

# THE SCIENCE OF ATOMS AND MOLECULES:

## Enabling the New Secondary Science Curriculum

*“...a dramatic revision of the science curriculum can generate a truly revolutionary way of teaching science in U.S. high schools.”* – Leon Lederman, Nobel Laureate in Physics

*“You mean there are air molecules hitting my arm all the time?”* – 9th grader after having worked with a molecular dynamics model.

### THE NEED AND RATIONALE

“A concise summary of [the last 100 years of science] is that atoms and molecules are 85% of physics, 100% of chemistry and 90% of modern molecular biology,” says Dr. Lederman in his attached letter, and, he contends, there is an urgent need to revise secondary science curriculum to reflect this reality. Perhaps the best known alternative curriculum is “Physics First” (ARISE, 2001; Lederman, 1998, 2002; Lederman & Bardeen, 1998), which involves switching the secondary science sequence from biology-chemistry-physics to physics-chemistry-biology (PCB). The same goals can be accomplished with integrated science courses that span two or more grades, which are also gaining interest (e.g., California Science Teachers Association, 2006).

Yet attempts to revise the secondary science sequence generally involve simply re-arranging the sequence of topics without changing them. For instance, most PCB curricula offer a simplified traditional physics course followed by standard chemistry and biology courses. Without a new emphasis on atoms and molecules and the connections that this emphasis enables among the courses, there is little benefit to students. Most attempts to teach unified science (e.g., Bybee, 2006) fall into the same trap of reordering without adding the new science content needed. Without a deep treatment of atoms and molecules as a unifying theme, this kind of reordering will not significantly improve the science curriculum and can result in a net decrease of the quality.

A solid set of materials that addresses atomic-scale science is the critical missing content needed to realize the dream of a better secondary science curriculum. The basic physics of atoms and molecules needs to be introduced early so that chemistry can take advantage of these concepts. Similarly, biology needs to leverage student understanding of atomic-scale physics and chemistry to address key introductory molecular biology concepts. This missing content represents only a fraction of each of the three courses. Biology, chemistry, and physics courses do not have to be re-written to profit from the new sequences. In many cases, the needed content can be substituted as an enhanced approach to traditional content.

Computational models of the atomic world can provide this content, allowing students to experience an otherwise inaccessible world and build mental models that can be used to understand and predict macroscopic phenomena. (Birk, 1997; Clark & Jorde, 2004; Hakerem, 1996; Stieff & Wilensky, 2002; Tinker, 2001b, 2001d, 2001e). Student explorations of these models can lead to a good understanding of connections between atomic-scale events and those events that they can observe at the macroscopic scale. (Berenfeld & Tinker, 2001; Buckley et al., 2004; Tinker, Berenfeld, & Tinker, 1999, 2000). Students can learn the atomic and molecular concepts that have been recommended for unified science or PCB curricula (California Science Teachers Association, 2006; Lederman, 1998).

Hundreds of individual schools and whole systems are developing PCB or integrated science sequences. Boston, San Diego, and many smaller districts, for example, have implemented PCB and Miami-Dade has a unified science approach. California has developed special standards for unified secondary science. AAPT (2002) has developed a position paper advocating PCB. A consortium of five schools in Rhode Island has just been funded to change to a PCB sequence.

Every teacher or administrator with whom we have communicated about these reforms has complained about the lack of appropriate curriculum materials addressing the science of atoms and molecules. Textbook publishers are eyeing the market, but the development of three new coordinated texts is expensive, so they are waiting. It is likely that many schools are dissuaded from implementing secondary science reform by the lack of appropriate materials. By providing the missing content this project could break this cycle and launch large-scale implementation of reformed secondary science curricula.

## GOALS AND OBJECTIVES

The goal of this project is to provide the materials and professional development resources that schools need to implement high-quality secondary science curricula with a unifying theme of atoms and molecules. Students will acquire a progressive understanding of the centrality of atomic-scale phenomena and their implications. Materials will be presented in a form suitable for all students. The project will also offer the support and professional development that teachers need to use the materials and integrate them effectively into their courses. Project objectives include:

**Student and teacher materials.** The project will produce 24 instructional activities, eight for each of four strands that cross all three courses of physics, chemistry, and biology. In each strand and course, there will be two activities, each requiring two-class periods. The activities will contain scaffolded computational models that permit students to learn core atomic and molecular content through guided exploration of the models. Instructional goals, student assessments, and teacher materials will be included.

**Formative testing and revision.** The materials will have formative testing in 18 PCB classrooms in four diverse sites nationwide. The materials will be revised on the basis of the findings of these field tests.

**Summative assessment.** Summative testing will assess student learning of the materials over two years in physics-chemistry and also in chemistry-biology sequences. Evidence will be sought for curriculum changes that the materials enable.

**Technology.** The molecular dynamics software will be upgraded to support the functions needed in the student materials and the ability to monitor and assess student performance remotely will be added.

**Professional development.** An online course, website, and written materials will be provided to support teachers who adopt the materials.

**Dissemination.** The project will actively disseminate the materials and research findings through presentations, professional papers and meetings. Materials for caregiver and administrators will be provided and all materials will be disseminated electronically. To ensure that the materials are publishable, the project will work closely with a prospective publisher.

## RESULTS OF PRIOR NSF SUPPORT

### MOLECULAR WORKBENCH PROJECTS

The proposed project is an outgrowth of a strand of research funded by the following grants to the Concord Consortium: **Reasoning with Atomic-Scale Models** (12/99 - 8/04. \$1,364,944. REC-9980620. Supplemental \$189,789. REC-0233649.) **Molecular Logic**: Bringing the Power of Molecular Models to High School Biology (2/03 - 6/06. \$1,416,623. ESI-0242701). **Molecular Literacy for Biotechnology and Nanotechnology Careers** (5/04 - 4/07. \$899,857. DUE-0402553). Drs. Berenfeld and Tinker served as PI/co-PI on all three grants.

#### The Molecular Workbench Software

The projects listed above have explored different applications of the *Molecular Workbench (MW)*, a computational model we designed for education based on molecular dynamics models used in research. The *Molecular Workbench* seamlessly integrates the following functions:

- A set of molecular dynamics models and their associated input and output components.
- An authoring system for constructing user interfaces to the models.
- A word-processor for creating hypertext in which components of models can be manipulated.
- An embedded assessment system that supports questions and collects student data.
- A delivery system similar to a web browser.
- Web services that support collaboration among authors.

**Capacity.** The *Molecular Workbench* molecular dynamics simulations are based on the physics of atomic-scale interactions and can exhibit fundamental phenomena in physics, biology, and chemistry (Berenfeld & Tinker, 2001; Tinker, 2001c, 2001e). Simulations in *MW* calculate the motion of atoms, molecules, and other objects in real time as a result of the applicable forces, including the Lennard-Jones potentials, electrostatic potentials, elastic bonds, and external fields. Because it is based on good approximations of physical laws, *MW* can produce emergent phenomena such as phase changes, crystallization, latent heat, diffusion, solubility, osmosis, absorption, chemical equilibrium, catalysis, self-assembly, and bio-molecule conformation.

Some novel features have been added to *MW* to handle computationally intense systems. An effective field is used to model the hydrophobic and hydrophilic effects that influence protein folding. Chemical bonds that have user-controlled energies can be made and broken to simulate chemical reactions (Xie & Tinker, 2006). Large molecules can be created and charges added to them to simulate biological molecules (Berenfeld, Pallant, Tinker, Tinker, & Xie, 2004).

**A new direction: light and matter.** Light-atom interactions are modeled with photons of selectable energy that interact with the excited states of atoms. Photons or thermal energy can excite an atom, which then can decay to a lower energy state by emitting a photon or generating kinetic energy. The excited states can be set by the user and the resulting spectrum of emitted photons can be observed. This capacity supports investigations of color, scattering, filters, colorimeters, radiation cooling, black body radiation, spectra, fluorescence, laser action, and photon pumping.

**3D.** *MW* can now display 3D molecules, and there are already activities allowing students to interact easily with these molecules (e.g. from Protein Database) and view component parts. *MW* will have the capacity to include 3D models more easily by the time the project begins.

**Authoring.** The built-in authoring functions can be used to create or modify an activity. The ease of creating *MW* materials has led to over 200 activities contributed by staff and collaborators. Many are housed in a database with fields that include an overview, learning objectives, a description of the central concepts addressed, textbook references, and extensions<sup>1</sup>.

*MW* is written in Java, so it runs under all common operating systems, including Mac OSX, Windows, and Linux. It is open source, so it can be shared and copied by any user. International use of *MW* is growing; users from more than 60 countries have downloaded over 10K copies of the software and 100K copies of models and activities.

### **Molecular Workbench Research Findings**

Highlights of the research findings are summarized here. (for details, see [Appendix H](#).)

**Overall gains.** Student use of the activities from the three projects listed above have resulted in overall increases in student understanding of atomic scale phenomena at high school and community college levels. Thirty classes analyzed in several projects, representing a cross-section of grade, level, and demographics, showed significant gains ( $p < 0.01$ ) on paired t-tests in pre/post-test analysis. In the community colleges the largest score increases were for questions related to interpreting results of a simulated lab procedure, problem-solving regarding unexpected results and applying molecular reasoning to understanding techniques.

**Molecular reasoning.** Students were able to transfer their understanding of atomic-scale phenomena to new situations and to reason about macroscopic phenomena on the basis of atomic-scale interactions. Using 10 sequential activities for biology helped high-school biology students achieve fluency in reasoning at the atomic scale. Results from testing in 24 classrooms indicate that students can use these materials to develop robust mental models about intermolecular interactions and apply these to reasoning about biological phenomena. Molecular reasoning, as measured by the accurate use of atomic-scale reasoning in essays, increased from 15% to 57%.

**A controlled experiment** was carried out to test the effects of models on learning outcomes using an activity on the forces affecting protein folding. Students in the experimental condition received the activity with models. Students in the control condition received a well-designed and fully illustrated substitute that did not use computational models. Identical pre- and post-tests were given. All students improved, but the treatment group showed greater gains in the more difficult questions that required immersive visualization and prediction of the next model states.

### **PROFESSIONAL DEVELOPMENT PROJECTS**

The proposed staff has considerable experience with online teacher professional development as illustrated by the following three projects:

**International NetCourse Teacher Enhancement Coalition (INTEC).** (5/96 – 4/00. \$2,856,628. ESI-9554162. PI-Tinker) This project was one of the first online Web-based courses for teachers. It was a 125-hour course that addressed the use of inquiry in secondary science teaching, reaching 800 teachers. One of the most important outcomes was the development of an effective model for online courses (Tinker, 2001a) and for preparing moderators for online courses (Collison, Elbaum, Haavind, & Tinker, 2000).

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<sup>1</sup> The database of activities: <http://molo.concord.org>. More on the model: <http://mw.concord.org/modeler>

**The Virtual High School Consortium.** (10/96 – 9/01. \$9,856,545. R303A960571. PI-Tinker). This project, funded by the U.S. Department of Education, created online courses for high school students and developed the only low-cost funding model that relies on sharing teachers between schools (Zucker, Kozma, Yarnall, Marder, & Associates, 2002).

**Seeing Math Telecommunications Project.** (10/00 – 9/05. \$12,060,964. R286A000006. PI-Tinker). This project, funded by the U.S. Department of Education, pioneered the integration of video case studies and interactive software into online professional development (Galvis & Nemirovsky 2003; Nemirovsky & Galvis, 2004).

## ANTICIPATED PRODUCTS

### CURRICULUM MATERIALS

**Four strands over three courses.** The content of the proposed student materials is summarized on the following two pages. There will be four thematic strands that span the three secondary science courses when they are taught in the PCB sequence. In unified science sequences the content flow would have to be adjusted, but would have many of the same dependencies.

The strands—Motion and Energy, Atoms and Molecules, Charge, and Light—are based on fundamental concepts that will be introduced in the physics course and then elaborated and applied in chemistry. The resulting understanding of atomic and molecular science will enrich and deepen the subsequent treatment of biology. These topics have been selected to match the content sequences developed by the ARISE recommendations (Lederman, 1998) and developed through extensive consultation with teachers and administrators who are implementing PCB.

**Two topics will be addressed in each theme each year.** Each topic will require two class periods, so the project will have materials for 16 class periods for each of the three PCB courses. This is approximately 10% of available instructional time—enough to have an impact on learning but little enough to fit into existing courses. This will simplify adoption— teachers will be able to keep their textbooks and introduce this new material gradually.

**Traditional content, nevertheless.** The content has been selected with the understanding that anything added to the curriculum forces out other content. In each case, the proposed materials provide ways to teach traditional content, but from an atomic-scale perspective. For example, when studying 2D motion in physics, applications of Newton’s laws to the motion of atoms can be investigated in place of other applications.

**Additional details.** [Appendix B](#) contains a sample activity. Interdependencies among the proposed activities are diagrammed in [Appendix D](#). [Appendix E](#) contains an example of a physics-to-biology content progression. Correlation of the proposed content to the AAAS Benchmarks (1993) are in [Appendix F](#).

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**Pedagogical Strategies.** The proposed materials will foster inquiry-based learning that emphasizes the connections between science disciplines and encourages students to go beyond the facts and concepts of a given discipline. The content will feature learning through investigations of *MW* models using its platform and delivery system. The pedagogical supports that are part of the *MW* platform are illustrated in [Appendix C](#). The investigations will be motivated by real-world contexts. Each activity will include embedded assessments that are aligned to the learning goals. The assessments will generate formative data that can be used by teachers to guide instruction. As shown in [Appendix C](#), the report-writing facilities of *MW* allow students to create electronic portfolios.

## TEACHER MATERIALS

Implementation guides (virtual and print teacher binders) will be designed for each activity and strand, providing the following: ways of integrating the model-based activities in their course content, learning goals and additional assessments, pedagogical strategies, key concepts, suggested laboratory connections, alerts for misconceptions or other predictable pedagogical difficulties, extensions, connections to national benchmarks and standards, suggested expected learning performances, screen printouts of student materials for reference and review and background on the content, annotated answer keys and scoring rubrics, and ways to obtain technical assistance. There will also be an accompanying CD.

Community web space with database of activities. All activities and software will be available for free download through a web space designed for this project. The project will facilitate the student and teacher communities through a password-protected portal. Teachers will be able to access performance of their students on the assessments embedded in the activities. They will also be able to store and access their customized activities. The portal will facilitate access to the software developers and other experts, support materials as they are developed by other teachers or by staff, student activities, chat rooms, and the online course.

Online course. The teaching materials will form the basis of an interdisciplinary credit-bearing self-paced course for teachers. This will be implemented fully in the last year of the project, but will be available earlier as a non-credit bearing self-paced tutorial. Teachers will be taught to easily customize the materials we create. We will use customization as a key feature of the teacher professional development, because it engages teachers in thinking about the content and pedagogy of the materials and results in versions of the materials that are better aligned with school needs and state standards.

## CAREGIVER AND COMMUNITY MATERIALS

Providing resources and avenues for parental involvement helps student success and improves overall school performance (Henderson & Berla, 1994). A brochure will be prepared for each subject that teachers can distribute to caregiver and other interested community members explaining the goals and methods of the instructional materials, the ways these instructional materials are new, and providing routes for them to be engaged, should they want to learn more. Suggestions for home discussions and activities that enhance classroom topics will be provided.

## WORK PLAN

### MATERIALS DEVELOPMENT

Student and teacher materials will be developed in year one for formative testing in year two, the first year of a two-year study. Year three will include summative evaluation of the materials based on the two-year study. For the timetable, see [Appendix G](#). Materials will then be disseminated, possibly through publication by Key Curriculum Press (see letters of support.)

Major steps in the materials development plan include:

**Initial meeting.** At a face-to-face launch meeting, advisors, project staff and teacher developers will review initial materials and teacher professional development (TPD) plans and propose revisions. Later reviews will occur in sessions before formative and summative classroom tests.

**Development.** Project staff, working with teacher reviewers and consultants, will start by defining the instructional goals and assessments for each activity (Wiggins & McTighe, 2001). The 24 activities will be completed in time for formative testing in year two.

**Content review and revisions** A committee of six—three high schools teachers (physics, chemistry and biology) and three college/university teachers (physics, chemistry and biology)—will review the design and executed content of the materials in regular annual meetings for content accuracy, pedagogical appropriateness and suitability for audience. Some are members of the Advisory Committee (see [Appendix A](#)). Three additional independent reviewers will be recruited. Materials will be revised appropriately following each review and in accordance with formative testing.

**Formative assessment** will occur in the second year (described below). See [Appendix A](#) for a provisional list of pilot schools that have agreed to work with the project.

**Summative assessment** occurs in the third year. Interviews and performance assessment will supplement the more quantitative measures.

**Dissemination.** All software and activities will be distributed widely. Key Curriculum Press has indicated an interest in publishing the resulting materials.

The project can complete 24 activities because it builds on extensive *Molecular Workbench* materials and the highly productive *MW* authoring system. Models for almost every topic have been developed and most include student activities that have been tested in real classrooms. The proposed materials will be more advanced than the existing activities that were designed to stand alone. The new activities will form a progression so that later activities will build on knowledge gained in previous activities. Additional curriculum development is needed to create a consistent treatment that progressively spans grades and courses in the appropriate sequence. In addition, some new models and model-based activities will need to be constructed.

### FORMATIVE ASSESSMENT OF MATERIALS

The project will undertake formative and summative studies in line with National Research Council's recommendations (NRC, 2001) on assessment in order to determine whether our approach results in student achievement of the instructional goals of the materials. Project evaluation will also determine whether the professional development program provides teachers with

the content knowledge, instructional skills, and technical ability to successfully enact project materials.

The focus of the formative study is designed to gain additional detail that can guide the materials revision process. Both formative and summative evaluation will address the following questions.

Will the use of model-based activities enable students to develop an understanding of central atomic-scale phenomena and their implications in physics, chemistry, and biology? Was there satisfactory student achievement of the goals of each activity? Is there evidence that shows the learning strands progressively build and impact student conceptual understanding of the atomic scale phenomena and their implications? Do students exhibit progressive reasoning skills about atomic scale phenomena?

The formative assessment will also have a materials evaluation part designed to inform revisions:

Are teachers able to use project materials effectively in their instruction? Do students understand the instructions for the use of the models? Do they explore relevant parts of the model, seek and receive appropriate scaffolding, and spend appropriate time using the model?

We will use pre- and post-test data as measures of students' achievement of the goals. Additionally, embedded assessments in the activities will be analyzed from student data collected throughout the implementation of the materials. We will also collect teacher questionnaires, classroom observations, and student reports (see below for more detail on data sources.)

Evaluation of the professional development courses and workshops will answer the following questions:

Are participants able to introduce the materials and concepts as planned? Are they able to improve the materials through customization? Are there improvements in teacher content and pedagogy understanding that are attributable to participation in the project? Is there a specific aspect of the professional development that results in the greatest changes in teacher knowledge of the content, pedagogy, modeling skills?

Surveys regarding teacher background characteristics, teaching environments and attitudes towards the content will be collected prior to their participating in the courses. Teachers' work will be collected and submitted for analysis. In addition, an electronic survey will be administered at the end of each activity on what they learned and what they felt they needed.

### **The Assessment Instruments**

**Pre and Post-tests** will be developed for each discipline and will cover the objectives of the activities across the discipline. The test items will consist of a variety of strategies such as short answer, drawing tasks and model challenges to address different learning styles. We will use pre- and post-test data containing items aligned with standards, released items from state and national tests (e.g. SAT II, NAEP), and items developed by the project as measures of students' achievement of the goals of each strand within each discipline.

**Embedded Assessment:** Each model-based activity will include embedded assessments of concept understanding and reasoning skills that are based on atomic and molecular concepts, e.g. students' ability to make reasoned predictions about phenomena they are studying. Student embedded assessment will be analyzed for evidence of learning progressions (Smith, Wisner, Anderson, & Krajcik, In press) that reveal their ability to answer questions with more sophistication. We will be looking for trends identified by Smith et al. that reflect increasing sophistication in de-

scribing, and classifying materials, development of a more sophisticated causal account of the observed phenomena and an increase in the theoretical depth by which students account for the phenomena. Randomly selected students will be followed, and embedded assessments will be coded for evidence of change in these categories.

**Student Work:** Student work completed in class, on the computer, or for homework assignments will be collected online using *MW*'s report features. The software will also log student time on task, progress, and online responses.

**Qualitative observations:** Classroom observations will be used to determine fidelity of implementation, classroom characteristics, and problems caused by the technology. An observation protocol will be developed using items from validated classroom observation protocols from Horizon Research (2000), and the Reformed Teaching Observation Protocol (RTOP) designed by the Evaluation Facilitation Group of the Arizona Collaborative for Excellence in the Preparation of Teachers (2000).

**Teacher feedback:** Online teacher feedback forms as well as end-of-semester teacher interviews will seek opinions about needed changes in the materials. Teachers will be asked to describe online the implementation of the *MW* lessons. Teachers will be prompted to describe how the materials were implemented, the connections they made, and what they think students got out of using the materials and what they learned and felt they needed. These descriptions will be used in the online course to help guide other teachers with their implementation.

**Teacher surveys:** All teachers will be asked to respond to a survey at the beginning and end of each school year. This survey will contain items regarding: demographics (i.e., gender, number of years teaching) professional practices, and confidence with content and the connections they will need to make. Items comprising the survey will be adapted from those used in Teaching, Learning and Computing (TLC) survey (Becker & Anderson, 1998), Classroom Practices of Science Teachers (National Assessment of Educational Practice, 1996), and Attitudes and Beliefs about the Nature of and the Teaching of Mathematics and Science (McGinnis, Watanabe, Shama, & Graeber, 1997).

All the instruments—surveys, activities, pre- and post-tests, online feedback forms will be piloted, data will be collected and analyzed for changes in teacher instructional practice and changes in student understanding. Tools will also be analyzed for their success in collecting information, and revised for summative assessment in the third year of the proposal.

## SUMMATIVE ASSESSMENT

In year three of the proposal, revised instruments—pre- and post-tests, surveys, feedback forms, observation protocols and activities (with included embedded assessments) will be used. Additional tools will be added to assess student learning progressions across years and how changes in teaching practice might affect student learning.

**Assessing progressions:** The full value of the chemistry activities will not be realized unless students have the prerequisite physics activities. The biology implementation, also, will require previous exposure to the physics and chemistry materials. These cross-discipline dependencies create special evaluation challenges. Consequently, progressions of students reasoning skills and students progressive understanding of atomic-scale phenomena will also be assessed. In schools in which all the science staff have agreed to participate, or where subsets of students follow set courses and the science staff for those courses have agreed to participate (i.e., Argo School in

Chicago has a physics first strand in their science departments for which parents and teachers sign up), evaluation of student achievement across years will be implemented in year three. The assessment will look at learning that connects the biology to chemistry studied the previous year, or the chemistry content to physics studied in the previous year. Data will be gathered from specially designed items in student pre- and post-tests and from interviews described below.

**Interviews and Performance Assessment:** Clinical interviews with students in groups of three local to Concord Consortium will be conducted in each subject towards the end of the third year of the proposal. The purpose of the interviews is to learn about how students reason—by probing their understanding of concepts in a way that is difficult using a paper and pencil test, by asking questions that specifically rely on concept development across the years, and by seeing how they might apply their understanding to new situations. Because of the ease in which we can create challenges and manipulate the models using the *Molecular Workbench* software, we will administer performance assessment items to enhance the interview. Having the students interact with the models will provide us with opportunities to understand about what students are learning from the concepts, determine how they engage with the modeling tool, and use the interactions to evaluate their ideas. The content of the interview will cover all the major strands of the proposal.

**Professional development as it affects student gains:** The survey and the descriptions will be analyzed for changes in teachers’ instructional practices and will be used as a covariate when analyzing student gains.

## TEACHER PROFESSIONAL DEVELOPMENT

Professional development is an integral part of this project, and will be conducted through an in-person summer institute and a self-paced online course. Extensive training materials, curriculum guides, and a dedicated community web space will form the foundation of the training (see “Teacher Materials” above). The approach will combine expanding teacher content knowledge with an exposure to the pedagogy and technology to develop pedagogical content knowledge (Shulman, 1986; 2000).

The **summer institute** will be scheduled between year one and two, with follow-up communication happening via online forums, email, and conference calls. The content of the professional development is described in the following sections.

### An introduction to the *Molecular Workbench*

Working with dynamic computer models will be new for most teachers, so time will be spent introducing teachers to the *Molecular Workbench* modeling environment. They will learn how to customize activities to the needs of their individual classes and applicable standards (Baumgartner, 2004; Slotta, 2002). This will allow teachers to explore the pedagogical aids afforded by activities designed with *MW* (see Appendix C). Teachers will also learn to create their own models from scratch, take ownership of the software and activities, and see ways to use *MW* as tool beyond the scope of this particular project.

### Exploring activities specific to a single discipline

Each teacher will be expected to complete eight modeling activities (two from each of the four strands) in their particular content area. At the summer institute, teachers from different schools, but within the same discipline, will be grouped together to work with the actual models that have been developed for their specific field, and to brainstorm on where and how they might implement these activities in their individual curriculum.

### **Making curriculum connections to other science disciplines**

By grouping teachers in interdisciplinary clusters at the summer workshop, teachers can help each other see how the four strands support each other; and together they can develop strategies for making connections among topics.

### **Classroom implementation of modeling activities**

Research has shown that there are optimal ways to implement model-based activities in the classroom, and that teachers want more training in how to do this. By providing them with examples of best practices, and asking them to contribute ideas on improving implementation, we should both improve the overall efficacy of the models and enhance the consistency of implementation, allowing for more uniform results when doing evaluation of the project and individual activities.

## **TECHNOLOGY DEVELOPMENT**

The Molecular Workbench software will require some development to serve the project:

Registration and records. We will integrate *MW* into a platform and portal that supports student and teacher registration so that student work can be securely shared, evaluated by teachers, and examined by researchers.

Improved assessments. Secure registration allows us to develop assessments that can be used for credit, which is not feasible in the current system.

Improved community tools. We will improve the capacity of the system to allow teachers and developers to author and modify activities, generate appropriate metatags, review the materials, and control when they are made available to their students, colleagues, and the world.

Named atom species. We will enhance the naming of atoms and allow users to assign properties to named atoms that more closely resemble actual atoms.

Improved solvent forces. The approximation used to model interactions with water and other solvents will be changed to be a local force. This will support more realistic protein conformation experiments.

Photon-bond interactions. We will implement interactions between photons and bonds. IR light will be coupled to vibrations, perhaps restricted to the stretching modes. More energetic photons will interact with excited states and be able to break bonds. This will support models of IR spectroscopy and photochemistry.

Dipole formation in chemical reactions. We will integrate dipole moments based on electronegativity approximations with chemical bond formation. Part of the energy required for disassociation will be related to creating neutral atoms from bound atom pairs that have an attraction due to a dipole moment. The size of the dipole moment will be calculated from the electronegativity difference of the two atoms.

System improvements. Many small changes will be made to improve *MW*, including reorganized menus, secure authoring, and improved graphing functions.

## **DISSEMINATION**

We will make a major effort to make the project resources and evaluation materials widely available in places where teachers, developers, and educational researchers will easily find them, making a special effort to work through NSF Implementation Centers (LASER, CESAME, EDC

and BSCS) and related publishers. We will work with staff of ARISE at the Fermi Lab to present and disseminate the materials to the teachers in the Physics First community. Materials will be made available or linked to Fermi's ARISE website that serves thousands of Physics First schools. We will make all grant-supported code available as open source. We will create a project Web page at the start of the project and will update it continuously. Through the Web site, software versions and draft activities will be released regularly. Information about these materials will be targeted to educators through our free newsletter @Concord, press releases, and popular articles. Articles suitable for peer review about the software and curriculum materials will be prepared for publication and professional talks.

## PROJECT MANAGEMENT

**Project Evaluation.** The role of project evaluation is to determine the extent to which the project achieves its goals and objectives and successfully executes an effective plan. The project and the materials developed will undergo an independent review by an experienced external evaluator. He will evaluate project execution and fidelity to plan, and will compile annual reports that will be provided to the project advisory committee and the NSF. The evaluation will address the following questions:

**Overall.** Has the project met its objectives and schedule? Were objectives and schedules changed? Did any changes result in better utilization of resources?

**Student materials.** Did the project produce the instructional activities planned? Do they include the features and content described?

**Formative Testing and Revision.** How was the formative testing conducted? What were the findings? What revisions were made as a result of the formative testing?

**Summative Assessment.** How was the summative testing conducted? What data was collected? How was it analyzed? What are the major findings? What are the implications for the PCB sequence?

**Technology.** What technological functions were generated by this project? How is the new technology related to the needs of the project?

**Professional development.** What professional development was provided? Was the program effective in preparing teachers to use the materials? What did the project learn about TPD?

**Dissemination.** How did the project disseminate its materials and findings? How widely was the materials used? Was there publisher interest in the materials?

To answer these questions, the evaluator will review the project formative and summative data, attend Advisory Board meetings, analyze the materials produced, and interview staff. Each year the external evaluator will visit each of the project sites and make an additional trip to the Concord Consortium. The program evaluator will produce annual reports that will be transmitted to the Advisory Board and the NSF cognizant program officer.

**Project Advisory Board.** An outstanding Advisory Board has been assembled to provide expert input to the project. It includes teachers, scientists in all three disciplines, a cognitive scientist, educational researchers, and experts in PCB implementations. The Advisory Board will meet once as part of the project startup, and twice subsequently to review progress and reports from

the project evaluator. Board members are described in [Appendix A](#). All have agreed to serve and selected acceptance letters are included in the Appendix.

**Project personnel.** The project will be administered by The Concord Consortium. The following team will be responsible for the project administration. Resumes are attached.

**Principal Investigator:** Dr. Boris Berenfeld will be responsible for the project curriculum, and ensure project integrity and quality. A biophysicist by training, his research was in epidemiology, toxicology, and the biological effects of radiation. As PI or Co-PI, his current research involves the use of technologies in the development of students' modeling skills in science learning in all of the Concord Consortium molecular modeling projects. Dr. Berenfeld is an associate editor for "Learning, Media and Technology."

**Co-Principal Investigator:** Dr. Robert Tinker will be particularly involved with the design of models, and will coordinate with partners. He holds a Ph.D. in low temperature physics from MIT. He has served as PI and co-PI for numerous grants from the NSF and the Department of Education that have led to widespread improvements in science education.

**Dr. Leon Lederman** will be involved in all aspects of the project including planning, materials review, and advocacy. He holds a Nobel Laureate in Physics, organized the Teachers' Academy for Mathematics and Science, which retrained 20,000 math and science teachers in the Chicago Public Schools, and is the former President of the American Association for the Advancement of Science.

**Scientist Programmer:** Dr. Qian Xie will be responsible for the software development. Author of the Molecular Workbench, he is the primary computational scientist on the project, responsible for adding functionality to *MW*. Dr. Xie holds a Ph.D. in Materials Physics from University of Science and Technology, Beijing, and held post-doctoral appointments at the Dresden Max Plank Institute and the University of Cyprus.

**Research Director:** Amy Pallant will be responsible for overseeing project research and assessments of student learning. She is senior science education researcher on the MW projects. Previously she developed curriculum at EDC for Insights in Biology: High School Curriculum, and the Improving Urban Middle Schools Project. Amy has an Ed. M. in Science Education from Harvard.

**Curriculum Designer and Programmer:** Daniel Damelin will assist in the development of activities and will be responsible for teacher workshops and online support. Dan teaches chemistry at Lincoln-Sudbury High School (MA). With an MAT from Tufts in chemistry, biology, and general science, and a triple major BA from Tufts that included computer science, he has developed and tested many *MW* activities.

**Project Manager:** Dr. Barbara Tinker is Project Manager for all the Molecular Workbench projects. She will manage the project and work with Dr. Berenfeld on curriculum adaptations. She is a psychologist with a B.A. from Swarthmore and a Ph.D. in Clinical Psychology from the University of Massachusetts, Amherst.

**External evaluator:** Dr. Sigmund Abeles will serve as external evaluator. He will evaluate project execution and fidelity to plan, and will compile annual reports that will be provided to the Advisory Committee and the NSF. Dr. Abeles has a chemistry and physics background, a Ph.D. in science education, has worked as high school teacher and school administrator, and has evaluated many project for the NSF.

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