A Technology Exemplar: Post-Textbook UDL Materials

A proposal to the National Science Foundation
From the Concord Consortium

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PROJECT SUMMARY

This proposal from the Concord Consortium for funding by the NSF Instructional Materials for Students program plans for the development of technology-rich science curriculum exemplars for grades 3-6 based on Universal Design for Learning (UDL) design principles. The project envisions the development of seven two-week inquiry modules united through an energy theme based on national standards. The modules engage students through driving questions, such as "Why are there clouds?" and "What do plants eat?" Probes are used for lab investigations and computational models are used for experimentation in virtual environments. Variable scaffolding is provided for both kinds of inquiry. Graph and modeling software is planned that can express data and relationships using text and vocalization as well as various representational formats. A total of twenty-five test classrooms in Acton, MA, Anchorage, AK, Maryville, MO, and Fresno, CA plan to participate in formative and summative testing.

INTELLECTUAL MERIT

To meet the needs of the diverse students found in many classrooms, flexible learning materials are needed that can be adapted to individual students. A promising, research-based approach to this need called Universal Design for Learning has been developed to teach reading comprehension, but no comparable effort has been made in STEM education. The goal of this project is to fill this need by creating practical science materials designed with UDL principles for students and teachers in inclusive classrooms. The project will create sufficient materials to test the effectiveness of the approach and provide an exemplar that can inspire additional content and further development. A rich set of professional development materials to support teacher implementation of UDL science curriculum in the classroom is planned.

The project is based on current research in science education, cognitive science, and educational technology. The project utilizes the two most promising kinds of technology-based tools for student investigations: probes and computational models. The Concord Consortium's team is a leader in both these areas, having developed the first educational applications of probes over 25 years ago, and also having created the Molecular Workbench, an extremely flexible educational molecular dynamics modeling system that is planned for use in the proposed materials.

BROADER IMPACTS

A functioning STEM exemplar focused in inquiry with probes and models, and designed using UDL principles would be extremely valuable. It can provide needed research data, stimulate important technical developments, and provide guidance for the development of additional STEM content based on the experience with the exemplar.

While this project targets just part of the grade 3-6 science curricula, the research results and the technologies developed are applicable to other levels and disciplines of science, as well as mathematics and engineering education. It is difficult to integrate probe and modeling tools with student inquiry in a UDL context, so the existence of the proposed exemplar should generate interest among practitioners for more materials, while the designs and technology developed by the project should simplify the task of creating additional materials in any STEM field. Wide dissemination is planned to spark this interest in the reform of STEM materials.

A Technology Exemplar: Post-Textbook UDL Materials

The Need

Teachers are challenged to teach the increasingly diverse students in their classrooms to high standards. Many classes include students who are struggling with learning disabilities such as dyslexia, English language barriers, emotional or behavioral problems, lack of interest or engagement, or sensory and physical disabilities. To help teachers reach these students, materials are needed that provide multiple representations, support multiple means of expression and engagement, and have different assessment strategies. The idea of Universal Design for Learning is to provide materials with this degree of flexibility. This is an exciting challenge because well-designed flexible materials are likely to help every student.

There are no classroom-ready STEM curriculum materials that use Universal Design for Learning (UDL). There is a particular urgency to developing UDL materials now because the 2004 Individuals with Disabilities Education Act (IDEA) included provisions for a process that will result in a voluntary National Instructional Materials Accessibility Standard (NIMAS). Initially, states adopting NIMAS will require all publishers to provide electronic versions of textbooks. These electronic versions of print texts will be a starting point that will support some UDL goals, but will hardly take full advantage of information technologies. Exemplars are needed now that demonstrate what is possible when UDL materials are designed from the start for electronic delivery. Because of NIMAS, an effective exemplar could have far-reaching impact.

STEM education is behind reading and language arts curriculum in terms of applying UDL. CAST—the leader in this area—has developed and studied two reading tools that are now commercially available: Wiggleworks and Thinking Reader[1]. These products are important because they demonstrate that the promise of UDL can be realized in practical products that educators will purchase. At this time, STEM educators have no comparable examples of how UDL principles could be implemented with electronic media. Compared to reading, it is more difficult to create UDL versions of STEM materials because of the importance of hands-on experiences, inquiry-based learning, abstract representations, and frequent need in STEM education to coordinate two or more representations.

A better understanding of how to adapt STEM materials to individual differences would have important equity implications. While the presence of a "digital divide" means that the hardware needed by UDL is unavailable today to some of the poorest students, the plunging cost of computers is rapidly eliminating that issue. Five years ago, it became clear to experts (Noll, 2001; Pea, 2001) that the digital divide was more an issue of how computers were used than whether they were available; the issue is not equity of access but equity of usage. Poorer schools tend to use lower-quality applications (Dickard, Honey, & Wilhelm, 2003) and make less use of the kinds of applications such as science models and tools that are associated with increased student performance. Research that contributes to a better understanding of how to use technology more productively is needed to address this aspect of the digital divide.

A substantial body of research shows that probeware (sensors, interfaces, and related software used to generate and analyze real-time data from physical inputs) can facilitate student learning

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[1] See http://www.tomsnyder.com

of complex relationships (Adams & Shrum, 1990; Beichner, 1990; Friedler, Nachmias, & Linn, 1990; Krajcik & Layman, 1993; Laws, 1997; Linn, Layman, & Nachmias, 1987). Probeware can capture many changing phenomena and increase reasoning skills and science knowledge (Brassell, 1987; Mokros & Tinker, 1987; Thornton, 1997).

Models have a unique role in science education, allowing students to understand through exploration causal relations in systems that are difficult or impossible to understand by other means. Computer-based modeling is part of the NRC Standards (National Research Council, 1996) and the Benchmarks (AAAS, 1993) because it uniquely enables students to explore chains of causal relationships (Barab et al., 2000; Buckley, 2000). When students learn to envision behavior as a sequence of cause-effect events in models that obey fundamental principles in science, and they can see emergent behavior, student performance in solving qualitative and quantitative problems improves (Feurzeig & Roberts, 1999; Frederiksen & White, 2000; Wilensky & Resnick, 1999).

Probes and models complement each other; probes bring reality to models; models give generality to the phenomena studied with probeware. The NSES states: “Teachers should help students understand that models are developed and tested by comparing the model with observations of reality” (National Research Council, 1996, p. 116). Computational models and probes are among the most important innovations enabled by technology and are associated with increased student performance. In 2000, the National Assessment of Educational Progress 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” (National Center for Education Statistics, 2002). Similar results were found at grade 12. For these reasons, UDL designs for science education need to be based on inquiry using computational models and probes.

A functioning STEM exemplar focused in inquiry with probes and models, and designed using UDL principles would be extremely valuable. It would provide needed research data, stimulate important technical developments, and provide guidance for the development of additional STEM content based on the experience with the exemplar.

Goals and Objectives

The goal of this project is to fill this need by creating practical science materials designed with UDL principles for students and teachers in inclusive classrooms. The project will create sufficient materials to test the effectiveness of the approach and provide an exemplar that can inspire additional content and further development.

Objectives

Develop designs for UDL science materials. The project will develop a science UDL design document that is independent of the specific science content, but explicates the principles and software functions that must be part of any science materials.

Develop supporting technology. UDL enhancements will be made in graphing and modeling software and a portal will be developed that controls UDL features for individual students as well as registration, formative feedback, and research data collection.

Develop student materials. Seven related science modules will be developed suitable for more than one semester of standards-based science in grades 3-6. The modules will be based on learning through guided inquiry using probes and computational models. An energy theme will be used to unite content from earth, physical, and life sciences.

Revise materials based on formative evaluation. Materials will be tested in a total of 25 classrooms that have geographic, ethnic, and social diversity. A revision cycle will create a final set of materials that incorporate the findings from the formative evaluation.

Develop professional development materials. Materials will be developed, tested, and revised for a blended face-to-face and online course to prepare the teachers to implement project materials.

Study UDL and student learning. A summative evaluation of the materials in 25 additional classrooms will focus on the relation of the UDL features to learning for sub-populations of students. The goal of the study is to characterize the use by students and teachers of the UDL functions and to gather evidence about the educational value of these functions.

Disseminate the materials, technology, and findings. The project will distribute the student materials commercially and make the technologies available as open source. Research results and findings will be actively communicated to researchers, practitioners, parents, and 10,000 readers of *@Concord*.

UDL adds cost to software development, so before significant UDL curriculum investments can be made, research is needed to determine whether the effort is worthwhile and what kinds of customizations are practical and effective. This project would provide the missing research as well as exemplary, tested materials that incorporate UDL and insights from cognitive research.

While this project focuses on just part of the grade 3-6 science curricula, the research results and the technologies developed will be applicable to other levels and disciplines of science as well as mathematics and engineering education. The dissemination effort will broadcast the project results and technologies widely. The existence of our exemplar should generate interest among practitioners for more materials, while the designs and technology we develop should simplify the task of creating additional materials in any STEM field. Consequently, this project could have an important influence on materials in all STEM disciplines and levels.

PRIOR WORK

The proposed project will draw from prior NSF projects on probes, computational models, and teacher professional development. These research strands are briefly mentioned here and more fully in the Appendix.

PROJECTS EXPLORING THE EDUCATIONAL USE OF PROBES

Microcomputer Based Labs. In 1983 Tinker’s team at TERC that included Bannasch received three years of funding for probeware development from the NSF Applications of Advanced Technology program. This funded the first work in educational uses of real-time data acquisition and established the acronym MBL. It also undertook the first research in the field (Mokros & Tinker, 1987) and stimulated related research (notably Brassell, 1987; Linn, 1986). This project developed the ultrasonic motion detector and some of the earliest probeware-based products.

Science Learning In Context. (9/95 – 11/00. $1,992,485 REC-9553639). This project, which included Bannasch and Staudt, was the first focused on educational applications of handheld computers. It developed the first probes connected to handhelds and studied the educational affordances of the resulting portability (Tinker & Krajcik, 2001).

Center for Innovative Learning Technologies. (7/97 – 3/03. $734,055 subaward, EIA 9720384 and 0124012). Tinker was co-PI of this center and led the "Ubiquitous Computing" theme that had a major role in stimulating research and school acceptance of handheld computers, generating a market for probeware that connects to handhelds (Sabelli & Pea, 2004). Bannasch and Staudt also contributed.

Technology Enhanced Elementary and Middle School Science (8/00 – 5/03. $1,214,087. ESI-9986419 and 12/03 – 3/07. $1,142,868. ESI-0352522). This pair of projects address the low utilization of probes in grades 3-8 by developing excellent student materials, providing extensive teacher resources and online courses, and developing software that runs on most computers using probes from most vendors. Bannasch directs the technology, and Staudt manages the project. Initial project research documented important learning gains (Metcalf & Tinker, 2004).

Computational Models

Molecular Literacy for Biotechnology and Nanotechnology Careers (5/04 - 4/07. $899,857. DUE-0402553). **Molecular Logic**: Bringing the Power of Molecular Models to High School Biology (2/03 - 6/06. $1,416,623. ESI-0242701). **Molecular Workbench**: Reasoning with Atomic-Scale Models (12/1/99 - 8/31/04. $1,364,944. REC-9980620. Supplemental $189,789. REC-0233649.) These projects developed the Molecular Workbench (MW) and its associated authoring and delivery system. This system allows students to experiment with atomic-scale systems to understand the physical origins of a very wide range of phenomena including phase change, light-matter interactions, chemical equilibrium, and the shape and function of biomolecules. The authoring system permits the easy development and delivery of learning activities and has resulted in over 150 activities in a wide range of science and engineering subjects for grades 6-14 that can be accessed through a database.[2] Users from more than 60 countries have downloaded over 10K copies of the software and 100K copies of models and activities. Many of the activities have been carefully tested, revised, and widely disseminated (Berenfeld & Tinker, 2001; Pallant, 2006; Pallant & Tinker, 2004; Tinker, 2000a, 2000b, 2001c, 2005a, 2005b; Tinker, Berenfeld, & Tinker, 1999, 2000; Xie & Tinker, 2006).

Online Professional Development

International NetCourse Teacher Enhancement Coalition (INTEC). (5/96 – 4/00. $2,856,628. ESI-9554162). This 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 (George Collison, Elbaum, Haavind, & Tinker, 2000).

The Virtual High School Consortium. (10/96 – 9/01. $9,856,545. R303A960571). This project, funded by the U.S. Department of Education, pioneered 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). It continues as a separate nonprofit funded by schools.

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2 See http://molo.concord.org

Seeing Math Telecommunications Project. (10/00 – 9/05. $12,060,964. R286A000006). This project, funded by the U.S. Department of Education, pioneered the integration of video case studies and interactive software into online professional development courses (G. Collison, 2006; Galvis & Nemirovsky 2003; Nemirovsky & Galvis, 2004). It prototyped *Smart Graph* technology we plan to use to provide alternative representations and modes of communication.

PROJECT MATERIALS

MATERIALS OVERVIEW

The project will develop seven two-week computer-based instructional modules that have a unifying energy theme. The materials will be highly flexible so that they can be adapted to individual students' perceptual and cognitive preferences. They will be suitable for use in grades three through six and aligned with local and state science standards and curricula. Probes will be used for lab experiments and computational models will be used for virtual experiments.

Universal design principles will be implemented that allow teachers and students to control the appearance of the materials, communication modalities, instructional strategies, content, and assessments. A web portal will give teachers the ability to monitor student progress based on embedded assessments and to change settings for each student accordingly. A major innovation will be a new "smart graph" that has various representations and can interact with the user about salient features of any graph being displayed. A corresponding "smart model" will be developed.

The materials will undergo one semester of formative testing in 25 classrooms in Acton, MA, Anchorage, AK, Maryville, MO, and Fresno, CA. The four major probeware vendors will provide the required probe hardware. Each district has agreed to provide the additional technology required and to participate fully in the testing.

Teacher professional development (TPD) materials will be generated for the teachers in the formative assessment, revised, and then evaluated when used to prepare a second group of 25 teachers participating in the summative research in the last year of the project. The TPD will be a blended design consisting of a workshop and online course. An important feature of the TPD will be engaging teachers in customizing the materials to their grade level, curriculum, and standards.

RESEARCH UNDERPINNINGS

Universal Design for Learning (UDL) has been successfully applied to reading and the language arts where the approach demonstrates that flexible, computer-based materials can help marginalized students, regardless of their ability (Freed, Rothberg, & Wlodkowski, 2003). "Applying universal design to learning materials and activities can increase access for learners with wide disparities in their abilities to see, hear, speak, move, read, write, understand English, attend, organize, focus, engage, and remember" (Rose & Meyer, 2000; 2002).

The team at CAST has synthesized their extensive experience with findings from cognitive research into the following guidelines (CAST, 2000):

- Students with disabilities fall along a continuum of learner differences rather than constituting a separate category.
- Teacher adjustments for learner differences should occur for all students, not just those with disabilities.

- Curriculum materials should be varied and diverse, including digital and online resources, rather than centering on a single textbook.
- Instead of remediating students so that they can learn from a set curriculum, curriculum should be made flexible to accommodate learner differences.

Research in cognitive factors, such as working memory (Baddeley, 1986; Clark & Paivio, 1991; Paivio, 1986) and multimedia learning (Mayer, 2001, 2003; Mayer & Moreno, 2003), has generated a significant body of findings that suggest how technology could be designed to achieve the goals of UDL (Tinker & Tinker, 2005). Design recommendations based on cognitive research with implications for this project are summarized in the Appendix.

The Design of UDL Science Materials

This project will follow the example of *Thinking Reader*, which is briefly described in the Appendix. This is a practical realization of UDL ideas that can be customized for individual students, but does not have so many options that teachers and students are overwhelmed. The fact that it is published demonstrates that the theories and research on which it is based can have a practical impact in real classrooms. In the same spirit, this project plans to create science materials that balance flexibility with practicality so that they can be used in classrooms and published, and so they inspire further development.

It is a common misconception that the "universal" in UDL implies a design that would support students with profound challenges. That is an unrealistic goal, primarily because the most challenged students require highly specialized devices, instructional plans, and individualized instruction outside the classroom.

Inquiry is the cornerstone of science education and must be central to any UDL design for science. To give the degree of control over the learning environment that UDL requires, it is important that inquiry be brought under computer management. Our approach will allow students to explore the real world using probes and simulated worlds using computational models. This will give students powerful tools in a software environment that allows the tools to be adapted to individuals. We have chosen tools and technologies that can be used in any STEM context, so the results of this project can have maximum impact. This section describes how these tools will be used to achieve the goals of any STEM UDL materials.

The proposed exemplars will provide a range of alternatives for the way tools are used in the classroom, the materials are represented and communicated, and learning is assessed. These alternatives boil down to a series of software switches and sliders that teachers and students can control in order to individualize the learning experience. The following sections summarize the various alternatives.

Alternative Representations

The proposed materials will be constructed from three kinds of objects: text boxes, graphs, and models. In *Thinking Reader,* text can be displayed in different fonts, sizes, and colors. The Exemplar's text boxes will have the same functionality. The challenge will be to provide comparable functionality for the graph and model objects. They will have full range of display options, including type of display, size, colors, and line width. English and Spanish versions will be available. Vocalization will be used extensively and different voices will be supported.

Alternative Communications

Thinking Reader can be said to have some semantic intelligence because the text can be selected and read in meaningful parts (e.g., words, phrases, sentences, or paragraphs) and it can explain text using a glossary. The graphing and modeling software would have comparable capacity.

The graphing object will be based on a prototype *Smart Graph* software object we have developed, which can generate text and vocalizations that describe the important features of a graph. The central idea is that software can identify semantically important features of an arbitrary graph generated by an equation or data from a probe, or imported from some other source. The kinds of graph features noticed by an experienced graph user can be identified by the software, such as the units and range of the axes, the overall shape, the location of maxima and minima, slopes, noise, and periodicity. This design meets or exceeds all the guidelines for graphs promulgated by the National Center for Accessible Media (2003).

The other major innovation will be a *Smart Model* based on our *MW* system. Like *Smart Graph,* this software would have semantic intelligence about molecular dynamics models and be able to communicate in terms of important features of the display. Features that it would recognize include the number and kind of atoms and molecules, the location of selected atoms, their temperature, pressure and volume, the average potential and kinetic energy, whether liquid or solids are present, when bonds are made or broken, and whether the distributions are random.

Alternative Instructional Strategies

The *Smart Graph* and *Smart Model* software will be the UDL tools used for inquiry. The next level of design involves instructional strategies that use these tools and can be tailored for different students. Again, we turn to *Thinking Reader* for guidance, in which different reading skills are taught by challenging students with thoughtful questions. UDL is implemented by allowing the teacher to select different levels of scaffolding that help students tackle the questions. We will have a comparable approach that will teach content and inquiry skills through challenges and the provision of various levels of scaffolding. Inquiry skills will be developed in the context of student investigations of the real world using probes and of the world of atoms and molecules using *MW* models.

Our categories of inquiry skills will be based on the National Science Education Standards (NRC, 1996): identify questions, design and conduct investigations, use tools to gather and analyze evidence, describe the results and make predictions, think logically about conclusions, and communicate results. For each skill, there will be several challenges that require student responses. For each challenge, we will have five levels of scaffolding:

Level 1: One or more examples of good responses are provided.

Level 2: The student selects the best of several suggested responses.

Level 3: Parts of a response are provided, but the student is asked to fill in missing content.

Level 4: Clues are given for data or information that students should use.

Level 5: Only context-independent scaffolding is provided.

Alternative Assessments

UDL design requires that alternative student assessments be utilized. One of the advantages of electronic media is that students can be assessed in a variety of ways both explicitly and through embedded assessments. The latter are particularly attractive because they provide detailed information without taking away from instructional time. The following assessments will be built into the materials.

Tracking. The software will track how students use the materials. This will include recording student time on each task, task completion, artifacts created, the UDL options selected, and the help or scaffolding requested. For work completed in a work group, the other members of the group will be recorded.

Performance assessment. Performance assessments will be part of each module using both probes and models. These tasks will be very much like the learning challenges, requesting students to perform an investigation or some part of one, such as data analysis, or communication.

Electronic portfolios. The electronic portfolio technology developed in TEEMSS will be used extensively for student assessment. Because the SensorPortfolio supports text, drawings, concept maps, and annotated screenshots, it implements the UDL goal of providing alternative forms of student expression.

Automatically graded quizzes. Because most students need practice using multiple-choice tests and other automatically graded items, quizzes based on these will be included in every module. They have the advantage of providing students with immediate feedback.

Additional Alternatives

Other UDL features to be implemented include the following:

Speed control. A slider will control how fast information comes to the student. This one control will set the vocalizing speed, the speed of objects the model, and the rate data are displayed by the grapher.

Big ideas portfolio. Students will be encouraged to use their personal portfolio to organize their thinking with concept maps, descriptions or illustrations of the driving question, or claims and evidence that frame their current investigation. They will be able to call up their portfolio any time to help orient their investigations.

Avatars. As in *Thinking Reader*, age-appropriate avatars with different personalities will provide the scaffolding that can be visual, text, or vocal.

Visual communications. Drawings or animations will duplicate most of the content that is conveyed in text. See the TEEMSS illustrations in the Appendix for the style that has proven effective.

Screen control. Students will be able to individualize their screen by controlling the number and size of elements displayed.

Content options. Each module will include parts that are optional. This will allow the module to be tailored to different student interests, grade levels, and amounts of class time. Teachers will be able to determine which students see which options.

Managing the Options

All these alternatives and options could easily overwhelm both students and teachers. The potential for confusion will be reduced by hiding and grouping options, and by providing templates for combinations of settings that have been found to be useful. Teachers will be able hide or disable any of the options for either all students or individuals. This will allow options to be introduced gradually as students gain familiarity with the system. In addition, options will be grouped, so that selecting one of these groupings will determine many options. Groupings and templates will relieve teachers from setting every control for every student. For example, one group control could disable sound outputs for a classroom without earphones. A template could set up a "low-stimulus" environment for certain students, giving them cool tones, an open screen layout, and low volume. To further simplify the option selection process, the system will remember teacher and student settings so they remain consistent across computers and modules.

Anticipated Products

Student Materials

To select appropriate content, we have analyzed the grade 3-6 curricula in the collaborating schools. Because of the differences in content and standards, we need to develop seven modules that each require two to three weeks of class time. Each will include a driving question that leads to investigations with probes and atomic-scale models. Energy conservation and conversion will be highlighted in each module, providing a unifying theme.

The seven modules each treat basic topics that are often taught at these grades, facilitating later dissemination. We will ask the collaborating schools to select three or four of these modules to be used in one semester, giving each school ample options to complete our assessments in one semester and to test the material in different grades.

The seven modules are briefly described below:

Why are there clouds? This is an earth systems activity on weather, air pressure and temperature, latent heat, and evaporation. The probe investigation will measure evaporative cooling and dew points and the effect of squeezing a plastic bottle. Comparable investigations will be done at the atomic scale using *MW*.

What do plants eat? This is a life science activity that introduces light and photosynthesis and addresses the pervasive misconception that biomass comes from the soil. The connection between light energy, color, and growth is investigated with temperature and light probes. *MW* models are used to investigate why leaves are green.

Is it getting hotter? This is an ecology activity on climate and climate change. The science is about the energy in sunlight and radiated IR, and light absorption by different molecules. Investigations with a temperature probe allow students to explore a physical model of the greenhouse effect. *MW* provides a model of how greenhouse gasses block light.

Why does water boil? This physical science activity addresses states of matter and phase change. A temperature sensor is used to measure various boiling temperatures and to see whether the rate of heating affects the boiling temperature. The same investigations at the atomic scale will be undertaken with a *MW* model.

What's a flame? This physical science activity introduces chemical energy and light emission. Unfortunately, open flame experiments violate safety standards, but students can use a temperature sensor to experiment with exothermal reactions and black body radiation. The flame reaction will be investigated using a simplified *MW* model.

What if there was no friction? This is a physical science activity focused on force, motion, and energy at astronomical and atomic scales where there is no friction, compared to our scale where we can only approximate the absence of friction. The motion detector will be used to measure the effect of friction on various moving objects. *MW* will be used in investigations of both atomic and astronomical motions.

What does soap do? This module addresses solubility from a perspective that can be used in life or physical science. Solubility will be investigated using *MW* as a question of the energy in forces between water and oil. Light and conductivity probes will be used to investigate real solutions. Soap will be seen as soluable in both oil and water.

The ideal classroom would have one networked computer per student. This is not unrealistic for a future-oriented project. One-on-one computer initiatives are increasingly popular, currently involving an estimated 250K students (Zucker, 2005, 2006). Five years ago, two-thirds of students lived in families with computer access, half of which had high-speed Internet access (Newburger, 2001). The trend is clearly toward ubiquity. It will, however, be possible to use our materials in classrooms with one computer equipped with a probeware system for every three students and we will include advice on how to do this in our guide to implementation.

Teacher Professional Development Materials

The project will develop a rich set of materials for teachers that will be available separately and will form the core of a blended course. The following materials will be developed:

General Information. We will develop a teacher-friendly review of research on UDL and background report that shows how features in the software are linked to the guidelines for UDL. We will also provide guidance for classroom management given different hardware and probe configurations and a correlation matrix for national, MO, CA, AK, and MA standards. We will use the formative evaluation as a source for a section on teacher-to-teacher advice on managing diverse classrooms and suggestions for different curriculum schedules.

User's Guide. We will develop a technical user's guide for using probeware and *MW*, installing and using the teacher portal, and setting up classes and registration.

Lesson Plans. Each of the seven modules will include lesson plans (from the formative implementation), a description of common student errors and misconceptions, answers to questions with explanations and rubrics for student evaluation.

The TPD course materials will consist of all the resources above, a syllabus, and schedule for both the face-to-face and self-study portions of the course.

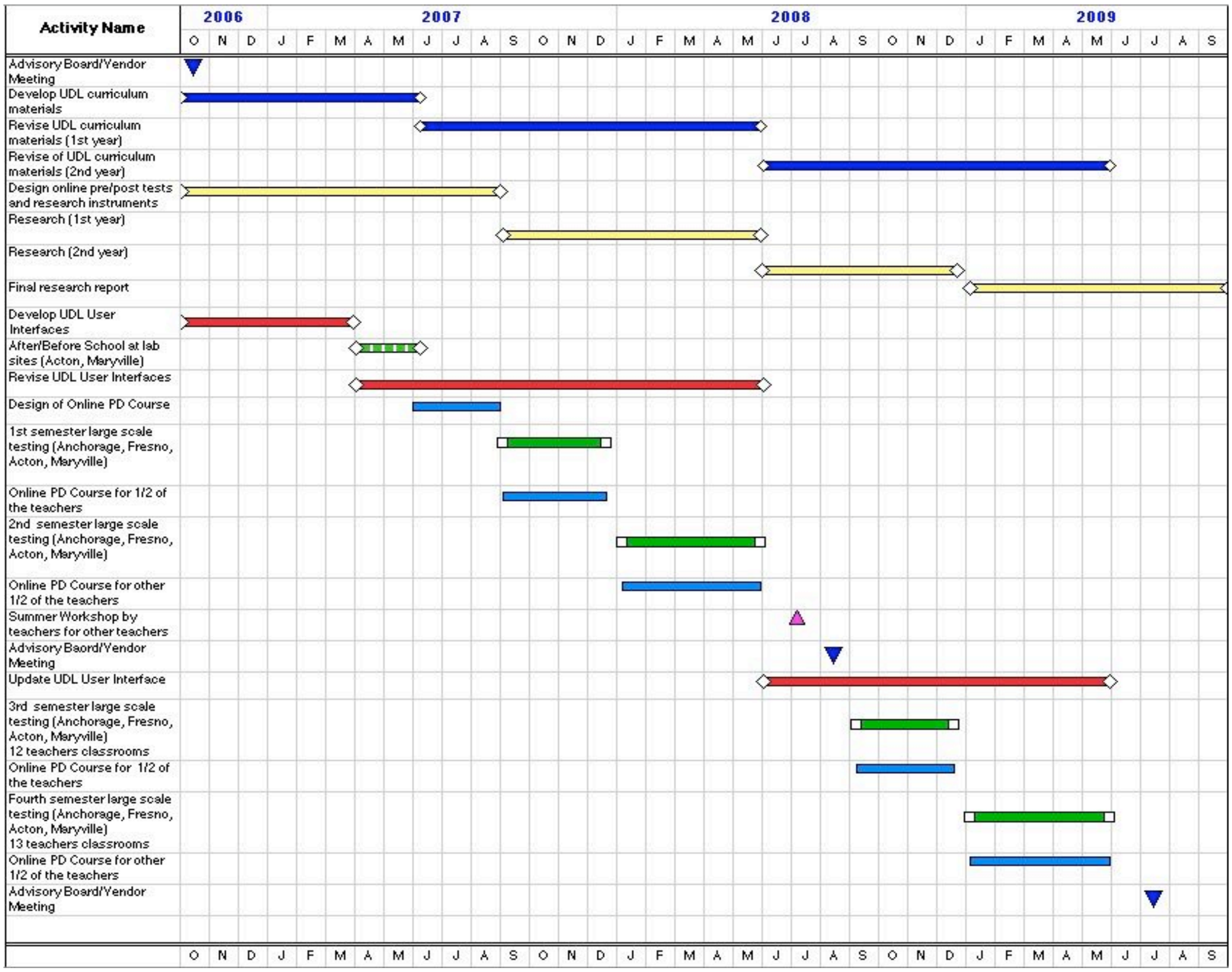
Community and Caregiver Materials

To provide support for parents, caregivers, and other members of any community where these materials are use, we will provide a popular description of our materials, their educational features, how UDL is integrated into the materials, and our research findings. In addition we will provide ideas for caregivers to supplement instruction by suggesting at-home conversations about each module, related activities and readings, and suggested websites.

Project Activities

Project Schedule

Materials and software will be developed during the 2006-7 academic year, in close collaboration with teachers and other experts. During that year, there will be some trial teaching with small groups of students after school. During the summer of 2007, the first group of 25 teachers will be introduced to the approach so they can implement the draft materials during the following year. Some teachers will test the materials in fall 2007 and others in spring 2008, giving us two revision cycles and allowing probes to be shared. A second cohort of teachers will receive professional development in the summer of 2008 and final drafts will be tested in their classrooms in the 2008-9 academic year. These steps are described in the timeline below.



MEETING THE OBJECTIVES

The project activities will be organized around the objectives listed above. In the following, the major activities in support of each objective are described as fully as space permits.

Develop detailed designs for science UDL materials. The project will first review the UDL designs in this proposal and then develop detailed mockups that illustrate the features that will be implemented. These designs will be independent of the specific science content, but incorporate general principles and artifacts that must be part of any science materials. The designs will involve consultation with partner teachers, experts in cognition, CAST, and publishers. The designs will have sufficient detail to define the software functionality needed.

Develop supporting technology. Application software will be needed to create *Smart Graphs* and *Smart Models* that are described above. A platform will be developed for creating, delivering, and controlling the proposed materials. We will use our open source platform technology for logging the choices and responses a student makes (Buckley et al., 2004; Gobert et al., 2004). A web portal will be developed that handles student registration, teacher formative feedback, and research data collection.

Develop student materials. Project staff, working with teacher reviewers and consultants, will start by defining the instructional goals and assessments for each activity (Wiggins & McTighe, 2001). The seven modules will be completed in time for review by the Advisory Boards and formative testing in year two. This will be feasible because of the extensive TEEMSS and Molecular Workbench materials and the highly productive *MW* authoring system. Material for each module has been developed and most include student activities that have been tested in real classrooms.

Revise materials based on formative evaluation. Materials will be tested in year two in a total of 25 classrooms in four schools that have geographic, ethnic, and social diversity. Formative evaluation will utilize standard observational and interview techniques and extensive data collected by our logging system. The project will develop a computer-based student performance assessment to measure student inquiry skills using probes and modeling. This assessment will be administered to all students at the beginning and end of the semester they use the materials. Based on the formative data, staff will prepare a description of changes needed in the pilot materials and undertake a revision cycle to create a final set of materials that will be reviewed by the Advisory Board. The performance assessment will also be reviewed and revised as necessary.

Develop professional development materials. The options inherent in UDL, the teaching strategies employed, and the student assessment system will be challenging. The project will learn by working closely with teachers in the formative tests what kinds of information, experiences, and assistance is needed. This experience will be used to create a blended face-to-face and online course for teachers that will be used to prepare the teachers for the summative implementation.

Study UDL and student learning. A summative evaluation of the final materials will be undertaken in the third year by the external evaluator again using one-semester implementations of the materials. Using the 25 formative sites and 25 new classrooms, the study will focus on the relation of the UDL features to learning for sub-populations of students. The 25 new teachers in the summative evaluation will be recruited from Fresno and Anchorage schools and trained prior to the third year using our TPD materials through a combination of a four-day summer institute and an online self-paced course. Credit will be available for teachers completing a final project.

The primary student outcome variable will be the computer-based performance assessment administered at the beginning and end of the semester that students use the material. Additional student variables will be the UDL option groups used, any identified special needs, and ethnicity. Teacher variables studied will include science background, years teaching, and instructional style. This study will employ a two-level hierarchical linear model (Raudenbush & Bryk, 1986), where level one will be fit to individual students. In this level, student outcomes will be used as the dependent variable and other student level variables are designated as independent variables. The second level incorporates the regression parameters estimated by the level one analysis as the dependent variable, which are then regressed on the teacher-level data. In this way, the resulting regression estimates are unbiased with respect to the dependency of the student observations due to common teacher level variables.

Dissemination. The project will work closely with publishers and hardware vendors to create a product that can be successful in the marketplace. Tom Snyder Productions has expressed strong interest in this proposal and through their General Manager, will work closely with the project to help ensure its commercial viability. At the same time, we will make the software platform and associated technologies available as open source. Research results will be communicated to the profession and popularized versions developed for practitioners and parents. To reach the widest possible audience, a project website will be created where all project documents can be accessed. We will also write popular articles on the project for *@Concord,* which is disseminated free to 10,000 readers.

PROJECT MANAGEMENT

PROJECT EVALUATION

The role of the 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 Amie Mansfield, an experienced external evaluator (see Appendix for her CV). She will evaluate project execution and fidelity to plan, and will compile annual reports that will be provided to the project Advisory Board 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?

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 were the materials used? Was there publisher interest in the materials?

To answer these questions, the evaluator will review the project's 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. The external evaluator will produce annual reports that will be transmitted to the Advisory Board and the NSF.

PROJECT STAFF

Robert Tinker will serve as Principal Investigator and will be responsible for the overall scientific and educational quality of the grant. An experimental physicist by training, he holds a Ph.D. in low-temperature physics from MIT. He has taught college physics for ten years and has an international reputation as one of the most important educational innovators. He has served on many boards and committees, including the National Academy of Science advisory committee that developed the National Science Education Standards (National Research Council, 1996).

Carolyn Staudt will serve as the Project Director responsible for the overall coordination and budgeting of the project. She will be directly involved in creating and coordinating the development of the curriculum materials and teacher professional development course. She served in this capacity on TEEMSS and was the curriculum designer for several technology and Internet-based projects at the Concord Consortium. Ms. Staudt has twenty years of experience teaching science and math, including physics and chemistry. She holds a Masters of Education in Curriculum and Instruction in science from Kent State University and was a Christa McAuliffe Fellow in 1990.

Stephen Bannasch will serve as the Director of Technology. He graduated in 1982 with a BA from Hampshire College where his thesis involved designing a microcomputer-based monitoring system to measure the performance of an experimental passive-solar home. At TERC, he pioneered with Bob Tinker many of TERC's efforts in MBL, data-logging, and telecommunications technology, including the development of the ultrasonic motion detector.

Dr. Andrew Zucker has a doctorate in education from the Harvard Graduate School of Education. He will oversee all aspects of the research regarding school level data. Dr. Zucker has worked with technology in schools since the 1970s and has studied education policy and practice in a wide variety of contexts. He was a Co-director of the project that evaluated the NSF's Statewide Systemic Initiatives Program, and Principal Investigator of the Ubiquitous Computing Evaluation Consortium from 2002 to 2005.

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.

ADVISORY COMMITTEE

Richard Abrams is the General Manager of Tom Snyder Productions, a Scholastic Company. He is a member of the board of Concord Consortium and several other nonprofits. Rick has guided the growth of Tom Snyder Productions from a start-up company into one of the leading educational software publishers in the K-12 market.

Bonnie Bracey is a consultant for the George Lucas Educational Foundation, and a teacher-agent of change, specializing in the use of technology to change the way teachers teach and students learn. Bonnie is a former Christa McAuliffe Educator, and a winner of several awards.

Sherry Hsi is the Director of Research and Evaluation for the Center for Learning and Teaching at the Exploratorium. In 2004, she won a MacArthur Foundation grant to explore digital-mediated learning among next generation youth. She holds a Ph.D. in education from Berkeley.

Joseph S. Krajcik is a professor of science education in the School of Education at the University of Michigan, where he co-directs the Center for Highly Interactive Classrooms, Curriculum and Computing in Education. He holds a Ph.D. in Science Education from the University of Iowa.

Joe Oliver, Director of Instructional Technology for Los Angeles Unified School District is an administrator and mathematics/science teacher. Joe has also authored, co-authored and consulted for grants worth over 70 million dollars from state and federal agencies.

David Rose is the Founding Director/ Chief Scientist in Cognition & Learning for CAST and the leading authority on UDL. He is a member of the Concord Consortium Board. Dr. Rose holds a doctorate in education from the Harvard Graduate School of Education where he teaches.

Raymond Rose is an independent education specialist with over 20 years of experience working in schools as a trainer, consultant, and policy maker. He directed several teacher professional development projects at the Concord Consortium and served as vice president.

Eugene Stanley leads an interdisciplinary research laboratory, the Center for Polymer Studies, at Boston University. He has co-authored 820 scientific papers and 14 books and spends a major fraction of his time in education, where his primary contributions have been in the application of chaos and fractals and, more recently, molecular dynamics.

SCHOOL PARTNERS

All four school partners are firmly committed to the project and can provide one computer per student. Their letters in the Appendix confirm their enthusiasm for this project.

Fresno Unified School District has a very diverse student population of 78,000 students, which are 55% Hispanic, 16% Asian, 17% White, 11% Black, and 1% Native American. More than 80% qualify for free or reduced meals.

Horace Mann Laboratory School is located on the campus of Northwest Missouri State University in Maryville, Missouri. Maryville serves a rural, farming region experiencing a high rate of poverty. Currently, they provide free and/or reduced federal lunch program to 15% of the student population and the diversity rate averages between 12% and 15%.

Douglas Elementary School, in Acton, MA, has a K-6 program consisting of 21 classes with a 25% non-White population. The school has a 13 station computer lab staffed by computer specialists.

Anchorage School District enrolls over 50,000 students with 41% ethnic non-Whites. Over 33% of ASD students now live in poverty, and this proportion is increasing.

VENDOR PARTNERS

Data Harvest Educational, Fourier, **PASCO**, and **Vernier Software & Technology**—the leading probeware vendors—have all agreed to support the project (see attached letters of support) and each has promised to provide two classroom sets of probes.

PRIOR WORK: THE TEEMSS PROJECTS

The probe applications in the proposed project builds on a strand of research at the Concord Consortium called **TEEMSS: Technology Enhanced Elementary and Middle School Science** and funded by the NSF. In this section, the curriculum and research results from TEEMSS is described. Examples of the TEEMSS materials follow in the next section.

The TEEMSS Curriculum

TEEMSS responds to the extremely low utilization of probes and models in elementary science teaching. These technologies, although generally acknowledged as the best uses of information technology, have not been incorporated into NSF-funded projects. Our analysis is that computer cost, probe incompatibilities, and teacher professional development challenges have been the major barriers to implementation in elementary grades. TEEMSS addresses all three barriers.

TEEMSS reduces computer cost by supporting handheld computers as well as full-sized computers. If a school has some older computers or can only purchase handhelds, TEEMSS can be used. It is also common to find that schools have collections of older probeware from various vendors. By supporting seven lines of hardware from four different vendors, TEEMSS allows schools to use whatever they can find or have on hand.

Most important, however, is that TEEMSS has developed excellent curriculum materials that can be easily substituted for other content because it is aligned with national standards and treatments commonly used in NSF curricula. The following table describes the 15 units, which are organized into three grade bands and five standard themes.

Standard	Grades 3-4	Grades 5-6	Grades 7-8
Inquiry	**Sound** Explore sound and vibrations with a computer's microphone	**Water and air temperature** Mix fluids and measure temperature changes with a temperature sensor	**Air pressure** Explore soda bottle, balloons and lungs with a gas pressure sensor
Physical Science	**Electricity** Explore light bulbs, batteries, and wires using a voltage sensor	**Levers and machines** Design and test your own compound machine with a force sensor	**Motion** Graph, describe, and duplicate motion using a motion sensor
Life Sciences	**Sensing** Compare electronic and human sensing of your environment using temperature and light sensors	**Monitoring a living plant** Monitor a living plant in a plastic bag with relative humidity and light sensors	**Adaptation** Explore population, selection pressure, and adaptation with a computer model
Earth & Space Science	**Weather** Observe and measure weather-related changes with temperature and relative humidity sensors	**Sun, Earth, Seasons** Connect planetary motion to day/night cycles and seasons with a light sensor	**Water cycle** Study water phase changes and relate to terrestrial phenomena with temperature and light sensors
Technology/ Engineering	**Design a playground** Study your playground and build models of several pieces of playground equipment using force and motion sensors	**Design a greenhouse** Build a working greenhouse model and monitor temperature, light, and relative humidity sensors	**Design a measurement** Choose something to measure and devise a way to do it using any or all of the sensors

The TEEMSS Projects

There have been two rounds of TEEMSS research. A pilot study developed two middle school science units, Motion and Forces and Transfer of Energy, which utilized probes and interfaces developed at the Concord Consortium. That material was tested in 13 middle school classrooms and demonstrated the effectiveness of the approach in terms of student learning and teacher enactment. The second, two-year research study is underway in 47 classrooms in Missouri based on a design that uses controls. It is testing all 15 units described above in grades 3-7 and uses a mix of commercial probe hardware and both handheld and full-sized computers.

The TEEMSS software, called SensorPortfolio, is a distillation of 25 years of innovation in probeware by the key staff. Specifically, probeware and visual computational models are seamlessly integrated into a sequence to create learning activities with embedded assessments. All student work is saved in electronic portfolios. This includes students' writing, drawing, answers to assessment questions, as well as data predictions and graphs. These portfolios are available to both teachers and students. The software runs on almost any computer used in education, including Windows, MacOS, and Linux desktop operating systems, as well as PalmOS and PocketPC handheld computers. In the original TEEMSS project our software only worked with the CCProbe interface and probes. The TEEMSS2 project extended the software to support probeware interfaces from the following commercial vendors: Pasco, ImagiWorks, Vernier, Fourier, and Data Harvest. Our software is written in both Java and a dialect of Java designed for handheld computers called SuperWaba. Our custom web-based authoring environment allows developers to create activities without concern for either the computer or interface that will be used.

TEEMSS Research Findings

Highlights of the research findings are summarized here. Additional details on the research can be found on the TEEMSS website at http://www.concord.org.

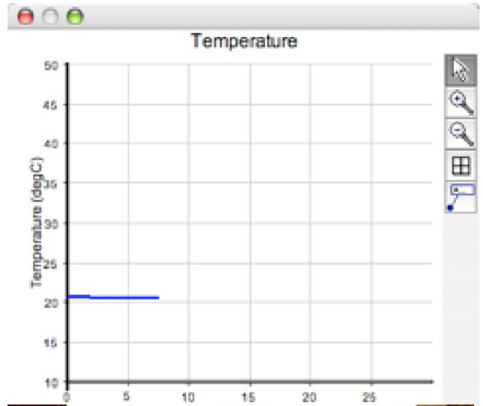
In the TEEMSS pilot study pre/post testing of 13 classrooms found that students showed significant gains, with up to 19% higher scores on post-tests. The greatest improvements were seen when students were able to spend extended periods of time using the materials. Looking closely at specific test questions, the most significant improvements were seen on questions that matched most closely with the curriculum: questions relating to position-time graphs, and questions relating to heat flow, insulation, and temperature-time graphs.

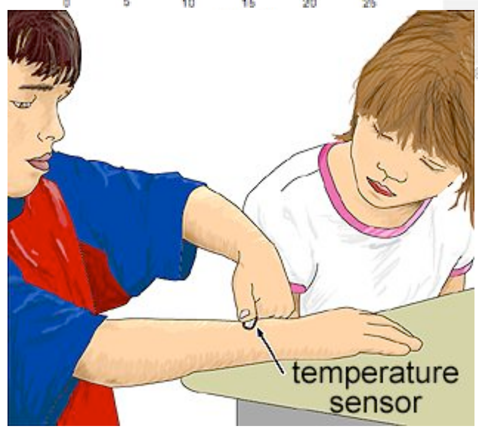
The pilot study also concluded that online teacher professional development can be effective for preparing teachers to use inquiry-based materials, as gains were measured for students of teachers whose only preparation for using these materials was through an online training course. Finally, the pilot demonstrated the feasibility of providing scaffolding with handhelds.

The full TEEMSS study is currently in progress and has completed the first year of a two-year classroom evaluation program. The first year results showed that treatment students in grades 3-8 made statistically significant gains in all five units tested. Furthermore, in a comparison of treatment and non-treatment students, treatment students showed significantly higher gains than non-treatment students in two units, Temperature and Pressure. For the Pressure test, the size effect was quite large. In the other three units, Sound, Sensing, and Motion, treatment students and non-treatment students both made similar, statistically significant gains from pre-test to the posttest. Currently, 47 teachers are participating in the summative evaluation, each teaching three of the fifteen TEEMSS units with their students during the school year.

Prior Work: TEEMSS Sampler

The following is a brief description of parts of two of the 15 TEEMSS units. The first is from initial experiments in a "Sensing" unit in which grade 3-4 students compare temperatures and light levels they perceive with measurements using probes. The second is part of a grade 7-8 motion unit. For access to these and all other activities, go to the main Concord Consortium page at http://www.concord.org/, select the TEEMSS2 project, enter the public portal, choose to view the activities, and select one of the hardware systems.



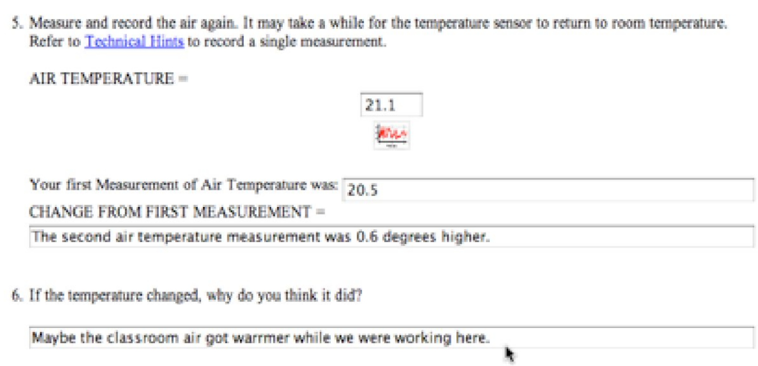


It is important to realize that TEEMSS works with seven different hardware systems connected to most handhelds and full-sized computers. The technical hints built into each activity are specific to the hardware system selected. The illustrations are constrained in size so they are meaningful on the small screen of a handheld.

The activities consist of steps in a free, open source platform called SensorPortfolio. When students launch an activity, they see a list of titles that link to steps that are specific to that activity. Some steps present material in a multimedia format. Another kind of step is the data tool that supports a sensor and graphs its output as shown at right. Other step kinds include: embedded assessments that support multiple choice and open response items; a student portfolio for student products; a notepad; a sketchpad; a table; and a concept mapper.

The Sensing Module

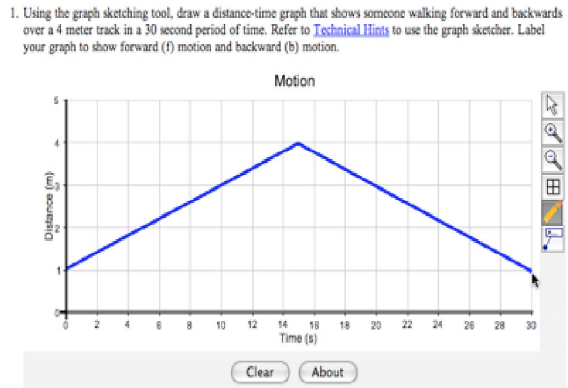
The first activity in this unit asks students to measure the air temperature. Clicking on a single-value data collection icon opens a smaller popup window allowing the students to collect temperature data and record a single value. Clicking the **Record** button closes the window and saves the last measured value.



Students are next asked to measure their arm temperature. Once again a single-value data collection graph is displayed and the last measured value is entered into the activity. Later in Trial 1, air temperature is measured again and the software displays the results of the earlier measurement and asks the students to do two things: first, the students have to calculate and enter the difference between the first and second measurements of air temperature; second the students need to come up with an explanation of why the measurements differ. After finishing this section students could see the screen above.

All of the data, writing, drawings, and assessments are saved in the student's portfolio. The portfolio is like a lab book that students can edit, turn into a report, and submit to the teacher. Teachers can use these reports to monitor class progress.

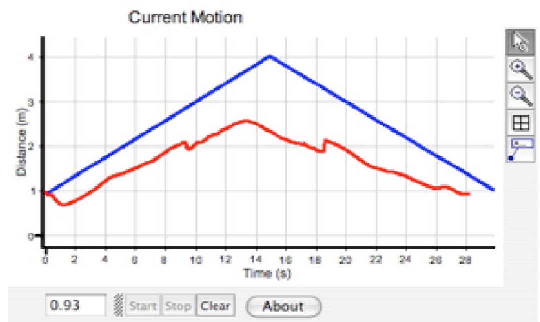
Later in Trial 2 (Feeling and Measuring Temperature Investigation), the authors have used the multiple choice assessment capability. The teacher can see these data in an aggregate form.



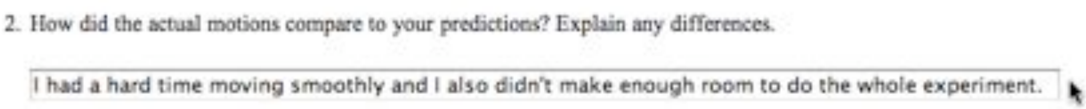
The Motion Unit

The same graphing tool used to collect and display data from sensors can be used to record student predictions. An early activity in the Motion unit asks the students to draw their predictions of a graph of them walking away and walking back over 30 seconds as shown at right.

After making four predictions, students then collect data and compare the results to their predictions. A typical trial generated the red line in the graph at right in real time. This provides a powerful medium where student can compare their mental models represented by the prediction to actual data.



Each prediction also includes an open response essay question asking students to reflect on their results and to explain the differences. A typical open response item is shown below.



Technical Hints

Throughout the activities are technical hints that jump to detailed and carefully illustrated explanations and directions. While the main activities are generic and apply to all senor systems, the technical hints are specific to the sensor system that the student is using. For instance, at right is one illustration of five for connecting the Pasco motion detector for the Motion unit.

Prior Work: The Molecular Workbench Projects

The models used in the proposed project were developed as part of an NSF-funded strand of research at the Concord Consortium called the Molecular Workbench. These projects have explored different applications of the remarkable *Molecular Workbench* software, a computational model developed at CC for education based on molecular dynamics models used in research. Molecular dynamics simulations in *MW* are based on the physics of atomic-scale interactions and can exhibit fundamental phenomena in physics, biology, and chemistry (Berenfeld & Tinker, 2001; Tinker, 2001b, 2001c). Simulations in *MW* calculate the motion of atoms, molecules, and other objects in real time as a result of the applied forces, including the Lennard-Jones potentials, electrostatic potentials, elastic bonds, and external fields.

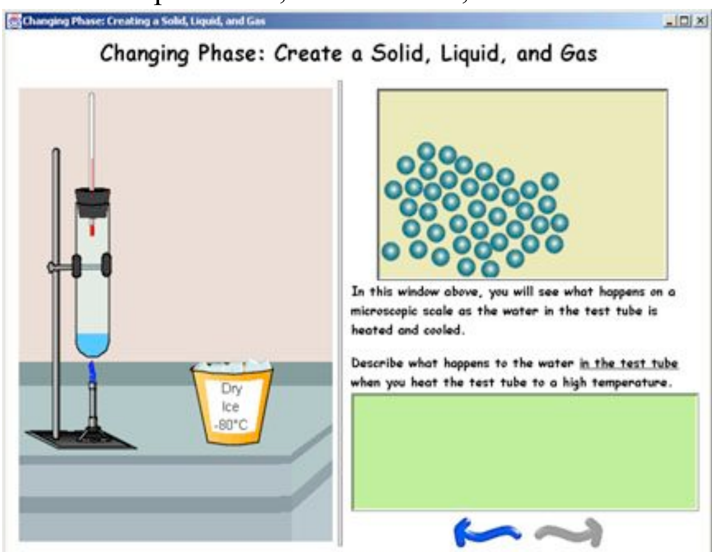


Figure 1. Making a learning activity from a MW model. The model in the upper right represents the water in the test tube. As illustrated, it is liquid, but it can also show solid and gas

Because it is based on good approximations of physical laws, *MW* can produce emergent phenomena such as evaporation, phase changes, crystallization, diffusion, solubility, and absorption. 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 resemble biological molecules (Berenfeld, Pallant, Tinker, Tinker, & Xie, 2004). Light-atom interactions are modeled using photons. This capacity supports investigations of color, scattering, filters, colorimeters, radiation cooling, and black body radiation.

MW is a sophisticated software package that includes many specialized functions that allow it to be used in different learning contexts. The properties of the atoms can be tailored. There are 47 tools the user can use to interact with the model. An optional recorder allows the user to replay a model and to find and examine individual frames. All kinds of input controls and output displays can be connected to the model. Snapshots of the model and outputs can be saved and annotated. *MW* models are intended to be embedded in learning activities. The author of a Molecular Workbench activity can set the initial conditions of a model, the options available to the user, and the output graphs or other representations. The model can be placed in a multimedia document that includes text, other models, molecular visualizations, and assessments.

For instance, Figure 1 illustrates how a learning activity is related to the *MW* model. This is part of an activity on the relationship between temperature and phase. The model on the right is controlled by what the student does to the test tube on the left. This helps establish the relation between the observable state of water and how this is determined by atomic-scale interactions.

Figure 2 illustrates the use of *MW* for a completely different activity that allows students to focus on just two atoms and how they collide.

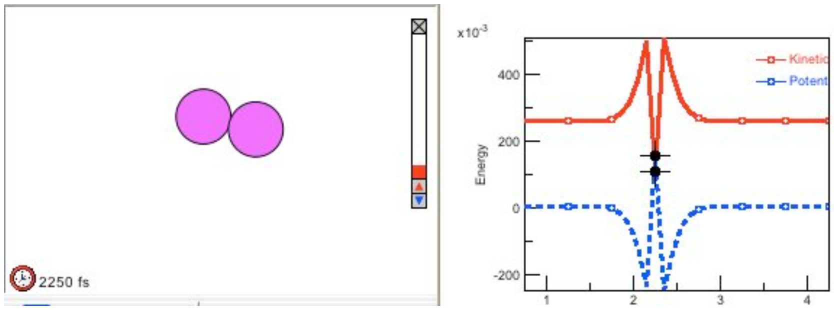


Figure 2. Two atoms in a box. In this activity, students measure the potential and kinetic energy of two particles as they collide. This figure used the recorder feature to capture the closest approach of the two, shown on the graph as black dots. Note how the red kinetic energy and blue potential energy exactly mirror each other, leading to energy conservation.

Creating or modifying an activity involves using the authoring functions, which is very straightforward. The ease of creating and uploading MW activities has led to over 150 activities that have been contributed by staff and collaborators. These are housed in a database with metadata that includes information for teachers.

MW is written in Java, so it runs under all common operating systems, including OSX, Microsoft, and Linux. It is open source, so it can be shared and copied by any user. International use of *MW* is growing and eventually there will be an international user community that will support and improve it. 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. Additional details on the research can be found on the Concord Consortium website.

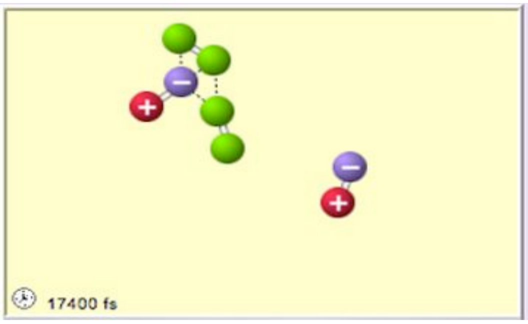
All three Molecular Workbench projects resulted in overall increases in student understanding of atomic-scale phenomena at high school and community college levels. All thirty classes analyzed, representing a cross section of grade, level, and demographics, showed significant gains ($p<0.01$) on paired t-tests for pre/post-test analysis. In the community colleges the largest score increases across the board were for questions focused on interpreting results of a simulated lab procedure, problem-solving regarding unexpected results and applying molecular reasoning to understanding techniques.

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 a set of ten 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%.

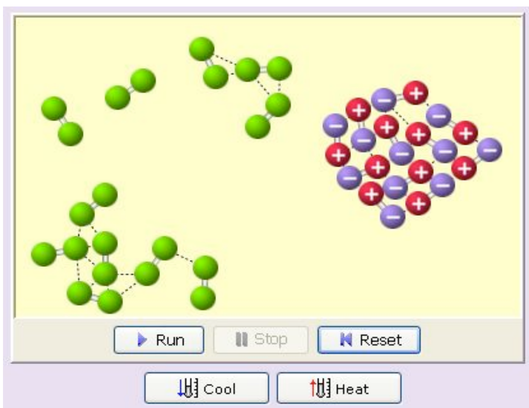
A controlled experiment was carried out to test the effects of models on learning outcomes using an activity on the forces affecting protein folding. Students in the experimental condition received the activity with models. Students in the control condition received a well-designed and illustrated substitute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

Prior Work: Molecular Workbench Sampler

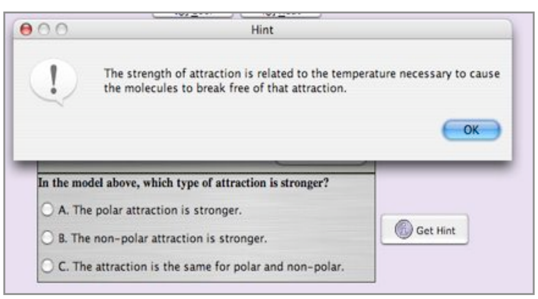
The following is from a unit on attractions between atoms and molecules. It is #227 in the database at http://molo.concord.org/database/



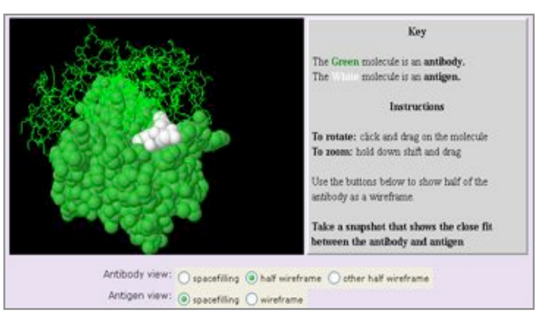
1. The unit begins with students exploring a mixture of polar (red and purple) and non-polar (green) molecules. They select different molecules as "probes", bringing them close to other molecules, thus making and breaking van der Waals (VDW) attractions depending on proximity. They discover that both polar and non-polar molecules are attracted to each another.



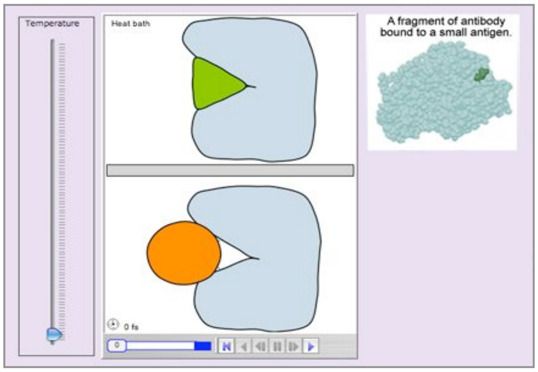
2. Students work with two liquid compounds, one polar and the other non-polar. They use heat to test the strength of the intermolecular attractions, and discover that in polar compounds the attractive forces are stronger, requiring higher temperatures to vaporize the polar substance.



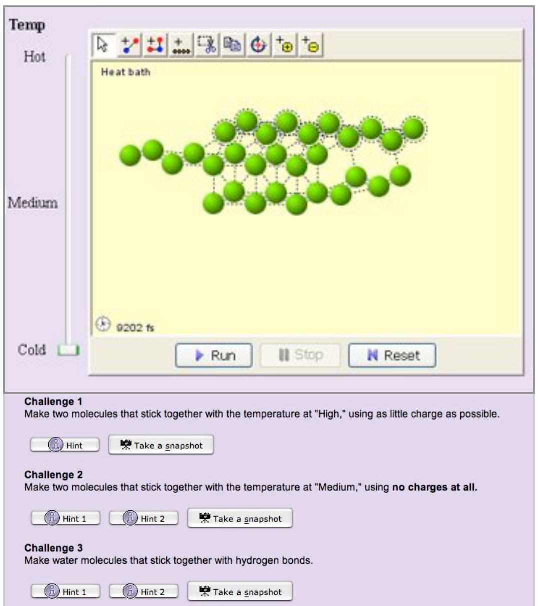
3. Students can choose to view hints as needed to help guide their inquiry.



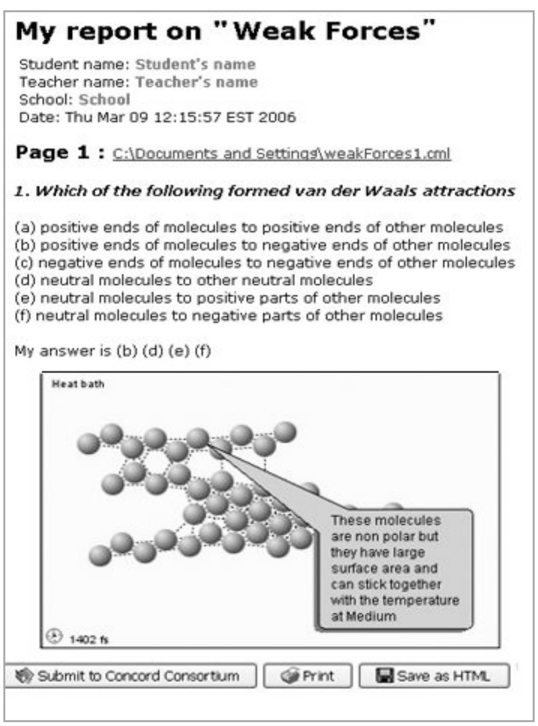
4. To provide relevance, students explore attractions between two molecules, an antibody (green) and its specific antigen (white). They discuss with each other how the antibody can attract and stick to its specific antigen. Using an interactive 3D molecular viewer, students uncover the inner structure of the antigen-antibody



5. In this dynamic model two identical antibodies interact with two different antigens, one that fits an active site (green) and one that does not (brown). Students discover that the attractive forces between the molecules increase with an increase in the area of complementarity. Using heat, they can assess the strength of the attraction.



6. Students undertake a set of challenges to test their comprehension. One of the challenges calls for students to create a set of non-polar molecules that can still stick together under moderate temperatures. Students design molecules with different charge distributions, experiment with changes in temperature and explain their results. Students should determine that such compounds will be composed of molecules with large interacting surfaces, allowing VDW attractive forces to be significant enough to resist disruption by heat.



7. Student answers to embedded multiple choice questions and essay questions, as well as their annotated snapshots, are automatically collected in a Final Report and recorded in a form that can be saved on the server as an HTML file or printed. Students use callouts in the snapshots to point to specific areas of the model to describe their observations. Collections of annotated snapshots representing different stages of the modeling activity can be saved. Teachers can use these reports to assess student understanding.

Universal Design for Learning
Related Research and Implementations

In developing the designs for the UDL science exemplars, we began with UDL principles, matched these against the research literature, and carefully examined the one UDL product, *Thinking Reader*. The following summarizes the findings that led to our design.

Universal Design for Learning Literature

Universal Design for Learning (UDL) draws upon principles of universal design that are now widely accepted in architectural and product design, and applies these design principles to the needs of teaching and learning[3]. UDL promises to result in materials and activities

> *that allow learning goals to be attainable by individuals with wide differences in their abilities… Universal Design for Learning is achieved by means of flexible curricular materials and activities that provide alternatives for students with differing abilities. These alternatives are built into the instructional design and operating systems of educational materials—they are not added on after-the-fact (Burgstahler, 2002).*

Curb cuts and ramps make buildings accessible to people in wheelchairs, but also help others with luggage, bikes, and rollerblades. In the same way, it is possible that UDL designed for special students will help all. As the Center for Applied Special Technology (CAST) notes, "the future is in the margins."

> *… a curriculum should include alternatives to make it accessible and appropriate for individuals with different backgrounds, learning styles, abilities, and disabilities in widely varied learning contexts. The "universal"…reflects an awareness of the unique nature of each learner and the need to accommodate differences, creating learning experiences that suit the learner and maximize his or her ability to progress*[4.]

The only practical way to provide the flexibility required by UDL is to use computer-based materials (Buelow, 2003; Tinker, 2001a). Software can present the same ideas using different media, it can adjust to different learning styles, it can control stimulus level and screen complexity, it can provide different kinds of assistance, and it can continually access students.

As a result of an extensive review of the literature by the National Center on Accessing the General Curriculum CAST (Rose & Meyer, 2002) developed the following framework for universal design:

> *Drawing from brain research and using new media, the UDL framework proposes that educators strive for three kinds of flexibility:*
>
> > *To represent information in multiple formats and media*
> > *To provide multiple pathways for students' action and expression*
> > *To provide multiple ways to engage students' interest and motivation*

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[3] See, for instance, http://www.cec.sped.org/osep/udesign.html

[4] See http://cast.org/udl/index.cfm?i=7

Rose and Meyer also stress that a fourth kind of flexibility is needed in assessment, because it is neither accurate nor rational to rely on traditional tests when UDL is used for instruction. Computer technology makes it possible to embed assessment in learning activities and track student progress, so the assessment can use the same technology as instruction. Flexible, accessible assessment should be a central design feature of UDL.

RELEVANT COGNITIVE RESEARCH

The literatures of cognitive load theory and media give perspectives that help instructional designers facing the challenge of converting UDL principles into student materials. In the following, design recommendations have been organized around the three kinds of flexibility recommended by Rose and Meyer: representation, action and expression, and motivation.

Customizing Representations

Control of input parameters, including rate and timing of feedback (e.g., Schwan & Riempp, 2004; Tschirgi, 1980), helps students perceive incoming information and to isolate the effect of each variable, thereby enabling them to identify rules (Klahr, Fay, & Dunbar, 1993).

Control of design features. Because complex models often require screens that contain multiple displays, their color, intensity, and visual design impact learning. Even allowing students to select color has been shown to positively affect learning (Freedman, 1989; Longo, 2001).

Dual modes of input. The simultaneous use of both auditory and visual inputs appears to reduce the load on working memory, as the channels are independent, and may provide their own preliminary integration of information. Having the computer speak text significantly improved some students' performance (Rose & Meyer, 2000, 2002). Studies have also found that audio narrative added substantially to learning when delivered close to pictures, but long audios that students are unable to "skim" are less helpful (Mayer & Anderson, 1992; Mayer & Moreno, 1998; Mayer & Moreno, 2003; Tindall-Ford, Chandler, & Sweller, 1997).

Proximity. Mayer and colleagues (Mayer, 1991, 2003; Mayer & Anderson, 1992; Mayer, Bove, Bryman, Mars, & Tapangco, 1996) note that it is important that words and pictures be placed closely together (though not always simultaneously) – a "spatial contiguity effect." Care needs to be taken not to overload users (Ainsworth, Bibby, & Wood, 1998; Ainsworth & Van Labeke, 2004; Mayer & Moreno, 2003; Tabbers, Martens, & van Merrienboer, 2000).

Arrangement of learning objects. Graphs, tables, formulae, and text are all critical to learning of science, and in many situations, simultaneous representations are necessary. Students need to use them in an array of varying degrees of complexity (Kozma & Russell, 2005), or serially.

Simplification. Field dependent students may be more successful with simpler arrays of elements. Lowe (2004) notes that students expend significant energy limiting aspects of animations to which they attend. Technology offers users a way to control the level of complexity in the learning environment by allowing users to remove extraneous or redundant material (Mayer & Moreno, 2003; Palmquist & Kim, 2000).

Activity and Expression: Multiple Pathways

Students need assistance from their learning environment so they can learn and problem-solve more effectively. This includes assistance in encoding and retrieving schemas in memory and help with problem solving and reasoning (Rose & Meyer, 2002).

Interactivity. In general, students learn better where there is more interactivity (Mayer & Chandler, 2001). Interactivity that provides rapid and meaningful feedback can decrease cognitive load and increase the rate and accuracy of schema acquisition.

Overview/concept maps or drawings are useful for "wholists," wheras "serialists," may need aids for description and procedure building (Ford, 1994).

Support: Hints and worked examples. Researchers found that partially or fully worked examples were not only better than conventional teaching strategies, but sometimes superior to discovery/inquiry strategies (e.g., Paas & van Merrienboer, 1994b; Sweller & Cooper, 1985).

Multiple forms of expression. In the UDL literature, multiple forms of expression (e.g., writing, drawing/animating, speaking) are consistently recommended (Rose & Meyer, 2000).

Motivation: Personalization and Discussion

Personalizing the Interactions. Students learn better when they are more engaged. Strategies for engagement include not only interactivity but also personalization. Learning improves when words, whether spoken or in text, are presented in informal rather than formal style – a "personalization effect" (Mayer & Moreno, 2003).

Discussion. When studying student learning with system dynamics, Spector and Davidsen (2000) found that most learning appears to happen in the small group discussions between model usage and not in the direct interactions with the simulation model. Here social motivation may pair with the power of audition in learning.

THINKING READER

Thinking Reader is an innovative, research-validated (Freed, Rothberg, & Wlodkowski, 2003) program that systematically builds reading comprehension skills for middle school students who are reading below grade level. The program presents core, authentic literature in a highly motivating and supportive environment. It embeds prompts, hints, model answers, and instant feedback into the text to provide individualized instruction. Students practice and master seven reading comprehension strategies while they read.

Thinking Reader features a flexible text display and text-to-speech reader. Text size, color, and background color can be selected. Words, phrases, or sentences can be read on demand, or the entire text read using different voices. There is a glossary that optionally provides Spanish definitions. Embedded assessments ask students to think about different reading strategies. To answer the questions, teachers can select one of five levels of coaching delivered by avatars with different personalities. At the simplest level, a sample answer is provided. At the next level, students must select the best of several answers. Another coaching strategy is to highlight parts of the text that are relevant to the question.

Student performance is monitored and summarized in a variety of interactive reports to teachers. The top-level report shows graphically what steps each student has completed. Teachers can drill down into these steps and see student work and send students reactions. The same top-level view allows teachers to set the coaching strategy.

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