HIGH ADVENTURE SCIENCE

THE NEED

> *Very few see science as the high adventure it really is, the wildest of all explorations ever taken by human beings, the chance to catch close views of things never seen before, the shrewdest maneuver for discovering how the world works. Instead, they become baffled early on, and they are misled into thinking that bafflement is simply the result of not having learned all the facts.* Lewis Thomas [1].

There have been many attempts to interest students in science by putting them in contact with scientists [2-4] and engaging them in research [5-8]. Neither approach has proven practical on a wide scale. There are too few scientists with the time and communication skills to have any impact on education, and, although doing real science and connecting it to classroom learning goals is exciting [5, 9], it has reached few students because it has proven difficult to sustain [10, 11].

This project will investigate a new, replicable, and sustainable strategy for injecting contemporary science into the classroom: engaging students in important unanswered questions that scientists around the world are actively exploring. Most of science teaching is a race to cover as many facts and concepts as possible. This can be baffling, deadly dull, and discouraging. Studies have shown that many students tune out of science not because they cannot master it, but because they don't see why science is relevant to their personal goals [12]. The emphasis on covering content also gives students the misconception that science is about what is known. They get no exposure to how science progresses, what is unknown, and what motivates scientists.

To celebrate its 125th year, *Science* published a special issue on "What Don't We Know" [13]. They had articles on the 25 top questions identified by a panel of scientists, and list 100 more. Just reading the list is exciting for anyone with a scientific bent. We propose to explore whether it is possible to generate similar excitement and motivation in middle and high school students by giving them a taste of the unknowns like the Science topics, but doing it in a way they can understand and is engaging, inviting, and solid education.

The way students learn about unsolved science topics needs to reflect the way science proceeds. Students cannot do the science, but they can explore aspects of it using computational models. Students can experiment with these models and learn deeply by exploring their models' emergent behavior. This ability to experiment with computational models that connect students to frontier research distinguishes our approach from other attempts to inject uncharted science into instruction.

Through their guided explorations, students can gain an understanding of a scientific problem and what is known about it. By addressing the supporting science, we can make these explorations fit into existing courses and meet both content and inquiry standards, particularly for courses in biology, ecology, earth science, and space science. We can give students enough understanding of the science that they can speculate on the answers and even participate in online debates. Prior projects have demonstrated that involved scientific controversies were quite motivating and powerful learning experiences [14].

GOAL, OBJECTIVES, AND RATIONALE

The goal of the High Adventure Science (HAS) Strategies ITEST project is to explore whether guided simulation-based student explorations of current science topics as presented by scientists themselves in video, can increase student interest in science and result in learning of important science topics. We will also examine the scalability of this approach and its potential for large-scale utilization. We will test this idea in 20 diverse classrooms using a limited set of topics that can be related to typical content in biology and earth and space science.

PROJECT OBJECTIVES

1. **Develop Pilot Materials.** For the research to detect an effect, teachers need to devote approximately two weeks of class time during the year. In order to ensure this, the project will develop five activities that could require 2-4 class days that are suitable for a secondary course in earth and space science (E&SS) and five additional ones for a secondary biology or ecology course. The five activities will be designed to simplify adapting the materials to specific courses.
2. **Engage Teacher/Developers.** Initial activities will be developed by curriculum design professionals at the Concord Consortium. Twenty teacher/collaborators will customize the materials these materials and plan their implementations. This collaboration will also provide teachers with the professional development they need for successful enactments of the activities. Teachers will be drawn from two pools: one group will be from Jefferson County, KY, and the other group will be a combination of local classrooms that can be observed easily and diverse sites nationwide.
3. **Project Research.** The project will study the use of HAS in classrooms of the 20 teachers over two years. Half the teachers will delay their implementation by a year to serve as a control. An instrument will be developed to measure student attitudes about science and science careers and their acquisition of science content. This instrument will be administered at the beginning and end of both years in classrooms of all 20 teachers.
4. **Support National Dissemination.** Project staff and participants will make presentations and offer workshops at major professional meetings. Supporting this effort will be a new website that will include a full set of resources faculty can use to review, manage, select, run, customize, discuss, and critique student activities that use the project's software. The project results will also be disseminated through annual articles in Concord Consortium's journal *@Concord.*

RATIONALE

This project explores a fresh approach to bringing science into the classroom in a way that is true to the sprit of science, uses modern technology, is based on current research in effective cyberlearning, and could be easily scaled up to have a measurable impact on science teaching. Unlike most efforts to motivate students in science, this project will measure the impact of its intervention using a powerful research design. The project is important because it will explore a practical approach to motivating young scientists and teaching science that is widely recognized but rarely implemented because of the lack of appropriate student activities and the pressure of tests (which, ironically, are based on standards that emphasize the process of science as much as its content). The project learning activities and professional development resources should be useful themselves and will be made widely available online. In addition, the findings of the project could easily spawn the development of additional activities and further research.

PRIOR WORK

Molecular Workbench Projects

Molecular Literacy for Biotechnology and Nanotechnology Careers (5/04 - 4/07. $899,857. DUE-0402553, PIs: Berenfeld and Tinker). This project was a three-year effort to enhance bio- and nano-technology curricula by engaging students in guided inquiry of computational models that illustrate key concepts. It studied new materials that embed atomic-molecular model-based activities in both core science courses and specialized courses teaching technology workplace competencies. The project developed 27 activities based on the Molecular Workbench system[1] and studied their implementation in five high schools and nine community colleges.

Project research analyzed student learning gains, transfer, retention, and faculty reactions. Student gains on paired tests given before and after use of the materials were scored for 47 classes that used a total of 22 of the 27 activities. Of these, 38 classes (81%) showed significant learning gains ($p< .05$), 16 of these (34%) at the $p<.001$ level. Those classes that did not show significant gains were almost all classes that used the MoLit activities for review. It appears that these materials give gains only when the primary instruction uses the model-based approach.

One set of transfer questions was designed to see how student learning about molecular interactions might impact student analysis of laboratory results. For example, one item asked how a change in protocol might account for unexpected results. Such questions were included in the pre/post-tests for eight activities that were tested in 20 classrooms. The fraction of students scoring high in these items increased from 19% on the pre-test to 53% on the post-test. Another measure of transfer used a "Molecular Reasoning" scoring rubric that measures the inclusion of appropriate use of descriptions of dynamic interactions of atoms and molecules in open-ended responses. In those activities where students were asked to reason about atomic-scale interactions, their Molecular Reasoning score increased significantly.

To measure long-term retention, students were interviewed two to six months after exposure to activities. In 20 interviews, before being prompted, 83% of the students could describe the concepts taught in the model-based activities and 54% could elaborate upon the concepts. When presented with a screenshot of the model in the activity and prompted, 100% could identify the key concept, 57% could elaborate on the concept and the importance of the interactions with the model, and 86% could describe what all the different parts of the model represented.

Thirty teachers completed a total of 86 feedback forms. On a Likert scale of 1 to 5, teachers liked the activities (the average score was 4.34 in the first year of testing, 4.22 in the second), thought the students understood the content (4.24/4.42), thought the concepts correlated to their classes (4.37/4.62), and felt the level was appropriate for their students (4.53/4.59). Twenty additional teachers from diverse two- and four-year colleges were engaged in a nine-week online course on "Molecular Reasoning" using the MoLit materials. Part of their assignment was to take their own constructed activities back to their classrooms. At the end all but one college teacher felt they could better teach with models using the MoLit materials and were committed to doing so.

The external evaluator for MoLit concluded: "MW not only allows [students] to move through the activities as written by project staff. It also allows them to generate ideas for experiments,

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[1] See http://molit.concord.org/database/browse/core/. This page is a list of the activity titles that links to descriptions of each, from which the actual activities can be launched.

design them, change the parameters as they are carried out, analyze the data that can be shown in graphical and pictorial formats, draw conclusions and share this information with their teachers and fellow students. For the purposes of simulating physical phenomena at the micro level, the Molecular Workbench is a strong and facile tool that can, and probably will continue to, find use in a number of programs beyond this project."[2]

Molecular Workbench: Reasoning with Atomic-Scale Models (12/1/99 - 8/31/04. $1,364,944. REC-9980620. Berenfeld, PI). **Molecular Logic**: Bringing the Power of Molecular Models to High School Biology (2/03 - 6/06. $1,416,623. ESI-0242701. Berenfeld, PI). **The Molecular Rover** (10/1/05 - 9/30/07. $299,815. REC-0537224. Tinker, PI, Xie, Co-PI). **Science of Atoms and Molecules** (DRL-0628181 $1,139,836. 10/06 - 5/09. Berenfeld, PI, Tinker, Co-PI). **Electron Technologies: Modeling Pico Worlds for New Careers** (5/08 - 5/11. $898,516. DUE-0802532. Berenfeld, PI, Xie, Co-PI).

These projects each involved research on materials using the Molecular Workbench (MW) models, platform, and editing system; each added new functionality to the technology. MW is an open-source learning environment that allows students to experiment with atomic-scale systems to understand the physical origins of a very wide range of phenomena such as phase change, light-matter interactions, chemical equilibrium, reaction pathways, protein conformation, the shape and function of biomolecules, electron-matter interactions, and plasmas.

The MW platform includes an intuitive authoring and customization capacity that instructors can use to create and alter activities for students, and students can use to create their own models. Instructors have access to both stand-alone models and fully developed model-based learning activities that they can use or modify. The authoring system has already generated over 200 activities in a wide range of science and engineering subjects for grades 6-16. Many of the activities have been carefully tested, revised, and widely disseminated [15-23].

MW activities consist of pages that can contain text, html objects, assessment items, MW models, graphs, molecular viewers, other Java applications, and links to other pages. Although there are numerous MW user tools, those not needed in a lesson can be hidden. A scripting language can be used to extend the range of possible models and interactions. Students can save their productions in an electronic portfolio, create a report, and submit it for grading. Using these options, an author can create a complete, sophisticated learning activity.

Geoscience Education Projects

Inquiring with Geoscience Data Sets (IGDS) NSF GEO-0507828, Dr. Edys Quellmalz and Dr. Daniel R. Zalles, Co-PI, 8/15/05 - 10/31/07 Total to SRI was $299,579. Concord Consortium's subgrant was $115,066.

The Center for Technology in Learning at SRI International and CC studied the impact on student learning of Web-based supplementary geoscience curriculum modules. Secondary-level students participated in projects that addressed two neglected geoscience education standards: system knowledge and inquiry. Using an Earth System Science approach, students interpreted and analyzed data sets and visualizations, and communicated their findings. Design principles, specification templates, and prototype exemplars designed to improve geoscience knowledge and

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[2] Final reports on the MoLit research, materials, and findings, as well as the independent project evaluator's report can be found at http://molit.concord.org/reports/

inquiry skills were developed. The project was responsible for the development of two proof-of-concept units, one focused on data analysis along plate boundaries and the other on climate change issues. Findings indicated it was possible to (1) prompt a range of data analysis tasks, (2) provide end-of-module assessment tasks that measure near-transfer, (3) find evidence that our modules filled a gap in the typical secondary-level science education programs, and (4) determine that there were learning gains [24].

Making Thinking Visible: Promoting Students' Model-Building and Collaborative Discourse in WISE NSF REC-9980600, J. Gobert, PI; Awarded January 2000; $264,000. Supplement of $50,000 awarded January 2002.

In this project, a design study approach [25, 26] was used to develop, test, and refine a curriculum for middle and high school students from the East and West Coasts to collaborate online about the plate tectonics in their respective locations [27]. In the curriculum unit "What's on Your Plate?" the students were engaged in many visualization-based inquiry activities, including: (1) model building, peer critique of models, and model revision; (2) online field trips where they "visited" USGS Web sites about earthquake and volcano data and relief maps of mountains; (3) dynamic models of the different types of plate boundaries (collisional, divergent, convergent, and transform boundaries); and (4) dynamic models of plate tectonic processes, including mantle convection and models of different types of plate convergence (oceanic-oceanic convergence, oceanic-continental convergence, and continental-continental convergence). Findings from this study showed substantial learning gains by students from diverse backgrounds of both content knowledge [26] and epistemological understanding [28].

Online Professional Development

The Concord Consortium (CC) has over a decade of leadership in developing new approaches to technology-rich professional development for STEM teachers. When launched in 1996, INTEC, the NSF-funded **International Netcourse Teacher Enhancement Coalition** was one of the first web-based online PD programs. It created and delivered a 120-hour online, credit-bearing graduate-level professional development course to over 800 teachers across the country. INTEC developed the Concord e-Learning Model, a successful course on online course facilitation, and a supporting text [10] that remains widely used today. The success of INTEC led CC to develop **the Virtual High School** [11], which in 1997 was one of the first online high schools. This highly successful program has made the transition to an independent nonprofit supported entirely from school membership fees. It is fully accredited and currently offers over 200 semester-long courses in all disciplines to students worldwide. In 2000 CC launched **Seeing Math**, an innovative in-service, online professional development project. The Seeing Math project developed 21 online short courses for teachers of mathematics at the upper elementary and middle school levels. Seeing Math courses are available from PBS TeacherLine and Teachscape.

This decade of experience with online PD led to a collaboration with Rhode Island institutions to create the **Rhode Island Technology Enhanced Science** project (RITES). This $12.5M NSF MSP project, just getting underway, will reach all Rhode Island secondary science teachers with online short courses. The design of the courses and their reliance on teacher customization of inquiry-based materials is identical to that proposed for this project.

Projects Using SAIL

The Center for Technology Enhanced Learning of Science (2003-2009. $10M. ESI-0334199. PIs Tinker, Linn, Slotta). TELS, a Center for Teaching and Learning, is advancing the state of the art for the effective use of information technologies in STEM learning. It has developed a theory-based approach that supports student learning through guided inquiry of dynamic visualizations. TELS research has resulted in 40 new fellows, nine postdocs, 104 teachers who use TELS materials in 42 diverse schools nationwide, and 106 published papers with 32 more in press.[3] The Center is continuing to attract grants to the three main partners: the University of California, Berkeley, the Concord Consortium, and the University of Toronto.

To support its research, TELS partners have developed **SAIL**, the Scalable Architecture for Interactive Learning, which includes facilities for launching client-side learning materials like MW and tracking student use of the materials. SAIL includes general ways of providing persistence, that is, saving the state of learning materials so that students can suspend use and then continue later, possibly on another computer. It also provides an instructor's portal that reports student progress and allows the instructor to make student assignments, poll students in class, and control student computers. In classrooms with wireless, SAIL permits students with portable computers to respond to probing questions, far exceeding the functionality of most classroom response systems ("clickers" [29]), because SAIL can handle responses that are graphs, MW models, or drawings. SAIL is so useful that it is being used in other projects at the partner institutions and other research groups worldwide.

PROJECT DESIGN

THEORETICAL FRAMEWORK

Students' Lack of Interest in Science

Numerous studies on students' interest in science document the decline in interest in science from age 11 onwards [30-33]. Students often enter secondary school with great interest in science, and their interest decreases with more experience of school science. This is particularly true for girls. In fact, Hadden and Johnstone [32] concluded that "Tragically, it would appear that school has done nothing for them in terms of stimulating their interest in science."

Many factors may lead to this decline, such as gender, culture, and the difficulty of science [34]. One key factor is that school science is often dull and unstimulating for students. Most science teaching is a race to cover as many facts and standards as possible. Curriculum materials and instruction typically lay too much emphasis on unstimulating activities such as rote memorizing and copying, and lack intellectual challenges [35]. As a result, students lose their interest in school science although they may still value the importance of science in general. For instance, Ebenezer and Zoller [36] questioned 1,564 Grade-10 (16-year-old) students about their views about science. Seventy-two percent of the students indicated that they thought science to be valuable, whereas nearly 40% indicated that they found science classes very boring. A similar finding is revealed in another study on Scottish high school students who dropped science classes [37]. Even 71% of these students still rated science as interesting, and 76% thought it helped understand things in everyday life. The ROSE study found similar results in all developed countries

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[3] See http://www.telscenter.org/. For a brief introduction to SAIL see: http://tels.concord.org/SAIL.overview5.pdf.

[38]. These studies suggest that students find science interesting, but not the science that they are taught.

Another problem is that school science covers content that is well established and students often find outdated. For example, one chemical concept that students dislike is the periodic table. Students do not think it is difficult to memorize the table, but they fail to see how it is related to their lives and argue that they never need to know all those facts or chemicals. In addition, school science texts attempt to demonstrate relevance by using topics such as the Haber process, which student see as science of the past century and omit interesting current applications such as nano materials and medical imaging [34]. Without relevance to modern technology and students' everyday lives, it is challenging to sustain interest in science. Students often gain no idea about how science progresses and do not appreciate the applications of the concepts taught in school.

Effective and Equitable Instructional Design

The High Adventure Science project will produce computer-based learning activities that rely on student inquiry. The structure and assessments used in the activities will be based on a knowledge integration framework. Teachers will be introduced to these materials using an online course based on the Concord eLearning Model design using a strategy that addresses the acquisition of pedagogical and content knowledge. Justifications for these programmatic designs follow.

Inquiry. A large number of studies have looked at the educational value of inquiry-based instruction [39-54]. There is broad agreement that science should be taught through student inquiry. The national science teaching standards [29, 55] are emphatic about the importance of inquiry to science learning. The AAAS Benchmarks place student inquiry front and center. Similarly, the NRC standards emphasize inquiry and assert that "Science as inquiry is a basic and controlling principle in the ultimate organization of ... science education." In other words, the entire curriculum should be organized around student inquiry, providing time for it, and making sure that prerequisite skills, attitudes, and knowledge are treated to support this.

Technology in support of inquiry. Research provides a strong justification for using technology to expand the range and impact of inquiry-based teaching. The central finding of 25 years of research on educational technology is that students can learn important concepts earlier and more deeply through guided interaction with computer-based models and tools, particularly in STEM areas [see, e.g., 52, 56, 57-66]. A distinguishing feature of this approach is its reliance upon student inquiry: students actively explore with tools and models by trying different parameters, arrangements, and initial conditions, and then run experiments and quickly see the results of their selections [49, 67-70]. Giving students controls can provide invaluable feedback, particularly if students systematically modify one variable at a time, allowing them to isolate the effect of each variable independently, and thereby to identify rules [71].

A substantial body of research shows that computational models and simulations allow students to understand through exploration the behavior of systems that are difficult to understand by other means [72-78]. They can also motivate students to participate [79, 80]. Dede has shown that virtual environments are valuable for both motivation and content acquisition [81]. The impact of these uses of information technologies can be seen in the 2000 National Assessment of Educational Progress, which found "Eighth-graders whose teachers had students use computers for simulations and models or for data analysis scored higher, on average, than eighth-graders whose teachers did not." Similar results were seen in grade 12 [82].

Instructional design. The HAS materials will use a "Knowledge Integration" framework, a fruitful synthesis of extensive research in technology-enhanced STEM learning [56, 83]. This framework emphasizes the central importance of engaging learners in guided inquiry which provide a range of experiences that use different learning modalities. Through reflections and communications students are asked to integrate their observations and link them with prior knowledge. . Curriculum designs produce this kind of learning when they emphasize student thinking and collaboration [84]. Assessments designed to measure knowledge integration can provide very accurate measures of student learning [85]. With formative feedback on student performance automatically generated by computer-based materials and used effectively by teachers in the classroom, substantial student performance gains can be expected [86, 87].

Effective Online Professional Development. CC has been using online professional development strategies effectively since 1996 when it developed the Concord eLearning Model [88] and a successful course on online course facilitation and a supporting text [89] that remains widely used today. The design features asynchronous, scheduled activities and carefully framed and facilitated discussions related to the activities among 12- 24 participants per section. CC has used this design in many successful projects, such as the Virtual High School [90] that CC developed and then launched as a separate nonprofit, which depends entirely on online courses for teachers and students.

Professional Development Content. One of the most influential recent developments in teacher professional development has been the realization that pedagogy and content must be taught together, the premise behind the idea of "pedagogical content knowledge" or PCK [91-94]. Teacher pedagogical content knowledge about inquiry has been shown to impact student learning [95-98]. A growing literature, especially in math and science education suggests that teacher experience enacting inquiry curricula in the classroom is critically important to the development of teacher PCK [98, 99]. HAS will implement PCK by engaging teachers in customizing project-generate materials. Customization is effective because it requires teachers to think deeply about the content **and** instructional strategies embedded in the activity that they customize [100, 101].

Inquiry, technology, and equity. It is sometimes asserted that inquiry based instruction is not appropriate in urban and under-performing schools. A number of research studies have come to the opposite conclusion [54, 102-106]. It appears that well-designed inquiry is just as valuable in an under-resourced urban classroom as anywhere else, even in ELL classrooms [107]. Similarly, it is also often assumed that technology is a barrier and a luxury in urban schools that need to concentrate on basics. Again research contradicts this; with support, technology can make significant contributions to student learning in urban settings [70, 108]. It has long been recognized that the "digital gap" in education is much less about the availability of technology than about how the technology is being used [109, 110]. High-quality materials supported with professional development, as proposed, are the best way to address these inequities.

OBJECTIVE 1: DEVELOP PILOT MATERIALS

In order to study whether exposure to activities drawn from current science research can increase student interest in science and increase their understanding of standards-based content, we will develop learning activities in several topics from current researcch that teachers can use throughout the year in existing middle and high school courses. The project will produce five model-based activities in biology and five in earth and space sciences (ESS). In each case, we will create a computational model that simulates a key experiment and permits students to gather data from the model system that illustrates the open questions and a video of a scientist presenting the research to a high school class.

As an example of our treatment, consider the first question on the *Science* list "What Is the Universe Made Of?" There are many unknowns in the universe, but the two most compelling are the apparent need to postulate the presence of dark matter and dark energy. The key observations for dark matter that were made by Vera Rubin [111, 112] involved rotations of galaxies that were inconsistent with their visible mass. We can provide students with a model of galactic rotation and star speed data that the model must match. We can guide them to understand that this match is impossible unless there is considerable additional mass. Students will be able to alter the distribution of dark matter to match the observational data. Similarly, we can give students spectra from distant supernovae that need to be adjusted for red shift. The only fit to the data will require some sort of anti-gravity or "dark force." To explore these models, students will need to learn about gravity, astronomical distances, galaxies, supernovae, the Doppler effect, and spectra, all of which are in most national and state science standards.

Obviously, not all open questions in science are amenable to this treatment. In many cases, the topic is too abstruse to the intended audience. In other cases, the experimental data are not easily simulated in ways that are accessible to students. However, we have identified ten topics that are suitable most of which are on *Science's* list of the top 25 unanswered questions. These are described below, along with the major topics that will be modeled.

Earth and Space Science

What is the universe made of? Dark matter and dark forces.

How does the Earth's interior work? Geodynamics and "seeing" with seismic waves.

How hot will the earth get? Models of global climate change and anthropogenic factors.

When will an earthquake occur in California? Historical data, statistics, and catastrophes.

Can far ahead can we predict the weather? Weather models and chaos theory.

Biological Sciences

Can we predict how proteins will fold? Hydrophobic effects, charge, and protein structure.

Can we make an HIV vaccine? Fast evolution and the immune system.

Will Malthus continue to be wrong? Modeling populations and the limits to growth.

How long can we live? The molecular basis of apoptosis and calorie restriction data.

How did life begin? Chemical synthesis of organic molecules.

With the help of the project advisory committee, we will identify 20-30 similar topics that appear to be interesting to students and we know that we can model. Early in the project, middle and high school students will be surveyed for interest in the topics, using short descriptions of each. We will also survey teachers who might join our project. Finally, we will survey the project's expert advisory committee. These surveys will help us decide which ten activities to develop. We will develop short computer-based activities that would each require two to three class periods aimed at high school students.

Once we have selected the ten topics for development, Concord Consortium staff will develop initial versions of instructional modules for each targeted at typical high school courses, relying on the middle school teacher/developers to later customize these for their use. The materials will be entirely online, centered on the simulations but embedded in a SAIL/OTrunk environment that supports questions, background, videos, directions, challenges, help, and assessments and also provides a teacher portal where student progress can be monitored and other

HAS will recruit one scientist for each topic to serve as a scientific advisor. We will ensure that the group of scientists is diverse in gender and race. In order to make the research more personal and immediate, we will video each scientist discussing his/her research with a class using the software that is part of the corresponding unit. The resulting edited videos will be part of the instructional module.

Objective 2: Engage Teacher/Developers

The project will recruit 20 middle and high school teachers for the research studies. They will be selected to ensure diversity in the students served in the courses offered and will need to have sufficient technology available. Each teacher will be expected to implement three or more modules during an academic year in their biology or ESS courses for a total of at least ten class periods. Teachers will participate for two academic years. Six of the modules will be available for the first year and all ten for the second.

Half of the teachers will be from Jefferson County Public Schools (JCPS), a large, diverse district that encompasses greater Louisville, KY. We can expect excellent collaboration at JCPS, because the superintendent is one of the founders of CC and the head of science has frequently collaborated with us when she had that position in Boston. They will be able to provide local support for the participating teachers. Most of the remaining ten teachers will be local to CC, so that we can easily do classroom observations. But, to test our online PD model, we will accept teachers nationwide and rely on online courses for professional development.

To test reactions to our proposal, we polled teachers who have been involved in the CC community. We were pleasantly surprised by the response, which was very positive and located more teachers than we need for the research. Typical responses:

> *I'd definitely be interested. This looks like it fits into my astronomy curriculum pretty well. I have found that it is the unsolved science that captures my students' attention. I can see this engaging my students and helping provide for them the "why is this important?" question I hear all the time.* Erik Berg, Belmont, MA.
>
> *It sounds like a wonderful idea and would be engaging and motivating to students.* Larry Weathers, Belmont, MA.
>
> *Thanks for your lovely invitation to work on with you on the proposal. Of course, I'd love to participate, if my schedule permits. My eighth grade class is fairly open for conducting learning experiments. I see myself simply as a conduit. I've recently conceptualized a semester long problem on biofuels production and hope to create some probe based activities in ITSI and use Molecular Workbench models. I've authored activities using both software packages. I find your work at Concord to be one of my main sources of inspiration.* Greg Louie, NC.

The following table lists teachers who have agreed to use the HAS materials (all are in MA except as noted):

Teacher	**School**	**Subject**	% Minority	% low income	% ESL
Rami Alwan	Lincoln Sudbury Regional HS	Bio	12%	4%	0%

Erik Berg	Belmont High School	ES	23%	5%	3%
Carolyn Brownsberger	Belmont High School	Bio	23%	5%	3%
Vanessa Bullard	Belmont Middle School	ES	23%	5%	3%
Russell Burwen	Rockland Senior High School	ES	10%	14%	1%
Miguel Carlucci	South Junior High, Brockton		70 %	72%	13%
Peter Elenbaas	Lincoln Sudbury High School	Bio	12%	4%	0%
Lanett Jauss	North Kansas City High School, MO	Bio	36%	37%	
Susan Lijek	Belmont High School	Bio	23 %	5%	3%
Greg Louis	Gravelly Hill Middle School, NC	Bio	40%	40%	3%
Charlie Mixer	Lexington High School	ES	26%	4%	1%
Larry Weathers	Belmont High School	ES	23 %	5%	3%

All participating teachers will be engaged with the project staff through an online course and online collaboration area. They will learn about the materials and be supported by staff in customizing the activities for their classes. Part of the customization will be to simplify the activities for middle school. Between the two trials, staff and teachers will revise the materials. We will also refine assessments based on the pilot study data and rewrite ineffective questions.

OBJECTIVE 3: PROJECT RESEARCH

The research questions for this project are:

1. Do the HAS materials increase student interest in science and science careers?
2. Do students using HAS materials learn science content as well using traditional material?
3. What aspects of the HAS materials are most effective?
4. How scalable is the HAS model?

The project research will use a lag design that provides a control group but ensures that all students eventually use the materials. Ten of the teachers (five from JCPS) will be selected randomly from the 20 recruits to start using the project materials in the second project year, while the remaining teachers will serve as a control group for that year. All 20 teachers will use the materials in the third project year.

To address the first two questions, the project will develop an instrument that can be administered in one class period that measures student perceptions about science and content knowledge. This instrument will be given at the beginning and end of the two academic years to all participating classes. The science perception items will be based on the Relevance of Science Education (ROSE) survey [113]. This excellent survey has been used in 40 countries and administered to tens of thousands of 15-year-old students. There are over 100 items in eight cluster areas using a four-level Likert scale. We will use about half the items, the ones that address motivation (the "What I want to learn about" cluster) and STEM careers (the "My future job" cluster.)

Content acquisition will be measured using knowledge integration scoring of items designed to measure student ability to reason using standards-based concepts. Items that address the standards related to the modules will be used. This means that the content-related items used in any one class will depend on which modules were used. For the control groups, we will use content for modules that the teachers intend to use the following year. Where relevant, we will use TELS items that have already been analyzed using Item Response Theory and whose difficulty is known. These can serve as anchors for items that need to be created.

The automatic logging provided by the SAIL/OTrunk environment will generate data on how long students used each activity and how much they interacted with the model. These data will generate a measure of student exposure to the materials.

The research design allows us to compare student gains with and without treatment in the same classrooms in different years, reducing much of the variability from teacher and school environmental factors. For this study, the unit of analysis is the teacher. Gains across years in the control classrooms can be expected from our PD and simple maturation. The classes that use the materials both years will give an indication of the size of this effect.

We will also analyze student gains for which student is the unit of analysis. With an expected 4,000 students in 160 classes over two years, we will be able address the first two research questions with a MANOVA analysis using three dependent variables and a collection of independent variables. The dependent variables will be student content gains, motivation gains, and career interest gains. Independent variables will include a cluster of student variables, including gender, income, ESS, grade level, course grade, and exposure to the materials. This analysis should be able to detect important but small effects, such as increases in positive attitudes toward science that correlate with exposure to, and success with our materials. We will be able to undertake a fine-grained analysis of student data that would use, and teacher characteristics as independent variables. The project will observe selected classes, review the logs of the online courses, and survey teachers on their science background and attitudes toward science.

The answer to the fourth research question will depend largely on whether the project keeps to its model of online courses and student materials. The approach could be feasible for large-scale dissemination if it is easy to implement, requires minimal PD, and addresses existing standards. The project will compare the PD strategies used with the Jefferson County teachers to the national group. Data for judging implementation fidelity and effectiveness and fit to standards will be gathered through questionnaires, surveys, and classroom observations.

Objective 4: Support National Dissemination

The project will create a rich legacy of materials: workshop materials, student activities and units, and teacher guides. All these materials will be available in electronic form on the HAS project website at no cost. All project-developed software will be open source and available free. We will bring these resources to the attention of educators nationwide through our website and newsletter *@Concord* that is mailed free to 10,000 educators twice a year and posted online at our website. Project staff will present research findings in professional (NSTA, NECC, and NARST) meetings and publications and also prepare informal descriptions and short workshops for magazines and conferences that reach teachers and school personnel.

Technology

Much of the software required for this project is available, in use at CC in other projects, and integrated into the SAIL/OTrunk framework so that creating model-based activities for student to explore will, in many cases, be a question of authoring in the existing environments. Because this framework will be used, all activities will generate logs of student use and provide teachers will near-real-time data on student progress and inquiry skills. The logs will show, for each teacher, how many students registered, which activities and units were started and completed, and the total number of minutes each activity was used, by student. The student progress data will include automatically scored items, teacher scored items, and an “inquiry index.”

The Molecular Workbench can be used for many of the models needed. It has been applied to situations far beyond the simulation of the motion of atoms and molecules, which was its original domain [114]. For example, Figure 1 shows MW used to explore bending and breaking of a beam. MW can easily model galactic motions as needed to explore dark matter. MW already is used to explore the factors that influence protein folding, molecular self-assembly, biological docking, and light-matter interactions [115].

BioLogica is another engine developed at CC that can be applied to a many of the simulations required by this project. BioLogica can simulate system involving genetics, including population drift, random mutations, environmental pressure, and evolution. Users can view a system at the molecular, gene, phenotype, individual, and population levels.

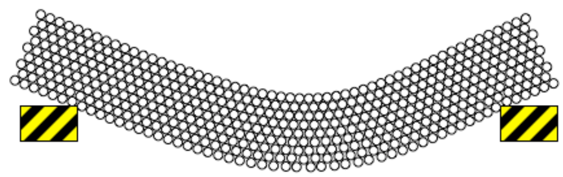

Figure 1. A MW particle model of a bar. With the addition of more particles, properties of real structures can be explored. Here a bar bends under gravity.

We have also integrated NetLogo [116] into our framework so that data can flow between NetLogo and other OTrunk objects. NetLogo is a general-purpose programming language designed for interacting agents. Extensive libraries exist of NetLogo applications to science [117, 118] and we have used it to create two highly acclaimed global climate models [119].

Some topics will require models that involve solving coupled differential equations with boundary conditions, such as the flow of mater inside the earth. For these, we will need to develop new computational engines: finite element methods and particle-in-cell (PIC) approaches [see 120 for a general introduction]. Figure 1 illustrates how PIC is a natural extension of MW. These methods will open up a wide range of applications in biology and ESS.

Project Management

Project Schedule

This will be a three-year project beginning October 2009. Activity development will begin immediately and continue for two years. The second year will focus on formative testing and revisions. Summative testing will occur in the final year. Research will span project years two and three.

Project Year One – October 2009-September 2010. The fall of 2009 will focus creating a list of research areas, implementing surveys with teachers and students. The first meeting with the Advisory Committee will also take place. The team will choose topics and work with three bioscientists and three earth scientists to create models that correlate with their research. Activities will be developed. Starting in January the project will begin the development of the online course. In the spring of 2010, video of the scientists will be created; they will be edited for use in the course and in classes beginning in the fall of 2010. In the spring all instruments for research will be developed and piloted.

Over the summer of 2010, work with the two remaining scientists in each field will begin. In September of 2010 the teachers participating in the field-testing will begin the online course and simultaneously give the class surveys and pretests for use in research.

Project Year Two – October 2010-September 2011 Activity development and revisions will be going on throughout this year. Videotaping of the remaining four scientists will occur in the fall and be made available for incorporation in the spring of 2011 as will the remaining pilot activities. As each activity is tested the materials will be revised. Research data will be collected on control classes and implementation classes. The data analysis will inform revision of activities and the online course. A revised course will be offered to the second cadre of teachers in the late spring of 2011. A second meeting with the advisory committee will take place.

Project Year Three – October 2011- September 2012 Development in this final year will be limited to features that are requested as a result of the course. Summative tests will be conducted, data collection and analysis will be intensive. Materials will be revised for dissemination. Results will be summarized and presented through reports, papers, and conferences. The third and final meeting with the Advisory Committee will occur.

SENIOR PERSONNEL

Amy Pallant will serve as Principal Investigator. She will be responsible for overall coordination and budgeting of the project. She will direct the development of the curriculum materials, coordinate the videotaping, the professional development courses and the research. She is currently the project manager, educational researcher, and curriculum developer on the MW projects and the Earth science curriculum development and research efforts at the Concord Consortium. Previously she developed science curriculum at EDC. Amy holds an M.A. in Science Education from Harvard and a B.A. in Geology from Oberlin College.

Qian Xie will serve as Co-PI and the chief computational scientist of the project. He will be responsible for adding new capacity to MW, and supporting the authoring of the activities. Qian holds a Ph.D. in Materials Science and Engineering from the University of Science and Technology, Beijing. He has extensive experience in modeling physical, chemical, biological and engineering systems. He is the creator of the NSF-funded *Molecular Workbench* software. He is currently a Co-PI of the NSF-funded Electron Technologies project that helps students use simulations to decipher the quantum mechanics concepts behind many electronics topics.

Cynthia McIntyre will be the project manager and will be responsible for the creation, facilitation, and implementation of the online courses. She is a recognized expert in online course design and delivery; she co-authored the book “Essential Elements: Prepare, Design, and Teach Your Online Course” [121] and regularly offers courses on online course design and facilitation.

Frieda Reischman will be responsible for the development of the five Biology Exemplars and coordinate with Cynthia on the professional development needs in the course for the biology teachers. She holds a Ph.D. in Molecular & Cellular Biology from the University of Massachusetts at Amherst, where, as an NIH fellow, she also did her postdoctoral training. As the owner of Molecules in Motion Interactive Molecular Structures, she designed interactive 3D animations of molecular structure She has taught biochemistry, and co-developed the “MyDNA” undergraduate course at the University of Massachusetts.

Dan Damelin will be responsible for the development of the five Earth Science Exemplars and facilitate the customization options in the online course. Dan has a B.S. in chemistry, computer science, and environmental studies, and an M.A.T. from Tufts. He has developed numerous instructional materials based on simulations. He is the PI of an NSF-funded ITEST project at CC.

Robert Tinker will serve as Senior Science Advisor and will help locate scientists and evaluate possible topics. He holds a Ph.D. in experimental low temperature physics from MIT. He founded the Concord Consortium and has served on numerous boards and committees, including the National Academy of Science advisory committee that developed NSES [29] and the President's Committee of Advisors on Science and Technology [122].

External Researcher

Helen Zhang will serve as an external researcher and project evaluator. Helen is just finishing her Ph.D. in Marcia Linn's group at the University of California, Berkeley. She studies secondary student learning of chemical reactions using computational models. She will prepare annual reports on the progress of the project and its research findings.

Project Advisory Committee

The project will have a balanced, diverse, and expert Advisory Committee that will meet annually to review project progress, research findings, and the report of the project researcher. The following have agreed to serve on the Advisory Committee.

Vanessa Bullard is a middle school Earth Science teacher at Belmont Middle School, Belmont MA.

Marilyn Decker is the director of Analytical and Applied Sciences, Jefferson County Public Schools, KY.

Marcia Linn is a professor of development and cognition specializing in education in mathematics, science, and technology in the Graduate School of Education at the University of California, Berkeley.

Gregory Louie is a Biotechnology Teacher at Gravelly Hill Middle School, Efland NC. He has already incorporated Molecular Workbench models in his teaching.

Lynn Margulis Professor of Geosciences at University of Massachusetts, Amherst MA who has made many fundamental contributions to science, including the idea that many cell organelles originated as bacteria.

Dan Murray is a professor of research, Emeritus, Department of Geosciences, University of Rhode Island and Principal Investigator for the Rhode Island Technology Enhanced Science program, a targeted NSF MSP projects.

Liz Pape is President and CEO of the Virtual High School, Maynard MA and a nationally recognized expert in online professional development.

Dagmar Ringe is the Director of the Petsko/Ringe Laboratory and a professor of biochemistry and chemistry at the Rosensteil Basic Medical Science Research Center for Protein Crystallography, Brandies University, MA.

Ron Snell is a Professor of Astrophysics at the University of Massachusetts, Amherst who uses radio astronomy in research on molecular clouds and star formation.

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