

Java
http://www.java.com

After completing this activity students might also be interested in the story of the T4 phage, a virus with a beautiful self-assembling icosahedral capsid. The virus contains a small amount of genetic material, which seems hardly enough to contain the instructions for building its complex, symmetrical shell made of thousands of parts. It turns out that these parts are identical monomers that self-assemble.

Another interesting question for class discussion is whether or not *everything* biological is constructed through self-assembly. You can point out that chemical reactions catalyzed by enzymes are required to form the covalent bonds that hold many structures together. These bonds are much stronger than the charge attractions students see in the self-assembly activity. You can also describe the roles of template-based synthesis (making one nucleotide strand by copying it from another) and chaperone molecules, which push and pull and protect a protein as it folds.

In all these cases, one key principle applies: there is no industrious toddler snapping together all the Lego pieces. These processes are all part of a complex system that, amazingly, organizes itself.

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NEWS at Concord Consortium

Professional Development Opportunities
concord.org/courses

The Concord Consortium offers unique opportunities for teachers to learn to use our technology-based materials, including a dozen short courses that can be offered online or as face-to-face workshops. The topics cover mathematics and science for teachers in grades 3-12. Each short course features free software that illustrates new content and teaching strategies that technology makes possible.

Workshops at NSTA
www.nsta.org/conventions

Visit us at the NSTA national convention in April 2006 in Anaheim, California. We will hold 21 sessions based on our short courses.

VHS is Ten
govhs.org

The Virtual High School is in its tenth year! The idea of an online collaborative secondary school was conceived at a Concord Consortium staff retreat early in 1996 and funded later that year by the U.S. Department of Education. VHS now offers over 170 courses to students worldwide and is completely self-sufficient. Most importantly, it offers the best high school online courses anywhere because of its long experience and solid, theory-based design. Not only is VHS providing a great service to thousands of students, it has developed a design that others can use. The Virtual High School model for high-quality online education is both economical and scalable.

CC Receives Two New Grants

The National Science Foundation recently funded two proposals. The "Inquiring with Geoscience Data Sets" project at SRI International and the Concord Consortium will study the impacts on student learning of web-based supplementary curriculum modules. These modules will engage secondary-level students in inquiry projects addressing important geoscience problems in an Earth System Science approach. Students will use technologies to access real data sets in the geosciences and to interpret, analyze, and communicate findings based on those data. The project will develop design principles, specification templates, and prototype exemplars for technology-based performance assessments to provide evidence of students' geoscientific knowledge and inquiry skills.

The "Molecular Rover" project at the Concord Consortium will develop and apply new educational technology tools that will guide students' exploration of complex 3D molecular structures and the forces that affect them. Equipped with a set of virtual probes, students will navigate above, below and through molecules, exploring forces among molecules that define structures such as large biopolymers (e.g., DNA or proteins), ionic lattices, liquid crystals, cell membranes, or ligand-receptor complexes. Virtual probes will help students recognize the effects of functional groups on electrostatic properties and characteristics of complex molecular surfaces. The universality of those molecular structures, coupled with the use of a friendly interface, will allow for a qualitative introduction to the molecular underpinnings of material science, physics, chemistry and molecular biology appropriate for both high school and college. Using the Molecular Workbench, the project will create a unique blend of molecular dynamics and 3D environments with teacher-authoring capabilities.

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@Concord is published two times a year by **The Concord Consortium,** a nonprofit educational research and development organization dedicated to educational innovation through creative technologies.

Forty-five percent of the contents of this newsletter were developed under a five-year $14,882,925 grant from the U.S. Department of Education (R286A000006), of which 23% of its funding is provided by non-governmental sources. The remaining 55% of the contents were developed under several National Science Foundation grants (ESI-0242701 for $1,416,623 over four years; ESI-0352522 for $2,706,805 over three years, DUE-0402553 for $899,857 over three years; and a subaward under ESI-0334199 for $3,309,351 over five years), for which 1% of funding is provided by non-governmental sources. These contents do not necessarily represent the policies of the funding agencies, and you should not assume endorsement by the Federal Government. All opinions, findings, conclusions, and recommendations expressed herein are those of the authors.

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