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The Concord Consortium
Realizing the educational promise of technology
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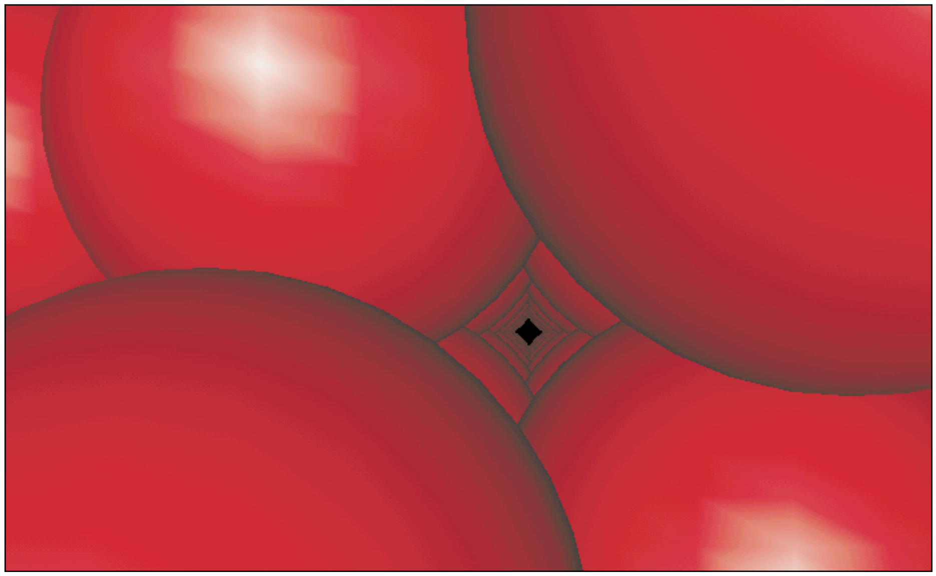

A newly developed modeling package allows students to view crystals microscopically from different angles. (See article page 4.)

Pedagogica to the Rescue

A short history of hypermodels

by Paul Horwitz and Robert Tinker

Genetics is a particularly difficult topic to teach because it involves complex, interrelated, mostly unobservable processes that occur at different levels. With this in mind, we created a great simulation called GenScope to help students learn about genetics. Great, except that it didn't help them pass genetics tests.

Our research in 26 classrooms showed that students were engaged and able to use GenScope to solve genetics problems, but we were unable to measure any increase in their ability to solve closely related paper-and-pencil problems. Clearly, students were unable to transfer their model-based learning.

Trying to understand why we fell short of our goals, we designed a solution called "hypermodels," which might turn out to be a significant development in educational software.

Levels of GenScope

The illustration on page 13 shows how GenScope represents the linked, multi-level processes of genetics. At the organism level students can view the phenotype (the collection of physical traits), but they receive no direct information concerning the organism's genetic makeup. When they move to the chromosome

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GenScope—genscope.concord.org

Perspective

Hypermodels: New Tools for Learning

by Robert Tinker

Hypermodels represent an important new approach to learning that has major implications for schools and researchers.

In this issue we introduce hypermodels: environments for learning fundamental concepts through guided inquiry under the control of scripts. Hypermodels, when used with powerful software tools and carefully designed scripts, represent an important new approach to learning that has major implications for schools and researchers.

Our front page article recounts the genesis of hypermodels, which Paul Horwitz invented to solve a problem of knowledge transfer with GenScope, his genetics simulation package. As he improved GenScope, Paul realized that his solution could be applied to other simulation and probeware tools we were developing. Consequently, we are adding Pedagogica to our Molecular Workbench project to create a hypermodel for teaching about atoms, molecules, and the macroscopic consequences of their forces and interactions (see article, page 4). And, we will add Pedagogica to our probeware and simulations to guide student learning about heat, temperature, and heat flow (see article, page 6). We hope to collaborate with others to generate a dozen hypermodels that can address most of the fundamental concepts within math and science.

We are excited about hypermodels because they solve a vexing set of practical problems that seem to have impeded the widespread application of content-rich tools, one of the most important categories of educational technologies. Many projects have demonstrated the value of software environments that incorporate important content that students learn through interaction and exploration (e.g., probeware, GenScope, ThinkerToys, Model-It). The impact of these and similar tools is diminished by the unrealistic demands they place on teachers: the tools require time to learn, they are difficult to convert into inquiry-based lessons, and learning that results from student interactions with these tools is difficult to assess.

It is natural for developers to build into their tools an array of capabilities and options that exploit the power of modern computers. But the result may be baffling to the beginner. In the past, we have tried to simplify these tools with help screens, online manuals, and scaffolding — guidance that can be removed when no longer useful. Too often, however, all this assistance is only makes it more confusing.

Pedagogica is like a puppet master who is controlling the puppet application's actions. Pedagogica can make puppets run or crawl, talk and listen, defy gravity, and even change appearance. It can control what the screen looks like and what options the user can access. It can pose a situation for the learner to explore, provide guidance, ask questions, and monitor progress. This monitoring can provide detailed assessment of student progress and problem solving strategies. Pedagogica is itself controlled by a script, so the entire user interaction can be easily changed in response to formative feedback or student learning. In a research setting, we can test different instructional strategies on students in the same class and obtain detailed data. It is possible to perform studies at a distance because both the scripts and the data can be communicated over the Internet.

Hypermodels share some characteristics with CAI (computer assisted instruction) applications, which also control what the learner sees, evaluate progress, and, if they are "intelligent," can adapt to student responses and learning styles. The critical difference is that hypermodels have at their

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GenScope—genscope.concord.org

Molecular Workbench—www.concord.org/workbench core a sophisticated tool that students can use to learn content through exploration and inquiry; a constructivist educational strategy. In contrast, CAI software is usually much more directive and "instructivist."

Our underlying tools embody a pure constructivist philosophy that permits students to learn through open-ended exploration. Even though this type of learning is powerful, students can take too much time and miss important topics and the tool can be difficult to disseminate and confusing for beginners. Pedagogica converts the tool into a hypermodel that is somewhat instructivist, because the script constrains the tool and guides the learner to discover specific concepts that a curriculum developer has selected. Done well, students still learn through their own explorations, but within constrained domains and with guidance that ensures that most students discover the important concepts.

Much of our past research has been dedicated to demonstrating the learning potential inherent in powerful tools. Well designed tools permit students to understand basic abstract concepts through interaction and exploration. Traditionally, many concepts have been taught only at advanced levels using abstract mathematics. If attempted at lower levels, the treatment is qualitative and verbal, too often requiring students to memorize apparently unrelated facts and sometimes reinforcing student misconceptions.

For most students, fundamental understandings that could simplify and unify science are qualitative and intuitive. The problem has been that it is difficult to develop a student's scientific intuitions. Intuition appears to be based on interacting with ideas, exploring, and making mistakes. It is often based on understanding dynamic situations involving chains of cause and effect. Other situations include randomness (e.g., temperature), hidden levels (e.g., genetics), or the emergent behavior of a system that depends on details of objects and their interactions (e.g., a flu epidemic). Lectures, illustrations, proofs, derivations, and even movies fail to provide the needed interactivity or to clarify the cause-and-effect relationships essential to building intuition. Appropriately designed software tools, however, can.

It is important to teach basic concepts earlier, not only because science is always adding content, but because an understanding of basic concepts can simplify learning by providing more links and causal relationships. Learning based on basic concepts should require less memorization, last longer, and facilitate further learning. Six to twelve powerful software tools could give beginning students an intuitive understanding of all the basic concepts of science. By concentrating on these areas instead of on the hundreds of standards and benchmarks, students could learn science in an integrated, logical way.

Hypermodels can revitalize education by concentrating on guided inquiry into core topics that have great explanatory power. While there can be debate about what the core topics are, the important point is that it is possible to envision a curriculum based on a small number of core ideas. A curriculum structured in this way, based on hypermodels, allows time for inquiry-based learning that is increasingly ignored in the rush to cover all the required standards. @

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CAI—www.auburn.edu/~mundecd/cai.html

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Molecular Workbench Zooms In

Using Pedagogica to focus on enhanced teaching and learning

by Barbara Tinker and the Molecular Workbench team

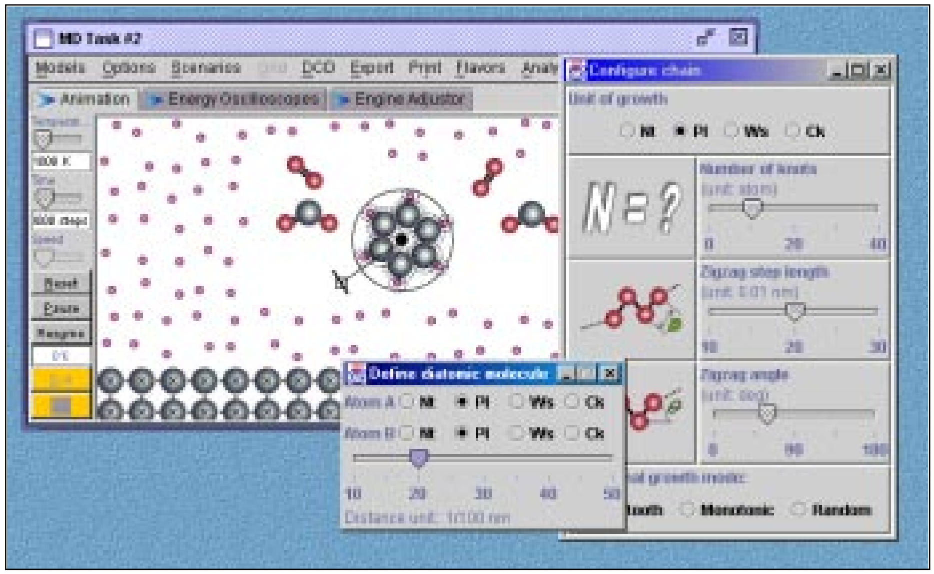

Figure 1. Oslet is a modeling engine within Molecular Workbench that computes the motion of atoms and molecules from the forces applied to them. The underlying model can adapt to the level of student knowledge about the subject.

Travelling between the atomic molecular world and the world visible to our eyes can be an uncomfortable journey. Rules and forces that govern one world are not necessarily critical to the other. For example, random movement belongs more to the molecular world than to the visible one. Gravity, on the other hand, is far more important to large bodies like people and trucks than for small molecules. Yet understanding why many macroscopic phenomena work the way they do requires a degree of comfort with visiting the atomic-scale world.

Many scientists spend their time at the atomic and molecular levels. Physicists focus on atoms, their constituents, and the energy that is transferred within that world. Chemists pay attention to the reactions of molecules. Biologists begin to perk up when the nucleic acids, lipids, proteins, and carbohydrates critical to life processes are mentioned. For many of these scientists, the micro world is inherently interesting. For students, this is usually not the case — they demand that their learning have relevance to their lives. Yet they are rarely given the opportunity to travel between the micro and macro worlds, and so grasp where the real explanations lie for much that occurs in their visible world. Wouldn't it be powerful if students could explore the implications of random movement by experiencing the atomic world where random motion is dominant, and see that changes in the atomic world can cause changes in the visible world? Imagine if they could enter a virtual laboratory and change the salinity bathing a cell, and then enter the atomic level of the cell to see what the changed solution looks like in terms of atoms and molecules.

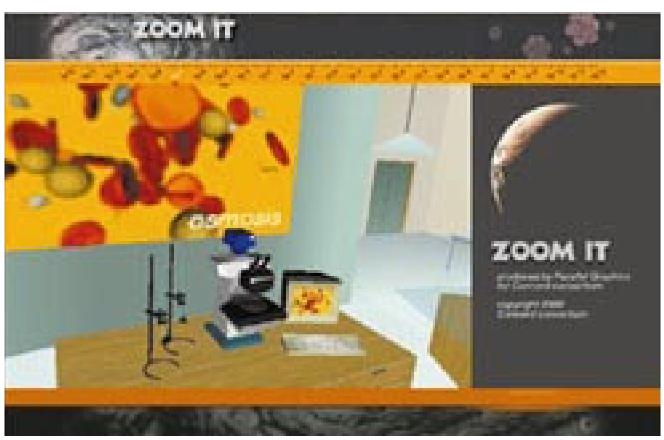

Figure 2. The Zoom It 3D laboratory.

Molecular Workbench Project

With the National Science Foundation's support, we are conducting research that asks whether exposure to key concepts and new modeling tools at the atomic level can help students understand a wide range of macroscopic phenomena. This work extends the investigations of Paul Horwitz with GenScope and Biologica (see article page 1) and builds on our previous modeling work.

Specifically, the Molecular Workbench project is investigating whether computer models can help students understand how the behavior of certain chemical and biological systems emerge from the

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Oslet atomic—rivendell.fortunecity.com/furcadia/736/concord/model1.html
Oslet molecular—rivendell.fortunecity.com/furcadia/736/concord/model2.html
Oslet biomolecular—rivendell.fortunecity.com/furcadia/736/concord/model3.html
Genscope—genscope.concord.org
BioLogica—biologica.concord.org

fundamental behaviors of their atomic and molecular constituents. Which macro themes have the greatest power to connect students with the micro world? And given the kinds of computers students are likely to have access to, what kinds of atomic-scale situations can be simulated best in this environment?

The Modeling Environment

Our objective is to have students learn about the atomic-scale world by interacting with it through a series of learning activities presented by three software packages. The first and most critical is an atomic, molecular, and biomolecular modeling engine, called Oslet (Figure 1). This modeling micro world computes the motion of atoms and molecules from the forces applied to them. Until recently, these computations were so extensive that they required a supercomputer. Now an average desktop computer will allow students to perform experiments on hundreds of atoms.

Students do not need to understand the calculations to learn from these models. By experimenting with simple models, they can see how individual atoms and molecules interact. When hundreds interact the same way, they can see emergent properties.

In Oslet, collections of neutral atoms can illustrate temperature, pressure, gas laws, states of matter, phase change, absorption, latent heats, osmosis, diffusion, heat flow, crystals, inclusions, and annealing. Add bonding, molecules, and photons that can exchange energy with bonds, and Oslet can exhibit chemical equilibria, heat gain and loss in reactions, explosions, stoichiometry, color, spectra, florescence, and chemiluminescence. Add charge and polar molecules, and Oslet can show plasma, surface tension, solutions, hydrophilic and hydrophobic molecules, conformation, binding specificity, and self-assembly. In short, a wide range of physical, chemical, and biological processes can be understood by interacting with Oslet's atomic-scale models.

The second software package, Zoom It (Figures 2 and 3), is a modeling world inspired by the Charles and Ray Eames film Powers of Ten and developed by Parallel Graphics in Moscow, Russia. Zoom It allows students to navigate in 3D and zoom to the atomic world in a series of factor-of-ten steps. Students can zoom from a solar system to an island and then enter a laboratory with a set of rooms and simulations and investigations leading to Oslet.

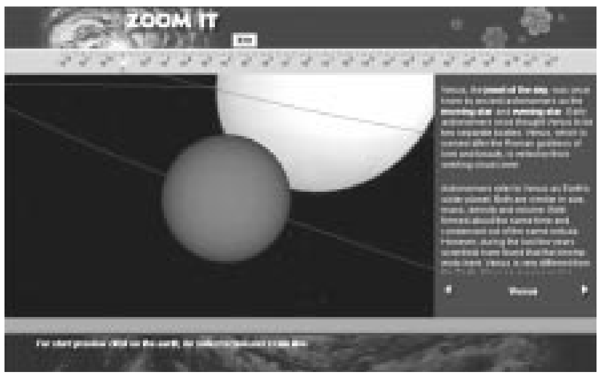

Figure 3. Zoom It is a 3D tool that allows students to explore models that support different science content. Students can zoom from the solar system to the atomic world.

The third software package is Pedagogica, which pulls Zoom It and Oslet together into a hypermodel (see article, page 1) and uses scripts to control what students see, presents appropriate activities, and monitors student progress. Pedagogica is able to provide multiple ways to enter and use the Molecular Workbench software. While manipulating the model a student might be queried by Pedagogica about the experience, be offered alternative paths, be given more or less complex versions of the same material, or be "followed" for purposes of evaluation.

Teachers will be able to use Molecular Workbench material to enhance existing lessons. But students can work on their own, too. Students can start with an exploration of Oslet's atomic-scale representations and work through a set of activities, or they can pick a case history and follow its implications and discoveries down to the appropriate use of the molecular engine. Such explorations include health themes such as sickle cell anemia, vitamins, and oral rehydration. We believe that all these cases have aspects that can be more easily understood with Oslet's simulated molecular explanations. For example, a student learning about solutions and osmosis can pick up the case of oral rehydration therapy for cholera, enter the laboratory, explore the effect of changing salinity on an erythrocyte, and then zoom into a membrane and arrive at the Oslet model of osmotic pressure.

Oslet's next challenge is moving into 3D, and knitting the movement between 2D and 3D together. Already students can move through crystal lattices built from first principles (see picture, page 1). As Oslet grows in power, our challenge remains to provide students with a motivating and strong but simple way to undertake challenges not only in the sciences, but in the arena of model building itself. As students move to develop models themselves, and to understand the workings of models such as Oslet, they will be better able to use atomic molecular understanding to make sense of their own macro world. @

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LINKS ON THIS PAGE
Parallel Graphics—www.parallelgraphics.com
Molecular Workbench—www.concord.org/~barbara/workbenchcc/workbench_index.html

Reconciling Conflicting Evidence

Researchers use models and handhelds to investigate how students learn science

by Carolyn Staudt and Paul Horwitz

What happens when a student's mental models do not agree with her observations, such as when a phenomenon observed in one situation fails to repeat itself on a larger scale? Does that mean all models are wrong, or are they just too simple to describe the complex situations that students face on a daily basis? To study this question, our Data and Models project is purposefully creating such conflicts for students in order to look at the interplay of theory and experiment and to develop strategies for dealing with it.

Using state-of-the-art wireless data collection, simulation, and visualization technology (see article, page 7), we are guiding students at the Fowler Middle School in Maynard, Mass., through the study of heat transfer. By doing experiments that involve the variation (both temporal and spatial) of temperature in solids, liquids, and gases, students form models to describe what they see, and extend and revise those models in the face of conflicting evidence gained from experiments and observation. When they encounter discrepancies they use this information to revise their model or improve their experiment, an iterative process that mirrors the real scientific method much more closely than the simplistic hypothesis-experiment-conclusion sequence that permeates the pre-college curriculum.

Students use iPaq handheld computers to collect and compare data and improve their experiment, thereby experiencing the iterative process that is at the heart of the scientific method.

Student Preconceptions

At the beginning of the study we administered to approximately 250 sixth and seventh graders a quiz designed to identify students' preconceptions regarding heat and temperature. Many of the questions drew on experiences related to situations familiar to the students' physical world, such as roasting marshmallows with metal coat hangers or wooden sticks, describing methods for cooling a hot bowl of oatmeal, and comparing the boiling rates of different amounts of water on a stove. The interviews allowed us to ask the students to elaborate on their initial answers, and many of their responses provided unique and sometimes conflicting theories. One student proclaimed that blowing on a bowl of oatmeal cools it down because "cool energy blocks the heat energy," yet he continued to explain that "heat energy moves faster than cool energy . . . so it [heat energy] can push it [cool energy] away." Conflicts continued to surface when their explanations seemed to contradict their real world experiences. The classic case that a "metal [coat hanger] is cold" and a wooden "stick is warm" caused visible confusion when a student was asked to explain why she thought the coat hanger was hotter in the fire compared to the wooden stick. The student started with the classic statement that "metal is cold, the stick is warmer" and then paused and said after some thought that "metal is made differently than wood and it warms faster."

We subsequently selected 13 students whose answers to the quiz needed more explanation or were contradictory to other answers provided on the quiz.

Conflicting Models

Through our literature survey and knowledge of the domain, we were able to identify two possible sources of confusion that might make it difficult for students to understand heat and temperature. Our initial curriculum development was aimed at those areas. First, we recognized that it is not so much the concept of temperature that is foreign to students as that of temperature gradient — i.e., the change in temperature over spatial separations. We imagined students were familiar with the concept of the temperature of an object but were likely confused by the idea of an object having more

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Data and Models—www.concord.org/data-models

than one temperature. As a result, our early activities centered on the notion of measuring temperature gradients along metal blocks and formulating a mental model about the role of heat flow in establishing thermal equilibrium in the absence of external energy sources or sinks.

Our second intuition was that student models about temperature are affected greatly by the fact that the students are themselves temperature detectors and heat engines. As mammals, all students maintain a relatively constant internal temperature that is usually significantly higher than that of their surroundings. All students are familiar with the method of estimating the temperature of something by touching it. Since their finger is in contact with a heat bath (blood) at a nominal 98.6°F, it does not cool down to the temperature of the object it is touching, but generally reaches equilibrium at some higher temperature. The apparent temperature of the external object has more to do with its thermal diffusivity — its ability to conduct heat away from the hot finger — than with its actual temperature.

Students test their mental models about heat and temperature against the data they collect and analyze.

This confusion can lead to a conflict between a student's mental model and his observations. Take, for example, the student who learns that "hot things cool off and cold things warm up" — in other words, objects in thermal contact with their environment tend to take on the temperature of that environment.

On a cold winter day, take such a student outdoors, show her a tree, and ask her whether it is the same temperature as, say, the school's metal flagpole. Following her newly acquired mental model, she may be tempted to say the two objects, having come to equilibrium with their shared environment, are at the same temperature. But if she touches them both with her ungloved hand she is bound to realize that the flagpole feels a lot colder than the tree. Her abstract mental model concerning temperature gradients, heat flows, and the inevitable approach to thermal equilibrium (the essence of the Second Law of Thermodynamics) is in direct conflict with her everyday experience that metal objects feel colder than wooden ones at

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Wireless Computers and Probeware Support a New Science Curriculum

Using iPAQ Pocket PCs to study science fundamentals

by Stephen Bannasch

The Data and Models project at the Concord Consortium is developing innovative probeware running on powerful wireless handheld computer systems that support student explorations into various forms of heat energy transfer.

In order to best support deeper personal ownership of the methods of experimentation, analysis and visualization, we gave every student in the study access to a wireless color handheld computer system: the Compaq H3600 series iPAQ Pocket PC. We selected the iPaq over several other options because it combined a fast 206 MHz processor, 32 MB of memory, a color screen, an excellent battery system, and 802.11b wireless Ethernet capability. In January 2001 an iPAQ Pocket PC outfitted with a PCMCIA jacket and wireless Ethernet card costs about $750; however, within two years we expect to see similar systems marketed for educational use selling for under $300. While an iPaq is small enough to easily fit in a hand, it has enough processing power, memory, and display capacity to easily function as a personal computer for a student. Systems like the iPAQ can easily function as a simple web browsing system, email center, advanced graphing calculator, student information manager, probeware system and by attaching a keyboard they can even be used for extended writing. Adding wireless networking not only allows portable access to web and email services, it also supports extended collaborative access to probeware systems such as the Concord Consortium's new Data and Models Thermal Conductivity System.

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Data and Models—www.concord.org/data-models/
iPaq—www5.compaq.com/products/handhelds/pocketpc/
Wireless Ethernet—www5.compaq.com/products/wireless/wlan/wl100-specifications.html
PCMCIA jacket—www5.compaq.com/products/handhelds/pocketpc/jackets.html

Monday'

Choreographed At

by Robert Tinker, Barbar

Multiple paths to learning include learning with the body, yet kinesthetic movement, one of the most powerful paths to embedding learning, is generally restricted to earlier grades. Working with 8th graders in Hands On Molecular Science (HOMS), we found that molecular models gained salience as students worked out the ideas in movement first, and then modeled their motions on the computer. The following is an example of a physical simulation that students can enact to illustrate the properties of a gas. These activities complement computer simulations using StarLogo or Molecular Workbench as well as investigations performed in the lab using probeware.

Activity Overview

How do molecules within a hot air balloon behave? How do droplets within a cloud stay up? How does a gas push on its container? For that matter, how does perfume get from me to you? Students can act as molecules in a container and make discoveries about how the properties of a gas emerge from the properties of its molecules.

Students carry a few batons, each representing an amount of kinetic energy, that is, energy of motion. They move in a straight line unless they collide with the walls of the "container" or with each other. Their speed is related to the number of batons they carry. If they collide with each other, then the student with more kinetic energy give one of his or her energy batons to the other "student-molecule." Several different starting scenarios can be set up to observe what happens to this simulated multiple molecule system over time. At certain points the whole class is asked to stop and reflect on what they are discovering.

Time

One 50 minute class period

Materials

Batons. You can use materials such as the cardboard tubing inside of paper towels, straws, or (more robust) pieces of wood. Make sure there are 3.5 times as many batons as kids. Each baton represents a unit of energy.

Steps

1. Make a container. Set aside the largest possible part of the room to be a "container" for the "gas." The walls can be defined by tables, desks, floor tiles, or tape on the floor. Draw a line down the middle of the container.
2. Go over the rules for this simulation.
   - Each student walks in a straight line unless they collide with a wall or with another student.
   - The speed a student walks depends on how many batons are carried. Students with more batons need to walk faster, but not run. It doesn't much matter the speed that each number of batons represents, but it is helpful if all agree. Have them practice a one-baton walk, a two-baton walk, etc.
   - If a student collides with a wall, he or she should "bounce" off it just as a ball would. Keep the same speed before and after. Have students practice.
   - If two students collide, then the student-molecule with more energy batons gives one baton to the other student-molecule and each goes off in a random direction.
   - If two student-molecules collide that have the same kinetic energy, then they play "rock-paper-scissors" to determine who gets the energy. On the count of three each student makes the symbol of a stone (fist), scissors (two fingers separated), or paper (hand held flat). Stone wins over scissors (it breaks it), scissors over paper (it cuts it), and paper over stone (it covers it). The one who wins takes one baton from the other. Try to do this quickly.
3. Run the simulation. Give students zero to six batons at random. Distribute everyone evenly in the container. Have students play the collision game for a while, and stop them periodically.
4. Reflect. When they stop, have the students think about what the simulation tells them about a gas. Use terms that apply to a gas. Whenever possible, refer to the students as molecules, the boundary as the container, and to the number of batons as their kinetic energy. Ask students:

LINKS ON THIS PAGE
Choreographed Atomic-level Science—www.concord.org/~barbara/homs/choreo_science.html
Hands On Molecular Science—www.concord.org/~barbara/homs/home.html
StarLogo—www.media.mit.edu/macstarlogo/index.html

's Lesson

mic Level Science

inker & Dan Damelin

- Will they ever all be in one corner? This is possible, but highly unlikely.
- Do they all have the same energy? What is the most likely energy? Least likely? The energy will be distributed around three or four per molecule, with much higher and lower values possible, but unlikely.
- Does the total energy ever increase or decrease? No. The total energy (number of batons) in the gas will always be a constant each time you stop the simulation. This is the idea of conservation of energy as long as you have an isolated system.
- Does the average energy per molecule change? No, because the average energy is the total energy divided by the number of molecules. Neither changes, so the average stays constant. This average is related to the absolute temperature of the gas.

By getting students thinking about this simple simulation, you can build their intuitions about energy conservation, energy distributions, pressure, randomness, entropy, and the measure of randomness. You can deepen and explore these topics through further kinesthetic experiments.

Experiments: What If?

The following experiments can be performed on the basic gas. You might suggest the overall question and have the students work out the details of performing the experiment.

1. If the molecules start in one place, will they spread out? Is there any way to keep the gas from spreading?

   One way to to answer these questions is to start all the students in one corner. Have them predict what will happen. After only a short time, the gas will appear random no matter how they start.

2. How evenly do molecules spread out?

   One way to answer this is to start with all the student-molecules in one half of the container. Run the experiment and count how many are in each half when you call "stop." Rarely will the numbers on the two halves be equal, but they will quickly be very similar. With 32 students, you would expect 16 in each half. Your results will cluster around that number, but almost as often the split will be 15-17, 14-18, and even 13-19. Statistically, you can be sure that two-thirds of the time the split will be no more uneven than 12-20.

3. How long does it take for molecules to spread evenly?

   No matter where the molecules start, they quickly randomize. You quickly lose track of the initial configuration. Identifying the exact time at which the molecules are randomized is impossible; it will happen over a range of times.

4. Does energy get randomized, too?

   The simulation could start with half the students having all the batons. Any other unbalanced distribution would be fine, too. Experiment with stopping after different times and counting how many students have each number of batons.

5. What happens when you mix hot and cold gases?

   Half the students on one side might start with all the batons while the half on the other side have none. Other unbalanced energy starting conditions would be fine. After only a short time, students should see that the energy distribution is about the same, regardless of the starting condition.

6. What happens when the gas is compressed?

   Students might "shrink" the container while running the simulation by having one student be a piston that can push all students into half the space. The piston-person can hold out her hands and all the students could pretend that this defines a wall that cannot be crossed. The pressure is the collision rate on a fixed part of the container. This represents the outward force of the gas on the container. What happens to the pressure as the gas is compressed?[1]

Background

The First Law of Thermodynamics says that the energy of an isolated system is constant or conserved. Since the energy of our gas is simply the number of batons, it should be obvious to

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Molecular Workbench—www.concord.org/~barbara/workbenchcc/workbench_index.html
First Law of Thermodynamics—www.cchem.berkeley.edu/~chem130a/sauer/outline/firstlaw.html

kids that their total energy is constant. If it isn't obvious, have them add up the batons each time you stop the simulation. They should catch on that the sum is always the same. That's all there is to the "First Law."

Energy is only conserved in a system that is isolated and has no energy inputs from the outside. Students might notice that energy is not conserved in the fourth system (refer to page 9). This is because photons carry energy into the system from wherever they originated.

At some point, you can introduce the idea of the temperature of the gas. Temperature is related to the average kinetic energy of gas molecules. Here is a way to calculate the temperature of part or all of the gas when you "stop" it:

- Add up the total energy (number of batons) in the atoms selected. Multiply by 100. Divide by the number of atoms selected. This will be an "absolute" temperature like the Kelvin scale. To get the gas temperature in degrees Celsius, subtract 273.
- At a temperature of zero Kelvins (0 K) the gas has no kinetic energy and is at rest. There is no way for it to go below 0 K because there is no negative kinetic energy.[2]
- The temperature of all the molecules will always become the same if the total energy stays the same and the number of molecules doesn't change. The only experiment that involves adding energy is when light brings in energy. Except in this case, the temperature will always become 77^{o}C. This is because if you have 3.5 batons per student, the temperature will always become 3.5 * 100 = 350 K or (350-273) = 77^{o}C. You can amaze your students by predicting this before they do the calculation!

The first four experiments illustrate that systems always get more random or disordered, but never spontaneously become more ordered. Starting with all the molecules on one side of the container or with some having all the energy is "ordered" or non-random. After running the experiment, these ordered starting conditions always disintegrate into similar disordered states. You can see that it is always possible that all the students will accidentally come back to the starting position, but it is so unlikely that you might as well say that it is impossible. They could play the simulation until the end of universe and still never assume exactly the starting position.

There is even a quantity, called entropy that can be calculated, that is a measure of the amount of disorder. If a system gets more disordered, entropy increases. The idea that systems become more disordered can be stated as entropy never decreases; it stays constant or increases. This is the Second Law of Thermodynamics, one of the most difficult physical principles to understand.

Assessment

Here are some challenging questions you can use to assess whether students have understood this lesson.

- *Is it possible for a molecule in our simulation to have no energy?*

  Yes. If two student-molecules each with one baton collide, one ends up with none. This is rare, but there is some chance that two student-molecules, each with one baton, will collide.

- *If we run the simulation long enough, does everyone end up with the same number of batons?*

  No. Energy is always being exchanged and a few molecules end up with lots of energy and some with little or none.

- *What motion would they observe at zero Kelvin?*

  All motion stops. No one has any batons.

- ***Is it possible to have a temperature below zero Kelvin?***

  No, you cannot have negative batons and you cannot go slower than a dead stop.

For more variations of choreographed molecular science, visit the Hands on Molecular Science website. @

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FOOTNOTES

[1] There is an inaccuracy in this simulation that should be noted. The energy of a gas will increase when compressed. This happens because the compression requires a wall of the container to move inward. When atoms hit this moving wall, they leave with slightly more energy. This increases the energy in the gas; our simulation does not include this effect.

[2] There are exceptions to these statements. In real gasses, there is a so-called "zero-point" motion at zero degrees. This motion cannot be extracted but is required by the uncertainty principle: we cannot know precisely where an object is and how much speed it has. If it had exactly zero speed, then it would have to be everywhere. Also, negative temperatures can be observed, in certain unusual conditions.

LINKS ON THIS PAGE
Second Law of Thermodynamics—www.secondlaw.com
Negative Temperatures—www.phy.ncku.edu.tw/chinese/uw_physics/neg_temperature.html

continued from page 7

Starting from research on student misconceptions regarding heat and temperature (see article, page 6), we have first created a system we call "blockmodel" to explore thermal conductivity and temperature gradients in different materials. The heart of our system for exploring thermal conductivity is a set of small aluminum, stainless steel and nylon blocks with an embedded network of temperature sensors.

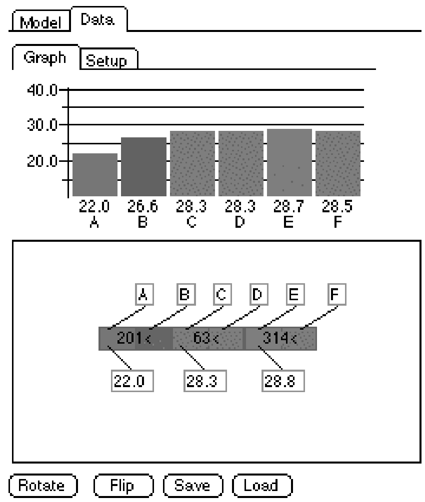
The blocks can be arranged in arbitrary two-dimensional patterns and heat can be pumped either into or out of any point of the thermal network of blocks using a Peltier-based thermal actuator we designed. The temperature of sensors embedded in the blocks is transmitted over a wireless Ethernet and displayed simultaneously on multiple iPaq handheld computers.

Because the blocks can be rearranged easily, many simple configurations involving topology and material can be investigated quickly. For example, students are often puzzled when asked "does heat flow around a corner as easily as it does in a straight line?" It is very simple to set up a test with the blockmodel system. Later issues of both thermal conductivity and specific heat come into play when comparing temperature gradients using different block materials.

In addition to measurement, visualization, and analysis of real physical systems, the software enables students to use simulations to construct and evaluate simple thermodynamic systems.

Going beyond our work on conductivity, we are working on an ultra-fast response temperature probe. While most computer-based temperature probes take over five minutes to settle to near equilibrium in still air, our new probe responds in seconds with a temperature resolution of better than 0.05^{o}C. This ultra-fast response allows a tremendous range of interesting investigations.

We believe it is important for students to understand how the mass of a finger and the nerve cells near the surface of their skin respond when touching objects at different temperatures. A finger is the first temperature probe that everyone uses. A classic misconception is that metal objects are colder than plastic objects. The ultra-fast probe can in seconds measure the actual surface temperature of the metal and plastic objects and determine that they are the same. However, the experiments become much more interesting when the temperature of the surface of the skin is measured both before and after touching metal and plastic objects. If this is done with different fingers students discover that the surface of the finger that touched metal cooled more than the finger that touched plastic. We hope that by using their previous learning about temperature gradients and heat flow through materials of different conductivities and specific heats, along with a simulation of finger thermodynamics, students will break through the misconception and achieve a deeper understanding of their body as a sensor.



The touch screen of the iPaq displays the students' experimental data.


The blockmodel system components and the Compaq iPaq handheld computer.

We also plan to use the ultra-fast probe for investigations of radiant heat flow. We experimented with the initial prototype by turning on an incandescent desk lamp and directing it horizontally at the sensor placed about 18" away. While the hand holding the sensor could feel the heat of the lamp the shiny surface of the sensor reflected most of the radiant energy coming from the lamp and did not heat up. However, when placing the sensor one millimeter above the back cover of a book and illuminating both with the lamp, the temperature of the air next to the surface of the book immediately rose. Moving the book away caused the sensor to immediately drop to the local air temperature. This experiment became even more interesting when we turned the lamp off, aimed it at the book and sensor and watched the air at the surface of the book immediately rise in temperature again because of the infrared radiation coming from the hot bulb and lamp housing. In effect we created a primitive thermopile.

An ultra-fast response probe can also be used for measuring the small and often ephemeral temperature differences associated with convective flow. The probe is sensitive enough to measure the temperature fluctuations of convective bubbles of warmed air three inches above the surface of a hand.

Developing student intuition to provide a context for interpreting results like this will be greatly enhanced by model-based visualization of convective flow. @

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LINKS ON THIS PAGE
Data and Models—www.concord.org/data-models
iPaq—www5.compaq.com/products/handhelds/pocketpc

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level, they can observe the genes carried on the chromosomes. According to Mendelian laws, altering those genes can change the appearance of the associated organism.

At the chromosome level, genes are simply markers — their exact nature remains as mysterious to students as it was to Mendel. We know now that the explanation of the genetic mechanism resides at the molecular level. GenScope enables students to drop down to this level to explore the DNA molecule contained within each chromosome and to alter it at will. Such alterations result in mutations that show up as changes in an organism's phenotype and may be inherited by its offspring.

Inheritance is handled at the cell level in GenScope by simulation of the twin processes of meiosis and fertilization. By using a special zoom tool, students are able to look at the chromosomes during meiosis and see which alleles they carry. By controlling gamete formation, and by selecting beforehand which gametes to fertilize, students can control the genotype of the resulting offspring.

Such control is not available to the students at the pedigree level. They must instead rely on probability and statistics to predict the outcome of a cross between two organisms. Deprived of information and control mechanisms that are also unavailable to scientists, students are forced to rely on their internal models of genetics to make reliable inferences from data analogous to that obtainable in the real world.

The Solution: Hypermodels

The difficulties students encountered occur frequently when students learn through the exploration of open-ended tools. Assessments outside the environment cannot measure learning within the tool. Students need prompting to transfer their learning to another environment. And teachers are often unable to provide the guidance students need to fully exploit the model-based environment. Because the problems we encountered with GenScope plague most modeling environments, we decided to solve our problem by creating a software architecture that could be applied to any software tool — a hypermodel.

Our hypermodel architecture, illustrated in Figure 1, consists of three software layers designed to separate functions relating to domain content from more general ones relating to pedagogy, and to give control over both.

At the bottom level is the domain content engine, which consists of a set of loosely coupled components, or views, that can be combined and integrated in a variety of ways.

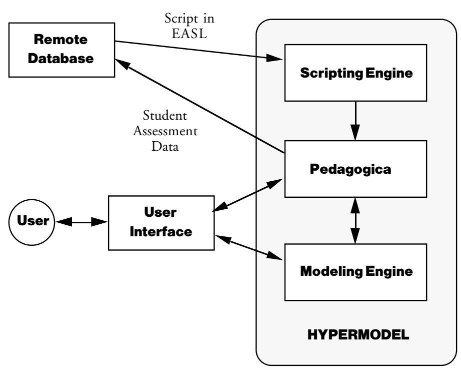

Figure 1. Hypermodel architecture. The three software layers designed to separate functions relating to domain content from more general ones relating to pedagogy, and to give control over both.

In our most elaborate hypermodel to date, BioLogica is the domain content engine. BioLogica is similar to GenScope but reprogrammed in Java. In BioLogica the chromosome view and the organism view share a common database that contains, among other things, the genotype of every organism. One of these views uses this information to display alleles on chromosomes; the other, operating with a set of built-in rules, determines and displays the phenotype of each organism. Altering a gene in the chromosome view, say, from a dominant to a recessive allele, will be reflected, as appropriate, in the form of changes in an organism's phenotype. In our implementation of the BioLogica domain content engine we ensured that its views are interoperable. (Each view is a Java Bean and each is serialized using XML, a common markup language.) BioLogica's views are purposely kept simple. They do not, for example, have a user interface of their own, but must be placed on the screen and configured by the next level of the hierarchy, Pedagogica.

Pedagogica, as the name suggests, handles all things pedagogical. It is responsible for all interface details, including the placement of text boxes, buttons, and domain engine views in various locations on the screen. Pedagogica also controls the flow of a student's activity by shifting from one set of views to another in response to a student's actions. Pedagogica can set up "listeners" (software agents that monitor views and other objects) and report on changes in their contents or properties. This enables the software, for instance, to react whenever a new organism is created, or when the student clicks on the image of a gene. Pedagogica can communicate with the student through graphics and text, and pose multiple-choice and essay questions. It also controls the collection and storage of data, maintains and controls access to student records, and manages the registration and login functions.

Pedagogica itself is controlled by the third software layer: the scripting engine, which has the job of interpreting short scripts written in a simple, interpreted language, called EASL (Educational Application Scripting Language) developed by us. These scripts implement the activities that students interact with, setting up the initial problem, configuring the hypermodel to match the problem, observing and reacting to students' actions, and communicating with them as they work through their investigations. Although EASL scripts are relatively straightforward to write, they are full-fledged programs and require greater attention to detailed computer functions than most curriculum developers or teachers are probably willing to put up with. We are working on simplifying EASL so non-programmers can create their own scripts and modify scripts of others.

LINKS ON THIS PAGE
Mendel—www.netspace.org/MendelWeb
GenScope—genscope.concord.org
BioLogica—biologica.concord.org

The First Hypermodel: BioLogica

The BioLogica hypermodel can be visualized as a newer version of GenScope linked to Pedagogica. Superficially, the BioLogica hypermodel looks much like GenScope. It uses the same dragon species and many of the same levels and tools. But where GenScope is a general-purpose tool that students can use to investigate genetics, the BioLogica hypermodel is a tool with which researchers and teachers can develop scriptable genetics curricula.

The difference between the two applications is most apparent in their interface. GenScope has a plain interface: it opens with an empty organism window and provides options for creating organisms, pedigrees, and populations, and to view cells, chromosomes, and DNA. GenScope's interface is designed to make it as easy as possible for users of varying sophistication to gain access to its many features; it is a tool-driven interface. BioLogica's interface, in contrast, is activity-driven: the layout of the screen and the actions and representations available to students are determined by the particular activity that is in progress. Whereas GenScope is intended to run as a stand-alone application, BioLogica is a utility for the creation of learning activities. BioLogica cannot be run by itself, but requires a script — a short executive program that implements the learning environment. The script embodies both the activity that students are to engage in and the indicators that can be used to judge their performance.

The hypermodel software is typically resident on each computer in a classroom, but the scripts may be located on a central server, either remote or within the classroom. This makes it possible to present students with customized learning experiences. For research, this means we can easily manage different treatments within the same classroom. For educators, this means that the activities can be adapted to match individual needs. Using scripts, we can control and limit the options presented to students. Instead of getting lost, they can focus their attention on a particular problem. They can still explore and learn through inquiry, but in a reduced space that is more easily explored and understood. We can also prompt students to think about what they are learning and to explore the links to other concepts.

Pilot Studies

At this writing, we have conducted three pilot studies with scripted BioLogica hypermodels and are about to embark on two more. While the data from these trials have yet to be fully analyzed, the initial results are encouraging. GenScope's main feature was its appeal to students, and adding scripting to BioLogica has not changed that. Moreover, there is preliminary evidence that the activities we created have overcome many of the difficulties we encountered with GenScope. Encouraged by this success, we are now converting probeware and our molecular dynamics package Oslet (see article, page 4) into hypermodels. We encourage other model makers to do the same so that there will be hypermodel tools for every subject that can use models.

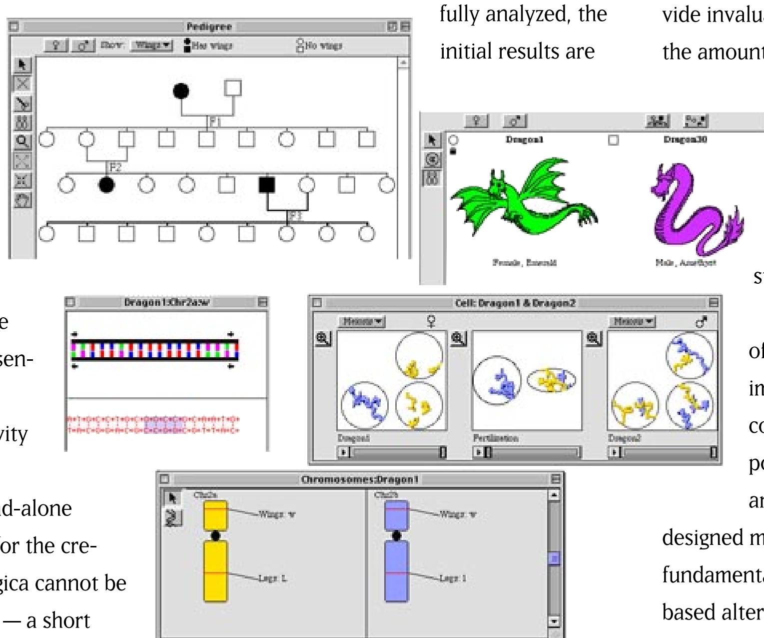

Figure 2. GenScope can display five levels of genetic information — (clockwise from top left) pedigree, organism, cell, chromosome, and DNA — all of which can be manipulated and the results observed.

Another benefit of our hypermodel design is its capacity for embedded student assessment. A student using the BioLogica hypermodel can be challenged in a lesson to discover whether a particular trait is sex-linked. Pedagogica can note which screens the student uses in answering the question, what order the screens were accessed, and how long each was viewed. From this, we can infer whether the student was guessing, how well the student understood the concepts, and whether the student was lost. This kind of embedded assessment could provide invaluable high-level feedback and reduce the amount of time spent on formal assessment. It is also a promising research tool that allows us to obtain at a distance detailed information about student thinking, knowledge, and problem-solving strategies.

The most significant contribution of information technologies to improved science learning is likely to come through the increased use of powerful, content-based modeling and data analysis tools. Well-designed models should help students learn fundamental ideas and give them computer-based alternatives to formal mathematical techniques. The hypermodel architecture could be the key to realizing this dream in real classrooms. @

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LINKS ON THIS PAGE
Genetics—www.people.virginia.edu/~rjh9u/pedsymb.html
Oslet—(see page 4)
Probeware—probesight.concord.org

Conflicting Evidence

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the same temperature.

To help resolve the conflict, we designed some preliminary activities involving human body temperature versus room temperature and tried them out on some students. This spring we will try the activity again with fast-response temperature probes (see article, page 7) that will enable the students to quickly compare the higher temperature data of their body first hand to that of their surroundings.

By confronting students' mental models with the evidence of real time data, we have watched the students adjust their theories. For example, during past and recent testing, the students made the statement that "heat cannot move around corners." After heating metal bars embedded with temperature probes in different configurations, the students quickly realized that heat can travel through the metal no matter what the alignment of the bars. Yet, they still hold to some of their original theories: although heat moves around the corners it "moves more slowly." In future work with the students, we plan to challenge this misconception with side-by side set-ups with different metal bar configurations, careful analysis of the graphs, and a stopwatch.

Real World Models

Based on our first year observations of student response to the gradient activities, our next logical step is to investigate two-dimensional systems that exhibit temperature change. Interesting new phenomena arise when we introduce fluids (liquids or gases), because now different parts of the system can move with respect to each other. As we extend our studies beyond conduction to other forms of heat transfer, such as convection and radiation, our students will be able to investigate ever larger and more complex systems. Computer technology will enable them to formulate increasingly complex models, run them as simulations and compare their behavior to experimental data. Eventually, they will be able to use this powerful technique to develop a qualitative understanding of such real world phenomena as weather patterns, seasonal variation, and global climate change.

Students use a blockmodel (see article, page 7) to explore thermal conductivity and temperature gradients in different materials.

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LINKS ON THIS PAGE

Second Law of Thermodynamics—www.secondlaw.com

Kluwer/Plenum Publishers—www.wkap.nl

Education for a Sustainable Future—csf.concord.org/esf

VHS Graduates

New independent nonprofit keeps familiar staff and mission

by Robert Tinker and Bruce Droste

October 2001 the Virtual High School™ graduates from a federally funded research project to an independent service. Since its inception five years ago, the Virtual High School has grown to include over 175 schools and offer over 150 courses. It has demonstrated that well-designed courses delivered by trained teachers can be successfully offered online.

A separate nonprofit corporation, VHS Inc., will take over the Virtual High School project on October 1, when federal funding ceases. The new organization will grow and refine its mission and continue the VHS™ history of success:

- courses that offer a breadth of intellectual riches to every school;
- a 20-to-1 student/teacher ratio;
- a 95% completion rate.

VHS has also rescued some schools from closure and proven the viability of online collaborative learning. But of all the unique ideas that inspired the original organization, the most important to emerge from VHS could be easily overlooked. VHS demonstrates how a decentralized cooperative can work. Administrators are often attracted to online courses because of the seductive argument that the Internet can lecture to mass audiences. The apparently large student/teacher ratios offer savings. However, teachers are vital to learning, and one full-time teacher simply cannot attend to the needs of more than 100-150 students at one time, whether online or in a traditional classroom. That translates into five courses of 20-30 students. VHS targets 20 and never allows more than 25 in a class.

All other projects offering online courses are centralized — an office, department, university, or business is offering the instruction. Someone has to pay for this overhead, which can be huge if good student/teacher ratios are maintained. Some projects do not charge for these costs initially, but if they are to be successful, local schools will eventually pay the cost, which will include the expense of regular courses plus the added cost of offering courses online. And centralization is bad for communities because it reduces the amount of instruction provided locally.

VHS works differently. Each school that contributes a course can enroll 20 of its students in any VHS course. Teacher time is contributed to the cooperative by the school. Joining the VHS keeps the amount of local teaching the same, so it supports the objectives of the community and supports teachers' unions.

This is why the charge for joining the VHS will always be lower than the actual total costs of comparable centralized projects.

During the transition to VHS Inc., the organization will maintain its current, successful administrative staff, with Bruce Droste and Elizabeth Pape as President and CEO, respectively, of the new organization.

When comparing online educational options, we are confident that educators will see the cost and quality advantages of the VHS model. @

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LINKS ON THIS PAGE
Virtual High School—vhs.concord.org

Putting the Pieces Together

The Noyce Foundation Challenge Grant

One of the basic challenges any nonprofit organization faces is maintaining its financial health. Our goals as an educational nonprofit include research and development into technology and curriculums that support students, teachers, administrators, parents, and the community in creating the best that education has to offer. We try out new ideas, share our discoveries, and encourage the development of teacher as well as student potential. Our goals also include maintaining our financial stability.
A certain amount of financial independence allows us the flexibility to venture into new, emerging areas of development, such as the use of handheld computers in the classroom. We were one of the first to study the potential of handhelds. We value our ability to think new thoughts and share our research and advancements with the world. Now we need your help to sustain that independence into the future.

The Noyce Foundation has generously given us a $100,000 challenge grant for support of our general fund activities. Many Concord Consortium supporters have responded in kind with donations that help support our work and independence. We hope we can count on your help, too. With this challenge grant, the Noyce Foundation is showing its support for the important and creative educational research and development that has taken place at the Concord Consortium, and it is helping to secure our continued leadership in the area of educational technology. You can help by sending a contribution in support of our work. All contributions at this time will help maintain the organization's health and independence. We are a 501(c)3 non-profit organization, so your contribution is entirely tax deductible.
Thank you!

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