LOGGING OPPORTUNITIES IN ONLINE PROGRAMS FOR SCIENCE (LOOPS): STUDENT AND TEACHER LEARNING

A DRK12 Proposal to the
National Science Foundation
to the DRK12 Program
From The Concord Consortium, with
The University of California, Berkeley
The University of Toronto
North Carolina Central College
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LOGGING OPPORTUNITIES IN ONLINE PROGRAMS FOR SCIENCE (LOOPS): STUDENT AND TEACHER LEARNING

SUMMARY

This proposal for a large-scale project is submitted to the DR-K12 category B, "Development of Resources and Tools" sub-category 2, "Instruction of K-12 Students and Teachers." LOOPS is a national program that uses the cyberinfrastructure to provide innovative resources that support inquiry in the middle school science classroom. The project makes innovative use of technology to create timely, valid, and actionable reports to teachers by analyzing assessments and logs of student actions generated in the course of using online curriculum materials. The reports allow teachers to make data-based decisions about alternative teaching strategies. The technology will support student collaborations and the assignment of different learning activities to groups, an essential function needed for universal design for learning (UDL). Project research is designed to quantify both student and teacher learning as a result of using the system.

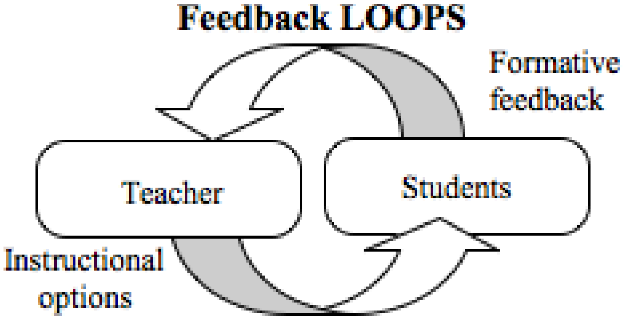
Intellectual Merit. LOOPS addresses the Grand Challenges by incorporating cutting-edge tools and models and by improving student assessment through sophisticated logging technology. The project also meets other DR-K12 priorities by incorporating UDL strategies and making extensive use of the cyberinfrastructure. Today's classroom computers can execute sophisticated simulations of complex systems such as computational dynamics and climate models. Similarly, real-time data acquisition and analysis from dozens of kinds of probes with excellent ranges and accuracies is now within reach of any classroom with commercial computers and probeware. These models and tools can greatly extend the range and depth of inquiry-based learning at early grades through real and simulated environments. The central challenge to wider use of these resources is that students often lack the inquiry skills to experiment meaningfully and to interpret the results, and that teachers need special talents to impart those skills. The proposed materials address these challenges by giving teachers innovative assessments and new options.

The project is a collaborative partnership that involves physical scientists, learning scientists, educators, and TELS, an established NSF-funded Center for Teaching and Learning. The proposed researchers have a 25-year history of collaboration that has produced influential and respected research in science education. The project is based on an extensive body of research and development in educational technology and represents a significant and innovative advance.

Broader Impacts. Guided student inquiry with models and tools is likely to be the greatest contribution of technology to STEM education. It is particularly challenging to provide this promising approach in schools serving low-income communities, where there is great diversity in the student body, limited resources, intermittent technology, and an itinerant faculty. Accurate, timely reports on student progress help teachers track every student and are particularly important for under-performing students who might otherwise be overlooked. The boost that technology promises to STEM education cannot be ignored in these schools because their students are most in need of quality education that can create new opportunities. And we must be prepared for the near future when computers will cost under $100 and every child can have one. For these reasons, we develop our most promising educational technologies in these environments and conduct our research there to ensure that our approaches can work in all schools. Our dissemination and commercialization strategies will ensure that all schools will have access to project products.

PROJECT DESCRIPTION

GOALS AND OBJECTIVES



The Importance of Inquiry-Based Learning. A central finding of 25 years of research on educational technology is that students can learn important concepts earlier and more deeply through guided interaction with computer-based models and tools, particularly in STEM fields (see, e.g. Linn & Eylon, 2006; Taylor, 1980). A distinguishing feature of this approach is its reliance upon student inquiry: students actively explore with tools and models by trying different parameters, arrangements, and initial conditions, and then run experiments to see the results of their selections (Krajcik, Marx, Blumenfeld, Soloway, & Fishman, 2000; NRC, 2000; Slotta, 2004; Tinker, 2003, 2004). Students can learn by manipulating variables, particularly if they explore systematically (Klahr & Nigam, 2004). Unfortunately, effective use of inquiry learning is far too rare in American classrooms (Becker, 1999; O'Sullivan et al., 2003; Schmidt, et al., 1997).

The Project Goal. Formative evaluation of teaching and student learning offers an untapped potential for improving teacher practice and student outcomes (Black and Wiliam, 1999). In a busy classroom using computer-based materials it is hard for a teacher to distinguish between a student who is learning intently by exploring a model or experiment and one who is just going through the motions or is confused. Outwardly, these two students look similar, but one needs attention. As materials get more sophisticated, it is increasingly difficult for teachers to play an active role in planning their delivery and enacting it in the classroom. *LOOPS will address this challenge by providing teachers with timely formative feedback that provides insights into student learning and gives teachers instructional options that are data-driven.*

Project Objectives. The project will put teachers squarely in feedback LOOPS based on a variety of data streams that inform their choices of assessments, actions, and curriculum customizations. These feedback loops will be classroom-tested with materials focused on eighth grade physical science standards. The principles derived from this research will inform design of new materials and supporting technologies. These will be general and portable, so that our approach will have immediate connections with other STEM resources. Specifically, LOOPS will:

Develop LOOPS technology. This project will develop software that unobtrusively monitors student choices and actions while they are engaged in inquiry using probes and models. These data, plus data from student assessments, teacher goals, and science standards, will be summarized for teachers to give them a detailed picture of student progress. Teachers will use these data to inform instructional decisions.

Integrate technology with existing materials. LOOPS will develop two curriculum units that are integrated with this technology: Force and Motion and Chemical Reactions. These will match the 8th grade California content and inquiry standards, representing about 50% of the science required for that year. To develop materials, LOOPS will substantially re-configure classroom-tested activities from prior NSF-funded projects.

Study inquiry learning. The project will work closely with three teacher-developers from low-income districts who will test the approach in 15 classes during the first three years.

Project research will expand to include at least 14 additional teachers and 1,500 students including low-income districts supported by North Carolina Central University by year five. We will also study teachers who spontaneously adopt the materials, available online. Project research will characterize the information teachers want, how teachers use information provided in four distinct time frames, the kinds of data-driven changes they make, and the impact of the changes on students' knowledge integration and inquiry skills.

Develop professional development strategies. The project will study teacher trajectories using LOOPS technology, starting with the three teacher-developers. We will assess beliefs, knowledge required for effective enactments, and changing practices over two to four years of using LOOPS. These findings will shape the design of teacher workshops and online mentoring that will be used and tested in the expansion stages.

Disseminate the materials and approach. To stimulate implementation and further research and development, the materials and teacher resources needed to implement the project will be available electronically. The software will be open source and the learning materials released under the Creative Commons license. Reports, articles, and presentations will reach all relevant educators. Business experts will participate in the project to help ensure commercialization potential that could lead to wide distribution.

This project has ambitious goals that can be accomplished because we have chosen a realistic scope and build on successful prior work. As described under Prior NSF Support, the partners are the Concord Consortium, Marcia Linn's team at the University of California, Berkeley, Jim Slotta's team at the University of Toronto, and North Carolina Central University. In the Technology Enhanced Learning in Science (TELS) center, we have created an extensive base of research, technology, curricula, and community support that will ensure the success of this project.

RATIONALE

Intellectual Merit. LOOPS addresses the Grand Challenges by incorporating cutting-edge tools and models and by improving student assessment through sophisticated logging technology. The project also meets other DR-K12 priorities by incorporating UDL strategies and making extensive use of the cyberinfrastructure. Today's classroom computers can execute sophisticated simulations of complex systems such as computational dynamics and climate models. Similarly, real-time data acquisition and analysis from dozens of kinds of probes with excellent ranges and accuracies is now within reach of any classroom with commercial computers and probeware. These models and tools can greatly extend the range and depth of inquiry-based learning at early grades through real and simulated environments. The central challenge to wider use of these resources is that students often lack the inquiry skills to experiment meaningfully and to interpret the results, and that teachers need special talents to impart those skills. The proposed materials hone in on these challenges by providing innovative assessments that will allow all teachers to assess student inquiry skills accurately and unobtrusively and to take considered, effective data-driven actions that are shown by research to increase inquiry-based learning.

The project is a collaborative partnership that involves natural scientists, learning scientists, educators, and TELS, an established NSF-funded Center for Teaching and Learning. The proposed researchers have a 25-year history of collaboration that has produced influential and respected research in science education. The proposed project is based on an extensive body of research and development in educational technology and represents a significant and innovative advance.

Broader Impacts. Guided student inquiry with models and tools is likely to be the greatest contribution of technology to STEM education. It is particularly challenging to provide this promising approach in schools serving low-income communities, where there is great diversity in the student body, limited resources, intermittent technology, and an itinerant faculty. Accurate, timely reports on student progress help teachers track and respond to every student. These are particularly important for under-performing students who might otherwise be overlooked. The boost technology promises to STEM education cannot be ignored in these schools, because their students are most in need of quality education that can create new opportunities. This project anticipates the near future when computers will cost under $100 and every child can have one. We develop our most promising educational technologies in partnership with several teachers and conduct our research there, with dissemination and commercialization strategies to ensure that all schools have access to the products of our work.

RESULTS FROM PRIOR NSF SUPPORT

LOOPS will draw on several prior NSF-funded projects, including:

The Computer as Learning Partner (CLP) researchers (Clark & Linn, 2003; Lewis, 1996; Linn & Hsi, 2000) followed 8th grade students for five years to assess the impact of intensive thermodynamics instruction on performance in high school. This research revealed that students hold a repertoire of ideas that are often contradictory, that the ideas become progressively more cohesive during the 12 weeks of instruction, and that the 8th grade experience improves students' performance in high school physics. The findings from these longitudinal studies have been summarized in design principles and design patterns (Linn & Hsi, 2000; Linn & Eylon, 2006, (Kali, 2006)) that will guide the design of the LOOPS curriculum materials.

The Web Based Inquiry Science Environment (WISE) projects, under the direction of Marcia Linn and Jim Slotta at UC Berkeley, developed and tested web-based science materials designed using a Knowledge Integration (KI) framework (Linn & Eylon, 2006; Slotta & Linn, 2000) to ensure in-depth student learning. This framework emphasized the central importance of engaging learners in guided inquiry through a broad range of experiences, which provide ample opportunities for students to integrate their observations and link them with prior knowledge through various forms of reflection and communication provided by a mix of technology and teacher interventions. WISE research demonstrated that well-planned, in-depth science teaching with technology enhanced projects created more knowledgeable students who were better equipped for life-long learning.

The Modeling Across the Curriculum (MAC) project directed by Paul Horwitz at CC developed two multiple-week modeling activities for each year of the usual three-year high school science sequence in order to develop general modeling skill development. The project automatically logged actions from over 10,000 students as they explored models. Synthesizing these logs gave indicators of the systematicity of student exploration. The project reports that students' systematic use of models was correlated with content learning as measured by pre-to-post-test gains (Buckley & Gobert, 2005; Horwitz & Gobert, 2007; Horwitz, Gobert, & Buckley, 2006).

The Molecular Workbench (MW) projects at CC under the direction of Bob Tinker and colleagues developed a sophisticated molecular dynamics modeling package that calculates the motion of atoms and molecules based on the actual forces and interactions at this scale. The usual molecular dynamics approach has been extended to include chemical bonding, light-matter interactions, and bio-molecules. The package also includes a powerful and intuitive activity authoring capacity. As a consequence, a very large number of phenomena can be simulated and have been integrated into hundreds of instructional activities for middle school, high school, and college.

The Technology Enhanced Elementary and Middle School Science (TEEMSS) project under the direction of Bob Tinker at CC has developed and tested 15 activities that use probes. The project has focused on reducing costs by using any probeware system and computer and fostering do-it-yourself approaches. Extensive classroom-based research has documented student learning and shown some TEEMSS activities are superior to prior instructional approaches.

UDL Science, a current CC project under the direction of Bob Tinker, is implementing the principles of Universal Design for Learning in middle school science. It is creating seven two-week activities and developing technology for giving teachers a convenient display of student progress and controls that can customize the student learning experience.

In response to the NSF requirement to describe one project in detail, we have selected the Technology Enhanced Learning of Science (TELS) Center because it is most closely related to the proposed research. TELS, a Center for Teaching and Learning, is a collaboration among the LOOPS PIs under the direction of Marcia Linn, that includes six other universities including North Carolina Central University, and seven school districts (ESI-0334199, 2003-2008, $10M).

The goal of TELS is to increase the numbers of teachers whose students are learning crucial science concepts by using proven, technology-enhanced secondary science curricula and to train the next generation of leaders. The project interweaves educational research, graduate training, and teacher professional development focused on research with online TELS instructional materials that address difficult concepts in middle and high school science.

After three years, TELS has already reached more than 10,000 diverse students, 150 teachers, and their principals. Using the KI framework, TELS researchers created 12 replacement modules each requiring about one week of class time. Assessments were designed to measure knowledge integration about the module topics. TELS devised a module review process that takes advantage of expertise in the discipline, assessment, classroom practice, standards, design principles, design patterns, and technology that will inform the LOOPS design process (Linn & Holmes, 2006).

There has been extensive research that has demonstrated the effectiveness of TELS materials. In one study, two large time-delayed cohorts of students were tested in schools that serve English language learners, students underrepresented in science, and students receiving free or reduced price lunches. Using a KI rubric to evaluate constructed response items, TELS resulted in over a quarter of a standard deviation improvement compared to the control group (effect size: .32, $p<.001$). Multiple-choice questions were not able to detect this gain, demonstrating the value of constructed responses scored with a KI rubric (Linn, Lee, Tinker, Husic, & Chiu, 2006).

ANTICIPATED PRODUCTS

A Technology-Based Physical Science Curriculum

The Computer Centric Classroom. As networked computer costs drop inevitably to the range of Negroponte's $150 XO computer, they will eventually become ubiquitous in education, even in low-income settings. Before this happens, it is important to have researched the best possible designs for educational materials. STEM education is moving from the occasional use of stand-alone computer models and tools to complete computer-based learning activities in which models and tools are embedded. Thus, under a teacher's control, a software platform presents and sequences the instructional materials, providing scaffolding, alternative treatments, background concepts, plus a variety of tools, communication, and assessment. Even activities that require lab experiments can be included through the use of probes that collect real-time data. Lessons that do not involve the computer can be scheduled, reported, and assessed through the computer. This technological convergence of educational resources creates an untapped opportunity for providing timely formative data to teachers about where their students are and how they are thinking about the materials.

Teachers need accurate formative data so they can adapt instruction to the progress and needs of their students. Having instructional resources coordinated by computers should not mean that teachers give up control over those resources. Just the opposite should happen: technology should give teachers increased flexibility to select resources, instructional strategies, and assessments for students in any grouping—individually, by group, or for entire classes. To begin to do this, teachers need formative data.

Student Progress Reporting. LOOPS will start with the obvious data on student progress—what activity or task each student is currently working on or has completed, any reports, responses to in-line questions, and scores on various explicit assessments. These are important and necessary, but the major innovation of LOOPS will be data on student inquiry skills obtained by monitoring how students learn from their explorations of models and tools. This is of particular importance to STEM education because of the central role of inquiry-based learning.

The WISE, TELS, and MAC projects have been collecting data on student actions for years for research, but in a volume and detail that would overwhelm teachers and in a format that only dedicated researchers tolerate. Based on what we have learned in our research, we can now confidently extract in real time a few key indicators of inquiry skills and present them in a format that teachers can use.

For instance, Kevin McElhaney has been collecting data on how students use one of the models in the TELS Airbags activity to investigate the factors that contribute to the driver's risk for injury from an airbag and the implications of these factors for designing safe airbags (McElhaney, 2006). To accomplish one task, students adjust three parameters and then run the model, repeating this several times. Part of the task requires reading a graph of position as a function of time; the central goal of this activity. McElhaney developed four measures of student experimental skill: the number of trials performed, the number of distinct values tested, the range of values tested, and the number of boundary values tested. The four measures were highly correlated, justifying using a single index of experimental skill, the average of all four scales. The large variation observed in this index suggests that many students lack the knowledge required to learn through inquiry.

Horwitz and colleagues have automatically logged large numbers of students (N=1027) as they investigate a model that requires adjusting two values—the masses of two colliding spherical objects. One goal was imposed—"Make the 'object ball' go as fast as possible after the collision."—and a question was asked—"Can you make the cue ball bounce off the object ball with the same velocity it had before the collision?" In each case, students' manipulations of the model were monitored for number of tries, percentage of tries that got closer to the goal, and percentage of tries in which only one mass was varied. A combined index based on these variables was predictive of learning outcomes as measured by question-and-answer tests, even when controlled for initial knowledge. This indicates that better inquiry skills can lead to increased learning.

McElhaney developed his index by manually examining student logs. In MAC, the index was generated automatically, but long after the enactment, using software that was scripted to extract the required data. LOOPS will generate the index dynamically during and immediately after students use an inquiry activity so that teachers are able to use it to alter instruction.

Inquiry Teaching Resources. LOOPS will generate data and provide options for acting on these data that are appropriate for four different time frames:

1. **Planning.** The LOOPS planning environment will help teachers establish a plan by reviewing the curriculum units, the state and national standards, pre-test items and annual assessment data from their students, as well as the aggregated results from all the classes using the units (Driver, et al., 1996; Hart et al., 2000; Hiebert & Carpenter, 1992; Linn, Eylon, & Davis, 2004; Puntambekar, Stylianou, & Goldstein, 2007; Schauble et al., 1995). Teachers will establish a sequence of activities for the school year, make predictions about student progress, and plan when and how to use the LOOPS diagnostic technologies to test their predictions.
2. **Enactment**. Teaching for inquiry with technology requires new skills from teachers (Borko & Putnam, 1996; Sandoval & Daniszewski, 2004; Schneider, Krajcik & Blumenfeld, 2005; Slotta, 2004). During classroom enactment of each lesson (i.e., while teachers are actually teaching), LOOPS teachers can access information that makes the task easier and scaffolds their practice. They can monitor student progress using a snapshot of the activities each group has completed, interrupt small group work for a whole class activity and receive suggestions about what action is likely to be most helpful, or review student responses to an activity (generated from logged data).
3. **Daily reflection**. While a unit is being taught, teachers can use personalized progress reports and adjust their plans for specific students or groups, consistent with recommendations to design educative materials (Ball and Cohen, 1996; Blumenfeld et al., 2000; Davis, 2006b; Fishman et al., 2004; Schneider et al., 2005). UDL settings can be altered to change aspects of the appearance and modality of the material for specific students. And, teachers can make notes to use when they customize the curriculum.
4. **Grading and customizing.** Post instruction teachers can use final student performance data, pre-test and post-test results, and logged data to assign grades. Teachers can also use these data to identify instructional strengths and weaknesses and suggest data-driven customizations.

The Curriculum. The two units will address the California standards motion, force, chemistry, and inquiry, representing about 50% of the content required for grade eight physical science. Because these standards are higher than most, it will be relatively easy to customize the materials for use in other states. Each week will introduce an interesting topic and a larger theme will unite each six-week unit. The Force and Motion unit will use the "hang time" of a basketball player for the larger theme. This motivates the study of one- and two-dimensional kinematics and forces. Using a simple video analysis tool, students will be able to measure and analyze free-fall motions that they record or are supplied by the curriculum. A final week provides support for independent student projects.

The Chemical and Biological Changes unit will use a candle flame as a unifying topic to motivate the study of chemical nomenclature, reactions, and light-matter interactions. This provides background for a week on the candle. The idea of combustion is applied to biology, specifically the molecular mechanism of muscle contraction. Again, the unit will finish with a guided project. A detailed synopsis of the proposed curriculum and the materials that it will use can be found in the Supplementary Material.

The project will use a participatory design process to create two six-week units for eighth grade physical science. The materials will draw on classroom-tested materials as described in Prior Support. The resulting sequence will use the KI design principles to integrate lessons, compelling, personally relevant contexts, visualizations and probeware-based experiments, and powerful embedded assessments. Some important elements of UDL design will be incorporated, but there are insufficient resources to make the materials completely universal.

LOOPS Technology

The project will produce general tools and techniques that can be applied to most well-designed software. The goal of LOOPS technology is to provide teachers with data they can use to better understand their classroom and a set of tools that allows teachers to take effective actions based on the data. More detail on how LOOPS technology will generate the data and what technical options will be provided is provided in the Supplementary Material section.

Several new technologies will be developed to support design of the resources and reports:

Logging and the Inquiry Index. LOOPS activities will automatically log all student actions and provide data dynamically based on automatic analysis of these logs. One form of analysis will generate numerical scores based on student interactions with models and probes by detecting actions such as the number of runs, control of variables, and repeats. Author-generated weighting factors will determine how these scores are folded into a single inquiry index.

The Student Progress Tool will include continuously updated data on each student's progress so a teacher can tell at a glance on a matrix where each student, student group, or class stands. This will include the inquiry index, along with other dynamically generated indicators. The matrix will allow teachers to drill down to see individual and group work and to link student performance to instructional goals, curriculum steps, inquiry patterns, and effort.

The Lesson Planning Tool will allow TELS projects/activities, assessments, and other resources to be matched to the calendar so that the right activity will be delivered to students at the right time. The lesson plans will be easy to edit, but if teachers do make changes, they will be encouraged to supply reasons for their changes

The Collaboration Tool will support the easy formation of groups and easy re-grouping of students during an activity, as well as the possibility of dynamic grouping of students during activities. It will also support sharing and collaborative development of files, models, and other artifacts.

The Teacher Dashboard Tool will enable teachers to interact dynamically with the class. Teachers will be able to freeze all student computers, poll students, accept multimedia artifacts, and offer feedback dynamically during class.

Professional Development Resources

LOOPS will create professional development resources that can be used by teachers or teacher professional developers. The workshop schedules, background readings, assessments, and plans developed for LOOPS professional development will all be available online. LOOPS technologies are designed to be cumulative. As more teachers use the planning and customization tools, additional alternative lessons and activities will be added, along with reflections and justifications. This growing body of resources will be available online for use by professional developers.

In general, teachers tend to participate in professional development activities at times that are isolated from curriculum implementation. To address this disconnect in timing, LOOPS will present two types of professional development for teachers. One will prepare teachers at a summer workshop for the implementation of LOOPS units, and the other will guide them during unit implementation in the classroom. In-class guidance will take place during the run of a unit and will be in the form of embedded online classroom resources geared to help teachers use inquiry activities. By using these tools during class, from day to day, and unit to unit, teachers will strengthen their pedagogical content knowledge and teach science more efficiently and effectively.

RESEARCH PLAN

LOOPS research will address four main issues: how teachers used LOOPS resources, what impact the material had on student learning, whether the LOOPS data and options improved learning, and how effective the materials design process is. These are addressed briefly below. The research rationale is provided in the Supplementary Materials. In order to support the research, the project will test the materials with three California teacher-developers in Stages II and III of the project. The number of participating teachers will be expanded to six in California and seven in North Carolina in Stage IV. Finally, seven more teachers will be added in Stage V. In these last two stages, LOOPS will recruit additional test sites through the project website. These spontaneous users will be included in the research. The stages are detailed in the Work Plan section that follows.

Question 1: How do teachers use LOOPS resources?

What resources help teachers plan, enact, reflect on, grade, and customize technology-enhanced inquiry activities and their practice more broadly? What is the trajectory of teacher learning using LOOPS? How do ideas about formative feedback change? Do teachers:

- Change how they prepare for and implement inquiry teaching (time allocated to planning, use of evidence from student work, classroom practices)?
- Develop expertise in planning and using time efficiently (sequencing activities, making day-to-day modifications based on student progress)?
- Improve ability to diagnosis student progress (predicting student responses, selecting diagnostic items, interpreting student progress)?
- Develop understanding of the science discipline and inquiry teaching (tailor classroom practices to inquiry, interpret progress reports, guide use of visualizations and probeware, design effective whole class activities)?
- Develop ability to monitor their own practice (diagnose problems, select professional development opportunities, capture reflections that inform customization of instruction)?

- Take advantage of suggestions from teachers, researchers (in daily planning, customization)?
- Incorporate new inquiry practices into teaching without technology?

LOOPS resources are designed to help teachers develop pedagogical content knowledge (Shulman, 1986, 1987; Sherin, 2002; Van Driel, Verloop,& de Vos, 1998). Wewill study the ability to *assess student progress* (develop skill in using formative evaluation data, diagnosing student difficulties, and recognizing obstacles to understanding), *plan a coherent curriculum*, (understand the science discipline, science standards, and connections across topics), *support inquiry learning* (orchestrate collaborative activities, interrupt class to add benefits such as pivotal cases or connections across topics, prompt students to develop independent learning skills), and *customize instruction* (identify curricular weaknesses, modify personal practices, suggest changes to the curriculum).

To investigate this question we will design classroom observations (during inquiry teaching with and without technology), create a survey of Teacher Practice Indicators that addresses the questions identified above, and synthesize feedback collected as teachers use the LOOPS resources (class pacing, use of resources during enactment, frequency and use of resources outside of enactment, customization of progress reports, etc.).

We will establish a baseline and follow the first three teachers for four years. We will augment the observations, survey, and automatically logged data with regular interviews of teachers using the LOOPS resources during Stages I-IV. We will work with the teachers to find an appropriate balance between the breadth of information available in LOOPS and the multiple demands on teacher time. These teachers will review their use of LOOPS resources at the summer workshop and help improve the resources for the next year. In Stage III we will revise the Teacher Practice Indicators, classroom observation format, and automatically collected information about teacher practice and use them to study the trajectories of the 18 or more teachers who use revised LOOPS resources in Stages IV-VI.

The Teacher Practice Indicators and observations will provide much needed insight into teacher beliefs and practices around inquiry teaching. They will inform the design of the LOOPS teacher professional development program.

To investigate the impact of LOOPS, we will compare trajectories of the three teachers who work with LOOPS starting in Stage II and the teachers who participate in Stages III-V, comparing teachers using the LOOPS resources to those only using the curriculum in Stages IV-V.

Question 2: What is the impact of the LOOPS curriculum on student learning?

Do students studying the LOOPS curriculum outperform the benchmark cohort who studied the typical materials? How does the feedback from real-time logging technologies strengthen the impact of visualization and experimentation using probes in LOOPS units? How can semi-automated feedback be designed?

To investigate this question we will design *assessments* and rubrics that validly measure progress in knowledge integration (Linn, Lee, et al., 2006) for the LOOPS topics. Starting with tested items from the TELS assessments (about 30 items are aligned with the LOOPS goals) that meet the standards of an IRT scale, we will add and validate items suited to measuring progress from LOOPS materials.

Our previous research shows that the *Knowledge Integration scoring rubric*, compared to coding schemes TIMSS used (correct vs. incorrect or correct vs. partial vs. incorrect), provides a more precise and sensitive measure for the development of students' ideas in science (Linn et al, 2006; Liu et al., 2006). The knowledge integration rubric clarifies the steps between a complete lack of knowledge (incorrect responses) and linked, coherent understanding of complex scientific concepts with credit for partial links among ideas.

We will create annual assessments to track student progress in participating schools (N=1000 students in Stages I-III, N=2500 in Stages IV-V). We will use tested items to anchor the results, and eliminate items that lack sensitivity or validity. We will establish a baseline by administering the annual assessment to students who studied the traditional curriculum taught by the participating teacher. In subsequent years we will administer the same assessments to students who studied LOOPS. Our assessments will allow us to determine impact of the instruction by week.

We will build embedded assessments and assessments deduced from logged data for use in progress reports and feedback to students during instruction. These indicators will be augmented with classroom observations, analysis of videotaped interactions among individual students, and post-instruction analysis of logged data.

To assess the impact of visualization and experimentation using probes and to design feedback to students and progress reports for teachers, we will combine pre-tests/post-tests, embedded assessments, observations, and interviews. We will use the observations and interviews to determine how to use logged data plus embedded assessments to gather valid information about student work. We will use this information to assess effective use of visualization and experimentation and to provide informative feedback to students and teachers.

These assessments will allow us to:

Compare annual assessment results for students using the traditional curriculum in Stage I to and those using LOOPS in Stage III.

Compare pre-test/post-test gains for the initial and revised versions of the LOOPS curriculum to determine gains in efficiency and effectiveness.

Explore the validity of the automated assessments that use logged student data compared to pre-test/post-test results, embedded notes, interviews, and observations. This research will allow us to establish principles for design of automated assessments and add them to the design principles database (Kali, 2006).

Compare students using the LOOPS resources to those only using the curriculum in Stage IV-V.

Question 3. How does the LOOPS professional development contribute to the impact of the LOOPS curriculum?

How do professional development workshops for planning and customization, LOOPS online resources for enactment and reflection, and online or face-to-face mentoring impact teacher learning? We will compare teachers working in schools with LOOPS developers (first three teachers in CA), teachers using LOOPS in schools where there are established users (subsequent CA teachers), teachers using LOOPS in new schools in NC, and teachers using only the LOOPS curriculum in new schools in NC. We will perfect in-class guidance in CA classrooms and design online versions for NC. The LOOPS resources will provide teachers with information about students' work and progress, guide teachers in next steps to remedy or enhance students' learning, and scaffold teachers in inquiry skills.

We will design professional development workshops that occur prior to and following enactment of the LOOPS curriculum for the 20-plus teachers who use the materials in Stages III-V. To test the effectiveness of these workshops we will study use of the LOOPS resources (effectiveness of plans, customizations, use of resources during enactment, between lessons), progress on the Teacher Practice Indicators, and student pre-test/post-test gains.

Since the LOOPS resources provide extensive guidance they may interfere with established inquiry teaching practices. To assess the value of the automated and online resources, we will randomly select a group of teachers from the NC site who use the LOOPS curriculum but get professional development without automated resources. We will compare performance of teachers and students in the two groups.

We will study how mentors support teachers in Stage III and devise methods for supporting teachers at a distance. We will study how mentors can help teachers at a distance and how mentors can support spontaneous users who choose to use the LOOPS resources?

Question 4: How effective is the LOOPS design process?

What refinements of the LOOPS resources were necessary, important for efficiency, and helpful for effectiveness of the curriculum? How can we capture effective design practices?

Research activities

To research our own practice in design we will document the design process and select a few topics for in-depth case studies. We will start by using the TELS design process (Linn & Holmes, 2006) and modify the activities based on the needs of the teachers and technology group.

The LOOPS external evaluator will contribute to this research by interviewing members of the design team and observing selected design activities.

To study the impact of our designs we will compare versions of the materials. Using the performance of students of established teachers in Stage II as a baseline, we can compare use of the curriculum and resources by new teachers in Stage III and in Stage IV.

We will capture effective aspects of the designs in design principles and record them in the design principles database. We will report on the improvements to the design process in workshops and research publications.

WORK PLAN

The LOOPS project is planned for six stages over five years starting in January 2008. These stages are summarized in a table in Supplementary Materials and detailed below.

Stage I Baseline Assessment and LOOPS Version 1.0 (Jan 2008-Aug 2008)

Student Assessment. We will create annual assessments to track student progress and administer the assessments in all participating schools (N=1000 students). Assessments will allow us to determine impact of the instruction by week.

Knowledge Integration Rubric. We will apply the Knowledge Integration rubric (Linn et al, 2006) to the annual assessments and summarize the results for the design partnerships.

Teacher Learning. To assess the trajectory of teacher learning, we will use interviews and surveys during professional development, classroom observations, and logged student data. We will establish a baseline and refine our methods. The pilot measures will be refined and used with additional teachers in Stage IV.

Design Force and Motion, Version 1.0. To create the Force and Motion unit, LOOPS will review student learning data from the baseline assessments and all the component units to identify weekly goals and assessments. A design partnership consisting of discipline experts (Tinker & Horwitz), technology experts (Slotta), classroom learning experts (teachers from three schools), assessment experts (Linn, Lee, Husic), and researchers (Linn, Slotta, postdoc, graduate student) will finalize the pilot version during the summer workshop. We will use the TELS design process (Linn & Holmes, 2006) with extensive review by all stakeholders.

LOOPS Planning and Classroom Enactment Resources Version 1.0. The design partnership will finalize functional specifications for the Planning and Classroom Enactment technologies for use in Time Frames 1 and 2, during the summer workshop. The resource designs will take advantage of the annual assessment findings that indicate the impact of the traditional curriculum in the participating schools. We will design a planner and progress reports for the Force and Motion unit.

Stage II Impact of Version 1.0 & Design of Version 2.0 (Sep 2008-Aug 2009)

Impact of Force and Motion 1.0 & Design 2.0. The Force and Motion unit will be tested in the classrooms of the three teacher-developers, 15 classes total. To assess the impact of version 1.0 on students, we will design and administer pretests and posttests using the KI rubric and variants of the items selected for the annual assessments and observe in the classroom. These results will inform version 2.0.

Design Chemical and Biological Changes Version 1.0. To create the Chemical and Biological Changes unit, LOOPS will review student learning data from the baseline assessments and all the component units to identify weekly goals. The design partnership will finalize the curriculum at the summer workshop.

Refinement Study of LOOPS Resources. To determine how teachers in the three participating schools use the existing resources and their needs for daily reflection and between offerings in Time Frames 3 and 4, we will conduct a classroom and interview study that will guide the design of the supporting technologies for use. At the end of each unit we will conduct a post interview where teachers are guided to use evidence from the unit for grading and customization. We will use this information to design the daily reflection, grading, and customization resources.

Design Daily Reflection, Grading, & Customization Resources Version 1.0. The design partnership will finalize the daily reflection and customization resources during the summer workshop and design a planner and progress reports for the Chemical and Biological Changes unit. These designs will take advantage of the refinement studies conducted during enactment of the Force and Motion curriculum.

Stage III Impact of All Resources & Full Curriculum (Sep 2009-Aug 2010)

Impact on Students. Both units (Force and Motion version 2 and Chemical and Biological Changes version 1) will be tested in the classrooms of the three teacher-developers To assess the impact of the full curriculum, LOOPS will use pretests, posttests, embedded assessments, and the annual assessments. Comparisons between the baseline annual assessment and performance after using LOOPS will allow us to determine the impact of the new curriculum overall and to measure the impact of each week of instruction.

Impact on Teachers. To assess teacher learning we will examine the trajectories of the three participating teachers on pedagogical content knowledge using progress reports, predictions, classroom observations, daily reflections, and customizations.

Design Teacher Trajectory Indicator. To measure teacher progress in pedagogical content knowledge, LOOPS will create a teacher trajectory indicator that can be used for all teachers participating in Stages IV and V.

Refine Curriculum and Resources. The design partnership will use assessment results to revise the curriculum and teacher resources. Teachers will use the Customization resource in collaboration with LOOPS mentors to improve the activities for their students and to create alternatives for new teachers. Mentors will help teachers appreciate the central elements of the units and to make productive customizations (see Li, 2006).

Summer Workshops. Design partnership will customize curriculum and prepare three new teachers in CA so that the curriculum can be enacted by six teachers with over 500 students in the fall. A second workshop will be offered at NCCU for seven new teachers from nearby schools.

Stage IV Test Curriculum & Resources in New Schools (Sep 2010-May 2011)

Teacher trajectory study. We will use the Teacher Trajectory Indicators to measure the starting point of new teachers. We will use primarily automatically scored, survey, and interview data from workshops and other meetings to track trajectories. When feasible we will collect observational data and videotapes of teacher activities.

Refine curriculum and resources. The design partnership will review assessment results from all schools as well as customization plans and use the information to revise the curriculum and teacher resources. We will include teacher commentary on customizations in the recommender system that forms a part of the customizer.

Annual Assessments in new schools. We will administer annual assessments as a baseline in the new schools in NC. We will invite volunteers using the materials to participate in the study.

Summer Workshops. In Stage IV we will conduct a workshop in CA to customize and refine professional development and in NC to prepare new teachers for LOOPS. A workshop will be offered at NCCU for seven new teachers from nearby schools, bringing the number of teachers in North Carolina to 14.

Stage V Test Comparisons Study and Spontaneous Users (Sep 2011-May 2012)

Comparison student learning study. In the three California schools each with two teachers, we will compare performance of students of the new teachers to the three teachers in the design partnership who have more experience with LOOPS resources. In North Carolina we will randomly assign teachers to the LOOPS group. We will use comparisons between annual assessments as well as pretests, posttests, and embedded assessments to capture student outcomes.

Stage VI Finalize curriculum and resources, analyze impacts (June 2012-Dec 2012)

Dissemination. We will create versions of all LOOPS resources that can be added to new online or print curricula. Materials are open source and validated by the research we conducted. We will create a syllabus for the professional development program we used.

Longitudinal results. We will analyze longitudinal and comparison studies of diverse students and teachers and report to varied audiences (policy makers, designers, teachers, researchers).

MANAGEMENT AND PERSONNEL

Dissemination

To disseminate the findings from the LOOPS project, we will address multiple audiences: researchers, curriculum designers, professional development designers, teachers, principals, and policy makers. A crucial element of our dissemination will be a website that will be used both for recruiting participants in the projects and for communicating to all of the audiences.

Because commercialization offers a powerful form of dissemination, the project will make a significant effort to interest commercial ventures in adopting the project's research-based innovations. Three members of the project advisory board have expertise in commercializing technology-based science curricula and will help us shape our designs to ensure commercial interest.

The project will make the LOOPS materials widely available through a project website. The infrastructure technology will be available as open source. Research results will be presented in reviewed papers and conferences. Progress reports will appear regularly in @Concord, a free newsletter with hard-copy circulation of 10,000.

Project Evaluation

LOOPS will be evaluated by Lud Braun who has extensive experience in educational technology. He will monitor project progress, review annual research plans, attend advisory meetings, and interview a random selection of teachers, collaborators, and students about the impact of each of the major program components. He will also collect numerical data on the impact of the project in terms of teachers, researchers, and students reached. Using these data, he will produce a report annually for the project advisors and the NSF.

Institutional Responsibilities

The Concord Consortium will be the prime awardee and take responsibility for coordinating the project and the technology. CC will contribute to the curriculum and research, but the responsibility for these will be at Berkeley. Toronto will contribute to the technology design. These teams will continue the collaboration strategies that have proven successful for TELS and previous projects: weekly teleconferences, occasional on-site visits, annual staff meetings, and annual meetings of an advisory committee.

The LOOPS project will have a coordinating team consisting of Linn, Tinker, Horwitz, and Slotta, who have all worked together on previous projects, including TELS, and have excellent communication strategies. A project advisory board of leaders in science education research will be formed. It will meet with the project annually and be asked to respond to written and face-to-face opportunities on an individual basis more frequently.

Project Leaders

LOOPS will have a coordinating team and leaders for each of the main goals. Tinker, Horwitz, Linn, Slotta, and Husic have worked together on previous projects, including the TELS Center. They have an excellent suite of communication strategies.

Robert Tinker, a physicist from the Concord Consortium, has overall responsibility for the project and will lead the curriculum goal. Tinker has collaborated with Linn since the 1980s when they researched thermodynamics instruction. Tinker has pioneered in the area of visualization and experimentation tools (Tinker, 1996; Pallant & Tinker, 2004).

Marcia Linn, at the University of California, Berkeley, and will lead the research goal. She has background in assessment (Linn, et al, 2006), student learning with technology (Linn & Hsi, 2000; Linn, Davis, Bell, 2004), and equity (Linn & Hyde, 2006).

Jim Slotta, at the University of Toronto and adjunct Professor at the University of California, Berkeley, is a cognitive scientist who led the design of WISE and SAIL He will lead the technology goal. Slotta has developed innovative, open source technologies for learning in varied contexts (Slotta, 2002, 2004; Slotta & Linn, 2000).

Paul Horwitz, a physicist from the Concord Consortium, will co-lead the technology goal. Horwitz designed ThinkerTools, Biologica, and other powerful learning environments.

Freda Husic at the University of California, Berkeley, will lead the professional development goal. She has coordinated the professional development for TELS and has developed excellent relationships with schools, teachers, and principals (Varma, Husic, Linn, 2007).

Project Advisors

We have assembled an outstanding Advisory Board that will be available to guide the project. The Board will meet once each year, reviewing project progress and the external evaluator report. Letters from Board members can be found in the Supplementary Materials.

Louis Gomez, the Aon Professor of Learning Sciences, Northwestern University.

Wayne Grant, Ph.D., vice president of PASCO and founder of ImagiWorks, Inc.,

Margaret Honey, Ph.D. Senior VP for Strategic Initiatives and Research for Wireless Generation, former Director of EDC's Center for Children and Technology

Tom Hsu, Ph.D. founder of Cambridge Physics Outlet and EduPedia.

Yael Kali, Ph.D. Senior Lecturer, Technion, Israel Institute of Technology, Haifa, Israel

Ken Koedinger, Ph.D. Professor of Computer Science, Carnegie Mellon University

Joe Krajcik, Ph.D. Professor of Education, University of Michigan.

Cathy Lewis, Ph.D. Senior Research Scientist, Mills College.

Chuck Olsen, partner in LTGO specializing in educational marketing and acquisition.

Brian Reiser, Ph.D. Professor, Learning Sciences, Northwestern University.

David Rose Ph.D. President and co-founder of CAST; member of CC Board.

Warren Washington, Ph.D. Senior scientist at NCAR and head of climate change research.

SUPPLEMENTARY MATERIALS

RESEARCH RATIONALE

Teachers and students can benefit from carefully designed guidance and feedback when learning or teaching complex science topics like chemical reactions and force and motion. LOOPS proposes to research guidance and feedback methods in collaboration with teachers, professional developers, and technology experts and to refine those that are most promising.

We will identify promising indicators of progress and communicate this online information to teacher and student participants. For example, we can log the actions of students as they use interactive models, conduct experiments with probes, or interpret data representations. LOOPS will identify ways to guide both the students and their teachers to optimize progress.

Teacher survey

In preparation for this proposal, we surveyed all the TELS teachers at the annual retreat (24 teachers from all grade levels in middle and high school science). Generally, they desire more information concerning student activities in the classroom. Specifically, they wanted diagnostic information about the progress of their students so that they could more effectively monitor progress, know when to interrupt the class to ensure that complex material is understood, and identify opportunities to encourage peer tutoring or help students who are facing special difficulties. Specific features requested by teachers included:

- A snapshot of the class showing the current progress of every student, so teachers can identify which students are racing ahead or requiring further help.
- Real-time results of embedded assessment items (e.g., reflection notes or multiple choice questions), so that teachers can identify places where large numbers of students are having difficulty, and those students who need tutoring during classroom instruction.
- Information about the frequency with which students check definitions of highlighted words or express difficulties with vocabulary. Such information can help teachers review the meaning of a word exactly when this information is linked to a meaningful context.
- The length of responses given by students to the reflection prompts in order to help them diagnose which students are constructing arguments versus asserting views.

LOOPS will work with teachers to provide such information, to determine how it is used, and whether it is effective. Additional ideas for LOOPS resources come from our prior research and still others will emerge from trials of pilot versions of LOOPS resources.

A cyberinfrastructure for formative evaluation

Formative evaluation of teaching and student learning offers an untapped potential for improving teacher practice and student outcomes (Black and Wiliam, 1998; Black, et al., 2003). Wiliam has explored the use of diagnostic questions to help teachers understand their students' ideas about complex science topics. Preliminary evidence suggests that the questions are difficult to write and the teachers find them useful.

Far too little attention is paid to evidence of effective and ineffective classroom practices and curriculum materials. Advances in cyberinfrastructure enable us to provide much more timely and detailed information to teachers for planning, classroom enactment, daily reflection, grading and personalized feedback to students. These capabilities can enrich formative feedback and contribute to teacher learning and professional development by revealing student progress within technology-enhanced environments. Analysis of logged student actions can be done by powerful technology engines to provide feedback to students and teachers alike. This information can help teachers decide how to introduce, frame, and shape the next instructional sequence. In conventional, text-based instruction, teachers often have no information concerning student progress until they give a quiz and grade it. With interactive curriculum materials delivered using the WISE environment, teachers can review student progress after each class meeting with progress reports in a variety of areas, such as developing disciplinary knowledge, understanding models, conducting experiments, and using inquiry strategies.

Analysis of student progress enables teachers to plan introductory remarks for ensuing lessons, to address the complexities that students are grappling with as well as surprising findings that deserve credit. When teachers have this detailed information about student ideas, they can tailor the pace of their course to student needs, spending additional time when students encounter difficulty and speeding up coverage of topics when students show evidence of understanding the material. LOOPS will expand this infrastructure to develop new forms of feedback and investigate its impact at various intervals for teachers and students.

Professional development research

Few professional development programs aimed at altering classroom practice and improving learning have succeeded (Little, 2004). Professional development research shows a gap between improved instructional practice and improved student learning (Ball & Cohen, 1999; Borko, 2004; Loucks-Horsley et al., 2003). Professional development that does succeed is complex, resource intensive, and ultimately unsustainable for efforts at broad systemic change (Blumenfeld et al., 2000; Fishman et al., 2004). Teacher beliefs and other context-specific variables influence the outcome of efforts to change teacher practice (Ball and Cohen, 1996; Songer et al., 2002; Schneider et al., 2005). Also, ingrained, daily, teacher curriculum preparation routines work against the adoption of introduced reform professional development (Loughran and Gunstone, 1997). Researchers introducing classroom technology have varied in their approaches (Shrader et al., 1997; Blumenfeld et al., 2000; Linn & Hsi, 2000; Fishman et al., 2001; Fishman et al., 2004; Schneider et al., 2005). TELS has pioneered a targeted professional development approach (Varma, Husic, & Linn, 2007) that requires very little initial time and empowers teachers to design their own future experiences. The LOOPS resources will strengthen this approach by offering teachers a more dynamic mechanism to seek information about the effectiveness of their instruction.

Pedagogical Content Knowledge

Teaching with technology-enhanced materials requires new teaching skills and practices (Borko & Putnam, 1996; Sandoval & Daniszewski, 2004; Schneider, Krajcik & Blumenfeld, 2005; Slotta, 2004). In general, pedagogical content knowledge about inquiry science impacts student learning (Shulman, 1986, 1987; Sherin, 2002; Van Driel, Verloop, & de Vos, 1998). More precisely, aspects of teacher practice that contribute to what we have called knowledge integration (Linn, 2006), generally impact student learning.

Shulman (1986, 1987) described pedagogical content knowledge (PCK) as knowledge of student difficulties with specific topics and knowledge of teacher remedies. Shulman called on researchers to address understanding of pedagogy as it relates to teaching within a specific domain. Shulman (1986) includes within PCK:

"…for the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the ways of representing and formulating the subject that make it comprehensible to others." (p. 9)

His description of PCK also includes an understanding of the conceptions and preconceptions of learners that might make learning within a domain difficult as well as the strategies that can reorganize these conceptions.

Efforts to extend and build on this initial description of Pedagogical Content Knowledge include measuring PCK within specific domains (Magnusson et al., 1999; Loughran et al., 2004; Ball et al., 2005; Hill et al., 2005, Smith & Banilower, 2006) and studying the role of PCK in pre-service teacher education programs (Davis, 2004; Davis, 2006a). A growing literature, especially in the math and science education domains suggests that teacher experience enacting inquiry curricula in the classroom is critically important to the development of teacher PCK (Van Driel et al., 1998; Ball, 2000).

LOOPS proposes to strengthen pedagogical content knowledge by enabling teachers to use LOOPS resources. These resources are designed to help teachers *assess student progress* (develop skill in using formative evaluation data, diagnosing student difficulties, and recognizing obstacles to understanding), *plan a coherent curriculum* (understand the science discipline, science standards, and connections across topics), *support inquiry learning* (orchestrate collaborative activities, interrupt class to add benefits such as pivotal cases or connections across topics, prompt students to develop independent learning skills), and *customize instruction* (identify curricular weaknesses, modify personal practices, suggest changes to the curriculum).

Educative materials

Curriculum designers have sought to design instruction that features **educative materials.** These materials help teachers enact instruction and make it easier for students to learn (Ball & Cohen, 1996; Blumenfeld et al., 2000; Davis, 2006b; Fishman et al., 2004; Schneider et al., 2005). Such materials support teachers in making decisions about when and how to intervene in student explorations.

To create educative materials, LOOPS is informed by the Knowledge Integration perspective on learning that calls for designing instruction that specifically respects prior knowledge – whether normative or not – and encourages exploring the use of these ideas in personally relevant situations to set students on a path of lifelong learning. For example, studies suggest that skill in guiding knowledge integration in inquiry science courses can impact student learning (Linn, Davis, Bell, 2004; Lee, Linn, & Varma, 2007; Songer, Lee, & Kam, 2002). Specifically, students benefit when teachers develop skill in leading discussions (Puntambekar, Stylianou, & Goldstein, 2007), identifying student naïve ideas (Driver, et al, 1996), making connections across activities (Hart et al., 2000; Schauble et al., 1995), and making connections among concepts (Hiebert & Carpenter, 1992; Linn, Eylon, & Davis, 2004).

Knowledge Integration will inform LOOPS as follows:

KI calls for introducing pivotal cases that help students contrast their various ideas about a scientific phenomenon. The LOOPS planning resources will help teachers develop and select appropriate pivotal cases.

KI calls for enabling students to guide their own learning and apply their ideas to novel situations. LOOPS will help teachers guide students to engage in autonomous inquiry by providing progress reports that diagnose problems and select remedies.

KI has motivated the design of assessments and rubrics that validly measure progress in knowledge integration (Linn, et al., 2006). These assessments meet the standards of an IRT scale and thus are well suited to measuring progress from LOOPS materials.

LOOPS will make the curriculum educative by devising a series of progress reports to provide evidence to inform decision making. In addition, LOOPS will scaffold teachers in using these reports when they engage in reflection on their practice.

Progress reports that have the potential to enhance teacher practice include:

Developing disciplinary knowledge. Research shows the benefit of diagnostic items when used in conjunction with effective teacher practices (Baker, 2005; Black & Wiliam, 1998; Quellmalz & Kozma, in press; Kozma et al., 2004). Numerous promising items have been developed (LOOPS can administer promising items during the regular class activities and summarize responses in progress reports).

Teaching with models, simulations, or visualizations. Using models is challenging for students and teachers (Hegerty, 2004; Linn et al., 2006; Tversky, 2000). Evidence of student understanding and diagnosis of difficulties could guide selection of teaching activities and enhance student learning in technology-enhanced settings (Michalchik, et al., submitted; Tabak & Reiser, 1997).

Teaching experimentation using probeware. Using probeware for experimentation allows for more sophisticated documentation of student activities and also often requires students to design their own complex representations such as graphs, data tables, and summaries of results (Linn & Hsi, 2000; Tinker, 1997). To diagnose student understanding we can ask students to plan all their experiments prior to conducting them. We can determine how closely students' implemented experiments match their planned experiments and investigate the benefit of interspersing reflection questions. Questions might ask students to go back, review their plan, and explain why they're departing from it. We might ask students for intermediate re-planning activities based on our diagnosis of their experimentation plan. LOOPS will gather evidence from student activities and use the evidence to generate progress reports to help teachers guide the use of probeware. This information can be used by teachers to encourage students to vary some aspect of the situation they have not investigated, critique experimental sequences and develop criteria, or apply criteria they developed to their own experimental sequence.

Teaching inquiry. Research shows that teacher activities can impact inquiry learning (Puntambekar, Stylianou, & Goldstein, 2007), through whole class discussions and the linking of ideas. For inquiry activities, we can document student experimentation and give feedback to students as they design experiments and reach conclusions. For students, deciding what information to log during experimentation and what forms of feedback will promote inquiry learning is the focus of this research. We will conduct a series of experiments to explore ideal ways for students to get feedback on their investigations.

LOOPS can integrate the information about student inquiry activities from models, simulations, visualizations, and experiments and engage teachers in reflection activities to help them integrate their own ideas. Teacher reflection can contribute to knowledge integration by helping teachers consider alternatives and incorporate evidence from the progress reports (Davis & Krajcik, 2005; Davis et al., 2006; Gunstone, et al., 1993; Williams, et al., 2004).

THE LOOPS CURRICULUM DESIGN

The LOOPS Curriculum

LOOPS will produce two six-week units, each with optional challenges and extensions that could occupy several additional weeks. The curriculum is designed to match each of the California standards listed below. Each unit will have an overall context that serves as a motivation and unifying theme for all six weeks. Midway through the six weeks, the context problem will be analyzed using the concepts from the prior weeks. The remaining weeks will apply and extend the concepts to new contexts. In addition, each week will have an interesting question or theme that will serve as a focus for the content of that week. Constructing the six-week units from smaller activities will facilitate making alternative lessons and including alternative activities. To simplify this, the six-week units will be constructed in the lesson planning tool.

Resources

Most of the one-week activities that will make up the six-week units will be based on tested activities from existing projects or from funded projects currently under development. These include the following:

TELS has developed and extensively studied in classes 14 weeklong projects for middle and high school students. Many of these incorporate Molecular Workbench (MW) models and several automatically log student actions during their explorations of models.

The Modeling Across the Curriculum (MAC) project at CC has developed six multiple-week high school modeling activities, two of which are in physics. These have been tested with over 10,000 students nationwide and all include automatic logging of student explorations.

The Molecular Workbench (MW) software has evolved at CC over six years and several projects that have developed and tested hundreds of student activities. Tested content is available for almost any secondary science topic and grade.

The Science of Atoms and Molecules (SAM) is a current CC project that is developing two-day activities for high school science courses in a “Physics First” sequence, starting with 9th grade physics. Most of these activities use MW.

The Technology Enhanced Elementary and Middle School Science (TEEMSS) project at CC has developed and tested 15 activities that use probes. The project has focused on reducing costs by using any probeware system and computer and fostering do-it-yourself approaches.

UDL Science is a CC project designed to implement the principles of Universal Design for Learning in middle school science. It is developing seven two-week units and developing technology for giving teachers a convenient display of student progress and controls that can customize the student learning experience.

By drawing on these projects as we develop the LOOPS materials, we can be assured that most of the activities have gone through several rounds of development. Additional development will be needed to ensure a smooth, logical development of the concepts and their consistent treatment over six weeks. Leveraging existing materials, however, speeds that development process and ensures that the core activities are effective.

Universal Design for Learning

In addition to providing some specific content, the UDL project mentioned above will contribute tools and expertise that will provide several UDL features to the entire LOOPS curriculum. UDL requires that the teacher and student have access to controls that can change the student-computer interaction in ways that accommodate individual differences (Buelow, 2003; Rose & Meyer, 2002; Tinker, 2001). Some of these accommodations require developing multiple versions of the curriculum. For instance, the UDL Science project will provide five different paths through much of the material. LOOPS, because it has a different focus, does not have the resources to provide these alternative treatments.

Some kinds of accommodation are more automatic, however. The simplest is font size and color, backgrounds, and other features that can be described as “skin” (Freedman, 1989; Longo, 2001). These skin characteristics can result in dramatic, busy screens for students who need stimulation or they can be muted for students who would most benefit from a calmer computer environment (Mayer & Moreno, 2003; Palmquist & Kim, 2000). One accommodation that has research support is an overall speed control that determines how quickly text is displayed or read, how fast models run, and how quickly graphs are generated (Schwan & Riempp, 2004). Another common accommodation is the option to have text read out loud, including difficult words, phrases, or whole passages (Rose & Meyer, 2000, 2002). Mousavi et al (1995) and Tindall-Ford et al. (1997) demonstrated superior learning when texts were presented as audio rather than text. The UDL Science project is extending this idea to graphs and models, which will be able to describe themselves in varying levels of detail in semantically meaningful ways. For instance, the Smart Graph will be able to describe and highlight important features such as a maximum, off-screen data, noise, and linear segments. The Smart Model will be able to describe and highlight atoms that are in gas, liquid, or solid phases.

These automatic features provided by the smart text, graphs, and models software developed in UDL Science will be used in the LOOPS project. The innovative feedback LOOPS provides from monitoring student inquiry will provide a new source of data for students that is not part of the UDL Science project and is likely to increase the appropriateness of teacher decisions for those UDL features that are available. Thus, while LOOPS is not specifically focused on UDL, it will have some very attractive features that support the goals of UDL.

Probeware

Wherever feasible, we have included activities that involve exploring a model using the Molecular Workbench and the real world using probes and real-time data acquisition. The probeware is an important part of our approach, but alternatives will be provided so that this is not a financial burden. The project will supply a probe kit to participating schools along with instructions and teacher resources for “do-it-yourself” probes. We will also suggest alternative low-cost “kitchen physics” experiments and simulations. Finally, for the motion studies, we will supply software that can be used to analyze motion obtained from a video. Since all recent Macintosh computers, most digital cameras, and even inexpensive cellphones can produce short video segments, most classrooms will have some way to digitize video motion data without needing expensive interface hardware.

Design Considerations

The Knowledge Integration (KI) framework created by the Berkeley collaborators will be used to guide the development of these activities. KI is a fruitful synthesis of extensive research in STEM curriculum design (Linn & Eylon, 2006; Slotta & Linn, 2000). This framework emphasizes the central importance of engaging learners in guided inquiry through a broad range of experiences, which provide ample opportunities for students to integrate their observations and link them with prior knowledge through various forms of reflection and communication. TELS has codified curriculum strategies for knowledge integration in a Design Principles Database[1] (Kali, 2006) which is an invaluable source of ideas and guidance for developers.

The project will develop the new materials using "backward design" principles (Wiggins & McTighe, 1998). The standards will be mapped onto each of the six-week sequences and matched to the existing materials. This will identify any missing content or excess content that needs to be trimmed. We will then review the assessments already in use for match to the standards, developing new items as needed. Most of the available units will require new inquiry assessment technology to measure various aspects of student exploration and analysis of the output of models and probeware. The goals of this implicit assessment and the technical requirement will be specified. Only then will the materials be modified as needed and prepared for testing.

The LOOPS Units

The following represents our tentative plan for the LOOPS units. As the detailed analysis of standards and assessments proceeds, some changes can be expected during the course of the project.

Force and Motion

Context. Hang Time. Videos of basketball players doing slam dunks will be used to ask whether professionals can defy the rules of physics, as they appear to at first glance. Naturally, students will have to learn the rules of physics to answer this. This theme will be used to place the abstractions of vector position, velocity, force, and forms of energy into a meaningful, human context.

Week 1. Kinematics. Airbags. This TELS activity will be combined with a motion detector and simulations of motion to explore the relationships between graphs of position, velocity, and acceleration. The project also addresses relative motion. We will connect this to the hang time theme by emphasizing that we need a way of describing the motion of athletes if we are to understand the physics of motion.

Week 2. Two-dimensional Motion. Hanging with Friends and Dynamica. The first title is a TELS project introducing vectors and vector addition in the context of moving around a town. Dynamica uses position and velocity vectors to find treasure and win a race. The connection to hang time will be made through the need to understand two- and three-dimensional motion.

Week 3. Forces. Tug of War. This new activity will focus on how forces add and the concept of net force. Through a combination of lab measurements and simulations, students will explore different kinds of forces, originating from gravity, muscles, electrostatics, magnetism, and friction, which are all at play in basketball.

Week 4. What If There Were No Friction? This UDL physical science activity is 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 and simulations 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. Friction and gravity are among the most confusing topics, so understanding a situation like basketball where they dominate is enforced by eliminating their effects and investigating what happens.

Week 5. Motion in Gravity. Sports Physics. With an intuitive understanding of 2D kinematics

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[1] Available at http://www.design-principles.org/dp/index.php

and dynamics developed in the prior weeks, students are now in a position to understand aspects of hang time in basketball. Videos of free-fall trajectories of balls and athletes will be analyzed, including basketball greats and school sports stars. Each student group will have a different video and their results will be compared.

Week 6. Projects. Students will undertake their own investigations using the tools and concepts developed in the earlier units. Students will be encouraged to videotape some motion such as a gymnast, dancer, or running animal and then analyze this motion in terms of position, velocity, and force. The curriculum will provide several ideas for projects as well as scaffolding for designing, conducting, analyzing, and reporting their projects.

Chemical and Biological Changes

Context. The Candle (with a nod to Faraday's Christmas Lectures). Flames are always fascinating and a careful observer of a candle flame can see phase change, oxidation, partial reactions, convection, and light-matter interactions. These provide a good introduction to physical change, chemical reactions, and their differences.

Week 1. Chemical Representations. How Can We Recycle Old Tires? This TELS unit is designed to help students integrate macroscopic, symbolic, and atomic-scale views of chemistry. The module addresses chemistry concepts that research has shown to present difficulties for students, such as chemical bonds (Nicoll, 2001), the differences between crystalline and molecular substances (Harrison & Treagust, 2000), the relationship between chemical formulas and visual representations of substances (Ben-Zvi, Eylon & Silberstein, 1987), and a particulate-level understanding of matter (Nakhleh & Mitchell, 1993). The module guides students through an investigation of how recycling methods used for common materials may be applied to the difficult problem of recycling used tires. This unit advances an understanding of the candle by acquainting students with the atomic scale.

Week 2. Reactions. Will Gasoline Powered Cars Become A Thing of The Past? Using a fuel cell as an example, this TELS unit introduces energy diagrams and energy changes in chemical reactions. In this module, a series of dynamic representations are employed to illustrate and support students to understand how energy changes along with underlying chemical reactions. The focus in this unit on energy release in chemical reactions provides another key to understanding combustion and the candle.

Week 3. Light Matter Interactions. How Do Lights Work? Candles, incandescent bulbs, fluorescent lights, and LEDs all illuminate our world through different mechanisms and with increasing efficiency. All, however, are based on excited atoms or molecules releasing photons and this is nicely modeled in the SAM unit on light-matter interactions using a MW model that includes photon-atom interactions. The unit introduces photons, the spectrum, and excited states.

Week 4: The Candle. What's a Flame? This new activity returns to the candle armed with the ideas students have been accumulating in previous weeks. The overall oxidation reaction is described and the production of water emphasized; the production and oxidation of carbon monoxide is illustrated. A UDL unit of the same name will provide many of the activities, including a simplified *MW* model that students can investigate.

Week 5: Combustion in Biology. How Your Muscles Work. Cells "burn" sugar much the way a candle burns wax, but in a more controlled way. This new unit will use MW models to introduce the chemistry of ATP – ADP reaction and give examples of the many ways this energy is used in cells. This will be applied to a model of the interaction of actin and myosin in muscle contraction.

Week 6: Projects. Students will undertake their own investigations using the tools and concepts developed in the earlier units. Students will be encouraged to investigate one of dozens of MW models of chemical reactions that will be available. These reactions will include explosions, combustion, and polymerization. The students will be challenged to write a report that includes 3D models and annotations that describe the partial reactions, the overall reaction and any catalysts. Additional projects will also be suggested.

SCIENCE STANDARDS FOR GRADE EIGHT

The following is a listing of the California standards for grade eight that will be addressed by the LOOPS project. In addition to these, California has standards for “Structure of Matter,” “The Periodic Table,” “Density and Buoyancy,” and “Earth in the Solar System.” In terms of the numbers of specific statements that describe what students are expected to know, the standards below represent 28 out of 46 total, or about 60% of the curriculum, including some of the most challenging material.

Also shown are overlaps with North Carolina, Massachusetts, and Arizona standards. These give an indication of how well material addressing the California standards will travel to North Carolina, where there will be large-scale testing, and other states where there will be volunteer schools later in the project. Arizona and Massachusetts are near the extremes in terms of the rigor of their standards.

In general, the California standards are more varied, detailed, and sophisticated than those from other states. In some areas, California 8th grade standards specify content that is considered high school level in Massachusetts and North Carolina, although these two states have higher standards in one area: NC and MA weave in standards for technology into their science standards, which are not considered in California.

MOTION

The velocity of an object is the rate of change of its position. (AZ, NC grade 7) As a basis for understanding this concept:

Students know position is defined in relation to some choice of a standard reference point and a set of reference directions.

Students know that average speed is the total distance traveled divided by the total time elapsed and that the speed of an object along the path traveled can vary.

Students know how to solve problems involving distance, time, and average speed. (MA)

Students know the velocity of an object must be described by specifying both the direction and the speed of the object.

Students know changes in velocity may be due to changes in speed, direction, or both.

Students know how to interpret graphs of position versus time and graphs of speed versus time for motion in a single direction.

FORCES

Unbalanced forces cause changes in velocity. (NC grade 7) As a basis for understanding this concept:

Students know a force has both direction and magnitude.

Students know when an object is subject to two or more forces at once, the result is the cumulative effect of all the forces.

Students know when the forces on an object are balanced, the motion of the object does not change. (AZ)

Students know how to identify separately the two or more forces that are acting on a single static object, including gravity, elastic forces due to tension or compression in matter, and friction.

Students know that when the forces on an object are unbalanced, the object will change its velocity (that is, it will speed up, slow down, or change direction). (AZ)

Students know the greater the mass of an object, the more force is needed to achieve the same rate of change in motion. (AZ)

Students know the role of gravity in forming and maintaining the shapes of planets, stars, and the solar system.

REACTIONS

Chemical reactions are processes in which atoms are rearranged into different combinations of molecules. (NC) As a basis for understanding this concept:

Students know reactant atoms and molecules interact to form products with different chemical properties.

Students know the idea of atoms explains the conservation of matter: In chemical reactions the number of atoms stays the same no matter how they are arranged, so their total mass stays the same.

Students know chemical reactions usually liberate heat or absorb heat.

Students know physical processes include freezing and boiling, in which a material changes form with no chemical reaction.

Students know how to determine whether a solution is acidic, basic, or neutral.

CHEMISTRY OF LIVING SYSTEMS (LIFE SCIENCES)

Principles of chemistry underlie the functioning of biological systems. As a basis for understanding this concept:

Students know that carbon, because of its ability to combine in many ways with itself and other elements, has a central role in the chemistry of living organisms.

Students know that living organisms are made of molecules consisting largely of carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur.

Students know that living organisms have many different kinds of molecules, including small ones, such as water and salt, and very large ones, such as carbohydrates, fats, proteins, and DNA.

NC includes standards about health and risk factors related to chemistry and chemicals. NC does not address the chemistry of living systems in 8th grade, but it does emphasize biotechnology.

INVESTIGATION AND EXPERIMENTATION

Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations. (AZ, NC, MA) Students will:

Plan and conduct a scientific investigation to test a hypothesis.

Evaluate the accuracy and reproducibility of data.

Distinguish between variable and controlled parameters in a test.

Recognize the slope of the linear graph as the constant in the relationship y=kx and apply this principle in interpreting graphs constructed from data. (AZ)

Construct appropriate graphs from data and develop quantitative statements about the relationships between variables.

Apply simple mathematic relationships to determine a missing quantity in a mathematic expression, given the two remaining terms (including speed = distance/time, density = mass/volume, force = pressure*area, volume = area*height).

Distinguish between linear and nonlinear relationships on a graph of data.

NC includes the use of technology to gather and analyze data.

LOOPS WORK PLAN TABLE

Technology Resources	Curriculum & Professional Development	Assessment
Stage I: Baseline Assessment and LOOPS Version 1.0, Jan 2008-Aug 2008		
Develop preliminary tools for Planning and Classroom Enactment. Use pilot findings from TELS. Design Planner and Progress Reports for Force and Motion.	Develop Force and Motion units (6 weeks of curriculum) with 3 teachers at summer workshop.	Develop assessments for students and teachers. Benchmark 3 CA schools (30 classes).
Stage II: Impact of Version 1.0 and Design of Version 2.0, Sep 2008-Aug 2009		
Test Planning and Classroom Enactment resources. Pilot studies for Daily Reflection, and Grading and Customization resources. Develop resources for Daily Reflection, and Grading and Customization. Design Planner and Progress Reports for Chemical Reactions unit.	Test Force and Motion units with 3 teachers (3 CA schools). Develop Chemical Reactions units (6 weeks of curriculum) with 3 teachers at summer workshop. Plan professional development for following year.	Develop online pre- and post-tests, embedded items, surveys, interviews. Develop longitudinal indicators for teacher progress.
Stage III: Impact of All Resources and Full Curriculum, Sep 2009-Aug 2010		
Test Daily Reflection, and Grading and Customization resources. Integrate new Daily Reflection resources into Planning Tool (e.g., improved diagnostic items). Develop Teacher Trajectory Indicator.	Implement Force and Motion units and test chemistry units with 3 teachers (3 CA schools). Summer workshops to customize curriculum and prepare new teachers in CA and NC.	Assess instructed students using benchmark items, pre- and post-tests, embedded items, surveys, and interviews. Use planning activities and interviews to track teacher progress.
Stage IV: Test Curriculum and Resourcesin New Schools, Sep 2010-Aug 2011		
Test and refine all resources Revise Grading and Customization tool based on workshop experience (e.g., incorporate patterns and recommender system).	Implement and test all units with 6 teachers (3 CA schools). Summer workshop in CA to customize and refine PD. Summer workshop in NC to prepare 7 new teachers.	Benchmark 14 NC teachers and their students. Assess instructed students in CA. Track teacher progress.
Stage V: Comparison Study and Spontaneous Users, Sep 2011-May 2012		
Refine and finalize all resources and connections to units (e.g., improve Progress Reports).	Implement with 6 teachers (3CA schools), 14 teachers (NC schools), and spontaneous users. Comparison study: LOOPS with and without resources in NC. Spontaneous user schools.	Assess instructed students in CA and NC using benchmark items, pre- and post-tests, embedded items, surveys, interviews. Track teacher progress.
Stage VI: Finalize Curriculum and Resources, Analyze Impacts, June 2012 - Dec 2012		
Finalize technology, curriculum, and assessment. Analyze longitudinal data on students and teachers, and report to varied audiences.		

THE LOOPS TECHNOLOGY

Technological Requirements

This section describes the functionality required to provide teachers with formative data and give them the tools to act on these data. These requirements will guide the development of the various tools described in the following section. LOOPS distinguishes four time frames in which different kinds of data are provided to teachers for their analysis, enabling different kinds of actions. For each of these, we discuss the technology requirements in terms of inputs and output options for teachers.

Time Frame Stages in offering a unit	**Formative Feedback** Data for the teacher	**Outputs and Options** Teacher data-driven actions
1. Planning a unit, before starting	Standards Data from prior offerings Student information	Register students Schedule activities Plan assessments Predict student learning
2. Classroom enactment, in the classroom	Student progress Index of inquiry skill Responses to polls	Dynamic grouping Communicate with students Poll groups or entire class
3. Daily reflection, while the unit is under way	Student progress Details of inquiry skills Teacher scored data	Create and disband work groups Select instructional strategies Alter lesson plan and calendar
4. Between offerings, over the summer	Final student performance data Predictions and reflections	Student grades and reports Customize the lesson plans, assessments, and activities

Time Frame 1: Support for Planning and Reflection by Teachers

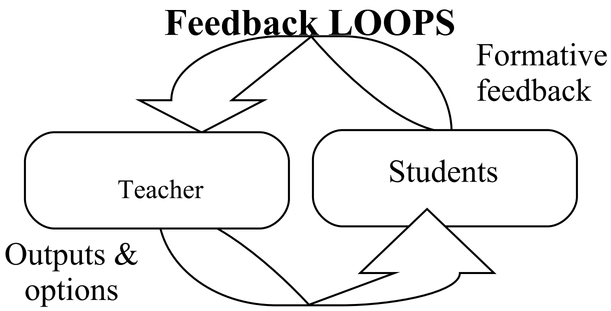
Prior to beginning a LOOPS curriculum unit, teachers can plan the sequence of activities and the diagnostic resources they will use. To establish a plan, teachers will review LOOPS content, state and national standards, pre-test and annual assessment data from their students, and aggregated results from all the classes using the units. They will map the unit onto the school calendar. They will also plan when and how to use the LOOPS diagnostic technologies (embedded notes, diagnostic items, logged data, etc.). LOOPS research will determine the best professional development practices for supporting use of the LOOPS diagnostic resources. Based on our prior work on the value of prediction (Linn & Eylon, 2006), if they have access to the relevant data, we will ask teachers to make predictions about their students' performance and to plan their use of these technologies.

LOOPS technologies for this time frame will include:

Input data:

Student information. To simplify student registration, we will design a general-purpose SIF (Schools Interoperability Framework) compliant registration portal capable of interfacing with common student information systems. This portal will expand on the highly successful portals developed by TELS.

Data from prior offerings. Teachers will be able to browse their own and others' notes and comments from previous offerings of the same LOOPS curriculum unit.



Outputs and options for teachers:

Register students. Passwords and usernames will be issued for each student and used to initialize a *student progress tool*. The teacher portal will help to manage student accounts.

Schedule activities. A LOOPS curriculum unit will consist of a series of computer-based activities and additional suggestions for teachers. LOOPS will provide a *lesson planning tool* to simplify lesson planning and modification, such as the scheduling of activities.

Plan assessments. The lesson planner will allow teachers to: develop assessments to be added to or substituted for existing LOOPS assessments; select diagnostic resources, progress reports, and whole group activities (described below); identify needs for UDL tools; use recommender system to see what other teachers have identified, then build on these.

Time Frame 2: Classroom Enactment

Teaching for inquiry requires new skills (Borko, Bellamy, & Sanders, 1992; Sandoval, Deneroff, & Franke, 2002; Slotta, 2004). During classroom enactment of each curriculum unit, teachers will access information that makes the teaching task easier and scaffolds their practice. LOOPS feedback will help teachers diagnose student difficulties in real time, and make such representations more effective. During classroom enactment, only the most summary data can be utilized—student progress and the index of inquiry skills. Similarly, teachers can manage only limited responses to data during class time—addressing individual students, grouping students to collaborate or guiding whole-class discussions. LOOPS technology supports for such in-class feedback will include:

Input data:

Student progress. The student progress tool will show student progress visually in a grid that is easily understood at a glance and has intuitive controls. It will help teachers monitor students' completion of the unit by getting a snapshot of the activities each group has completed and is currently attempting.

Details of inquiry skills. The components that make up the student *inquiry skill index* will be available for individual students and groups so that the teacher can determine what skills need attention.

Responses to polls. Teachers will see student responses to polls and other interactions.

Outputs and options for teachers:

Dynamic grouping. A *collaboration tool* will simplify creating and disbanding student groupings. These might be created on the fly to help lagging students, to attack new questions, or simply to encourage reflection.

Communicate with students. The teacher will be able to use the collaboration tool to send messages, images, and files to individual students, groups, or the entire class.

Poll groups or the entire class. *A dashboard tool* will allow the teacher to interrupt the small group work to pose a whole class question, diagnostic item, discussion, demonstration, or mini-lecture. Students can send responses, which the teacher can view and display.

Time Frame 3: Daily Reflection

While a curriculum unit is being taught (which lasts approximately six weeks) more detailed data will be available. Teachers will also use this time to generate new data—scores on items and reports that cannot be generated automatically. In this time frame teachers will be able to formatively adapt lesson plans either for specific students or groups. UDL settings can be altered to change aspects of the appearance and modality of the material. Each day, after using the LOOPS curriculum, teachers will be able to make notes about strengths and weaknesses of the curriculum, student progress, and their own classroom practice. They will use the student progress tool to give feedback to students, update activities for the next day (e.g., change diagnostic technologies), and get suggestions from other teachers who have used the curriculum in the past. We realize that teachers may have only 10 minutes to reflect on some days, and more time on other days; our initial three teacher-developers have committed to substantially more. The daily reflection tools will help teachers use the time they have efficiently.

Input data:

Student progress. Teachers will be able to use the student progress tool to obtain additional data about student and group progress. Teachers will be able to drill down in the matrix to see individual progress and artifacts.

Details of inquiry skills. The components that make up the student *inquiry skill index* will be available for groups and individuals so that the teacher can determine what skills need attention.

Teacher scored data. Teachers will see student responses to all questions and challenges, as well as reports, homework, and other artifacts. Answers and rubrics will be available, and teachers will be able to assign grades and comments that are automatically returned to students and entered into the progress tool.

Outputs and options for teachers:

Create and disband student work groups. Permanent or time-limited student grouping can be created along with instructions or challenges.

Select instructional strategies. Some activities will have alternative treatments or UDL settings. The teacher will be able to assign alternative activities to individuals or groups.

Alter lesson plan and calendar. The lesson planning tool will make it easy for teachers to adjust the pace and content of the unit to respond to student progress.

Time Frame 4: Post Instruction

After the curriculum unit is completed, teachers will have access to the final student performance data, any unit test results, and other testing data. These data can be used to generate grades and reports to students. Teachers also can use these data to identify instructional strengths and weaknesses, alter their lesson plans for the next offering, and customize the computer-based activities.

Input data:

Final student performance data. Teachers will be able to use the student progress tool to obtain additional data about student and group progress. Teachers will be able to drill down in the matrix to see individual progress and artifacts.

Predictions and reflections. Teachers will be able to see the predictions they made during the planning phase, together with student data for measures they specified. They will be prompted to reflect on the accuracy of their predictions and revise them for next time.

Outputs and options for teachers:

Student grades, comments, and reports. Teachers will be able to generate student grades.

Customize lesson plans, assessments, and activities. New lesson plans and alternative customizations can be created, although such changes should be evidence based and coupled to recommendations and justifications that future users can access.

LOOPS Technologies

Student and Teacher Portals

The portals will be the access points for students and teachers to launch the many technology elements that comprise LOOPS curriculum, as well as all tools and planning environments for teachers. Students will register, log in and receive instructional content that is tailored for them according to the teacher's plan. Teachers will log in, access their students' work, make and review lesson plans, group students, and customize materials. The portal will enable students to become "attached" to a teacher for purposes of an offering, so their data is available only to that teacher (or other teachers or researchers with whom permissions are shared). Portals are filters of information based on user permissions, providing a powerful way to create online communities for teachers, linking them to one another in a teacher recommender system.

Logging and the Inquiry Index

LOOPS will add significant functionality for measuring what students do in the course of curriculum activities, allowing powerful opportunities to provide feedback to teachers. LOOPS activities will automatically log all student actions, including assessment responses, written reflections, model settings and data input by hand or generated by probes. We will design sophisticated reporting and diagnostic tools that can be set up by teachers and researchers in order to capture specific events. For example, LOOPS could record "time on task" for all student activities. Previously, this would have resulted in a lengthy and imperceptible log file of time stamps that could only have been analyzed post-hoc by researchers with carefully designed subroutines. The inquiry index will generate numerical scores based on student interactions with models and probes by detecting actions such as the number of runs, control of variables, and repeats.

The logging of student data will enable LOOPS to embed logical operations within student activities that respond to logged data. For example, the LOOPS design team might add a feature that sends the teacher an instant message any time a student has attempted the same settings on a model more than twice. Another example would be to place students into discussion groups based on their responses to an earlier assessment item. Such logical operations can enable the design of student activities with a high level of student-centered responsiveness, delivering on the promise of technology for formative assessments.

The logging of student data will provide new opportunities for dynamic reporting tools that give feedback to teachers. LOOPS will systematically research the most effective structure for reports, and the use of logical operations within all curriculum activities. Real-time analysis of logs will be enabled by a series of software filters that look for specific indicators of inquiry skills, such as the following characteristics of students' investigation of a model:

- Number of runs. How many times did the student start and stop the model?
- Timing of runs. Did the student let the model run long enough for a result?
- Use of all variables. Has the student explored all the variables?
- Changing variables. What pattern of changes did the student make to variables?

- Repeats. Did the student repeat trials with the same collection of parameter values?
- Extremes. Did the student test the minimum and maximum of each parameter?
- Control of variables. Did the student change only one variable between runs?
- Initial conditions. Did the student change the initial conditions, and how?

The Teacher Dashboard

This environment will enable teachers to interact dynamically within the class, providing a window into real-time evidence of student progress and allowing the teacher to send immediate feedback to individual students or the whole class. For example, based on reports from the student progress tool, teachers can opportunistically freeze all student computers in order to hold a directed class discussion, or they could send all students a message (e.g., a URL to visit). Teachers will be able to offer timely feedback to individual students or groups during class, and share student work between groups.

The Collaboration Tool

This tool will support the easy formation of groups, or re-grouping of students during an activity, as well as the possibility of dynamic grouping of students during activities. It will also support sharing and collaborative development of files, models, and other artifacts. The LOOPS curriculum will be collaborative in nature, and will entail many activities where students perform complementary tasks, and teachers must be able to track individual and group achievement. For example, during the summer planning activity, teachers will receive data about student achievement on pre-assessments and subsequent project activities. Based on these data, they may decide to pair students who did poorly on the pre-assessments with students who did well. In daily reflections during the actual offering of the unit, LOOPS will provide the teacher with information about the effectiveness of such groupings. Perhaps students who did poorly on pre-assessments were not entering any of the model settings, leaving such decisions to their group partner. This could lead to an evidence-based decision to re-group students, or at least to an intervention where the teacher requests that the students within the group take turns leading the modeling activities.

LOOPS will expand greatly on the previous capabilities for connecting students who work within a group. No longer will groups be limited to those students working on a single computer. Students will have shared files and versioning capabilities for their designs, and will be able to collaboratively create more elaborate presentations that can be published for peer review or teacher feedback. Group members will be able to send one another instant messages (IM), and will receive IM communications from the teacher, as necessary. For example, the teacher might detect which groups of students were moving too hastily through the preliminary reflection activities, and send them a short message to go back and look more closely at those materials.

Group members will also be able to contribute to aggregated activities—such as by adding data to a group dataset, adding websites to a collaborative search page, or conducting complementary portions of a group design activity. Using TELS technology, LOOPS will be able to produce groupware that will allow individual group members to work on or maintain different aspects of a single application. Groups will be able to visit one another's workspace, setting up virtual presentations for peer feedback, and submitting final projects for teacher evaluations.

The Student Progress Tool

The student progress tool will be embedded within the teacher portal, providing continuously updated data on student progress so teachers can tell at a glance how each student, group, or the class as a whole is progressing. The progress tool will display teacher-generated diagnostic assessments and reports, as well as default ones, and will also be accessed by the lesson planning environment (detailed below) for purposes of designing and evaluating predictions about student achievement. Teachers will be able to dive into individual and group work, and connect student performance with instructional goals and predictions. Additional reports will be available at the end of a unit when pre-post data are available and at the end of the semester when all planned units are completed.

LOOPS will investigate the most effective representations of student progress within activities. The goal is to show student data to teachers in such a way that they can quickly perceive the overall progress of students within the project, as well as the relative progress of specific groups. The initial form of this display will be a grid that shows each student group (as a row of the grid) and how it has progressed across project activities (the columns of the grid). Teachers will be able to click on any group to see the individual students within that group and their respective contributions to the project. Teachers could also click on the individual steps of the project (the columns in the grid) and expand them further to see students' work on that step. LOOPS will develop a new assessment interface that allows teachers to diagnose which students require more feedback and which steps in the project are not working as well as they should.

The Lesson Planning Environment

The lesson planner will allow LOOPS activities, assessments, and other resources to be matched to the teacher's school calendar so that specific activities will be delivered to students at the right time. Teachers will plan day-by-day activities, customize assessments and design their own diagnostic reports. The planning environment will support not only pragmatic planning activities, but also strategic ones, as teachers will be prompted to predict student achievement on items they select, and will be provided with student achievement data in order to test their predictions. Through the participatory design process, teachers will jointly examine student progress reports, categorize the reports, and develop consensus about the most promising teacher actions for each category of student progress. We will use such input to design the overall system to record teacher choices and subsequent student performance. If treatment-effect patterns emerge, these will be added to the recommendations.

All planning decisions will be captured in a database to inform future plans by the contributing teacher as well as by other teachers. Access to such planning data will be mediated by a recommender system that draws on aggregated semantic metadata to enable teachers to see what others have done in various situations. The student progress tool will be used to make recommendations to teachers based on the student data, stored rationales, and historical data as well.

Activity Customizing and Authoring

LOOPS developers and teachers will be able to author changes to LOOPS curriculum, particularly in the form of customizations that respond to specific features of a student body, geographic locations, or principles of inclusive design. A LOOPS curriculum unit will consist of activities linked by the teacher using the lesson planner. Specific activities might involve undertaking a probe-based measurement, exploring a model, planning a discussion, or creating a report. Creating or altering these activities will be quite simple, thanks to a sophisticated design of authorware that emerged from prior research (e.g., TELS, WISE and MAC). Teachers will be guided to develop such customizations and add their designs to the wider library of activities, resulting in a growing social network relating to planning and enactment decisions.

Social Network and Recommender Engine

A powerful opportunity lies in the aggregation of teachers' planning and enactment data, including student outcomes for use within a social network. Emergent patterns of use will reflect a growing craft knowledge developed by teachers that reflects how best to enact a LOOPS curriculum in a variety of contexts, including schools that have a great number of English language learners, or classrooms with special needs students. LOOPS will develop a social network engine that allows such knowledge to be aggregated and indexed with semantic metadata that allows the growth of semantically related connections. Special needs teachers can examine the strategies used by the peers, for example. Teachers who wish to add probeware to an activity can look at what others have tried, and read teacher evaluations. By examining the instructional moves made by other teachers at certain points within a LOOPS activity, a first-time adopter could develop a more informed plan. LOOPS will connect teachers to one another through a community that leverages the most recent advances in social technologies, including semantic networking and patterns of activity.

Infrastructure Technology

It is important to realize that the technology described in this proposal is the product of advances made over the last 15 years and has been incrementally funded by various agencies through multiple grants to Berkeley, the Concord Consortium, and more recently, the University of Toronto. The current project will contribute new functions to this ongoing development work, functions specifically required by LOOPS.

The need for a general platform to support student activities was recognized independently at Concord in the Modeling Across the Curriculum (MAC) project, which adopted a client-based approach, and at Berkeley in the WISE project, which was Web-based. Both architectures had unique advantages and the TELS Center provided an opportunity to join them. The resulting architecture, called SAIL for Scalable Architecture for Interactive Learning, comprises a number of components and a set of protocols and standards for how they intercommunicate. The result is a hybrid system that captures the advantages of both its progenitor technologies.

Server-based systems like WISE are generally accessed using standard browser technology. This gives them definite advantages over client-based systems, but can place significant constraints on what the system can actually do. Below we describe the advantages and disadvantages of server-based systems.

Advantages of server-based systems

- **Ease of authoring.** Because server- (and more specifically *browser-)* based systems rely so heavily on HTML, authors can take advantage of many commercial products as well as open-source HTML editors in creating their materials. The explosive commercial use of the worldwide web has led to many extensions of HTML, which has evolved from a markup language to a formidable platform for embedded applications – “applets” – that greatly extend the power of the language.
- **Straightforward solution to the persistence problem.** Open source server environments exist that support the maintenance of individual, password-protected accounts and handle file services, updating, consistency management, and state-saving functions. Since it is assumed that users will be in communication with the server in order to run the activities, it is acceptable to keep all relevant user information on the server at all times. In contrast, most client-based systems are designed to operate independent of the network, so relevant student information must be maintained in two places at once.
- **Ease of installation.** School computers can be assumed to have browsers installed, and in-

ter-browser incompatibilities are rapidly becoming a thing of the past. Browser-server technologies have evolved to handle the problem of maintaining the privacy and security of client-side documents and applications, and caching of files is handled transparently, so schools are less reluctant to use browser-based technology, and the burden placed on them to keep it running is considerably smaller than with client-based technology.

Advantages of client-based systems

- **More complex interactions possible.** Applications that have to run in a browser are constrained to act somewhat like web pages. Browsers make it easy to navigate from one "place" to another because that's what they were built for, but when they switch from one site to another they typically don't "remember" where they have been[2]. This makes it difficult to build the complicated logic into a curricular activity that is required for scaffolding and reporting. (It also makes it much easier to author the browser-based activity, and to save its state.)
- **Logging can be done locally.** Applets (which, by definition, run in a browser) cannot access the local machine's file system, nor can they open Internet connections with other hosts. This makes it difficult, though not impossible, to log the students' actions. It also means that all such data is at risk if the network connection is unstable. This is especially problematic in situations in which the logged data is used for grading purposes.
- **Curriculum activities are standalone.** By design, Web-based systems require external services that must be maintained and supported—and that may go away when funding disappears. In contrast, a client-based application will continue to operate for many years, until changes in the operating system or underlying hardware of the machine make it obsolete. Schools can be assured that the technology they have come to rely on will not disappear when the project that created it comes to an end.

Having the best of both worlds

This project will continue the work begun by the TELS Center that is creating a platform that retains the advantages, such as ease of authoring of the WISE materials, without losing the pedagogical richness and logging capability of the MAC project. The new environment seamlessly incorporates sophisticated client-based software such as probeware as well as complex and computationally intensive models like the Molecular Workbench into easily navigable multimedia-rich educational offerings. Integrating the two approaches in a way that is well designed, supportable, and extensible to other client software has required significant resources. In particular, a major effort was required to provide student data "persistence," so that students' actions and data are preserved at all times. Such persistence permits a student to quit an activity at any time, resume later on any computer, and return to the same place with the same history and data. It is also an essential requirement for the generation of progress reports and scoring tools. TELS and four other projects at the Concord Consortium are currently contributing to the SAIL platform, particularly through an environment called OTrunk that incorporates screen layout functions and communication between autonomous Java components.

All SAIL resources can currently be accessed under open source license and a community of developers within the learning sciences helps researchers develop and exchange SAIL-based mate-

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[2] It is possible to create a "session" on the server so that it will keep track of a user's prior actions, but this is complicated and difficult to maintain.

rials[3]. LOOPS will benefit from the wealth of existing SAIL functionality currently available, and will contribute new resources to this community.

The SAIL architecture supports the creation, customization, deployment, and running of the interactive curriculum units described above. It also supports the registration of schools, administrators, classes, teachers and students through the creation of password-protected accounts, and allocates permissions so that, for instance, a student can see only his or her data, a teacher can view the work of all her classes, and an administrator can gain access to information bearing on the performance of the entire school or district.

Description of the SAIL architecture

SAIL has two complementary functions: (1) to link reusable pedagogically aware Java components into curriculum units or "curnits," and (2) to provide a network-enabled pedagogically aware persistence service that lets the curnits load and save learner data. Among the components that make up the curnits are:

- Computational models with rich visual representations. These currently include molecular, dynamics and biological models.
- Graphs for displaying both real-time and saved data, or for graphing functions.
- Sensor collection components for collecting and graphing real-time data from sensors as well as analyzing previously collected data.
- Drawing tools for creating anything from a simple bitmapped painting to drawing objects and constructing concept maps.
- General purpose modeling languages such as NetLogo.
- Assessment items ranging from multiple-choice questions to open-response alphanumeric input.
- Components that can render web content in HTML, CSS, Flash, and QuickTime.

Persistence is realized by the core SAIL framework that stores a complete revision history of what has been saved and assures that data is associated with the correct student, workgroup, class and teacher. This persistence is supported by the SAIL Data Service (SDS).

The SDS is designed to integrate with existing Web portals to allow them to easily deliver SAIL-based activities to their learners, persisting the learner data and reporting back to the main portal. At this time the SDS supports the TELS WISE portal as well as Concord Consortium's "Do It Yourself" portal, created by the TEEMSS project. These are two unique portals with different underlying architectures integrating with SAIL and the SDS to author and deploy SAIL-based curricula.

The MAC Project developed a scripting environment and framework called Pedagogica that supports dynamic adaptation of component presentation and interaction to learners based on learner actions and data. Pedagogica has been integrated into SAIL, and more recently we have done the same with our OTrunk framework. OTrunk, also developed on the TEEMSS project, supports the creation and modification of rich Java component-based interactive content. It also handles the persisting of both author and learner state, using a consistent and extensible semantically meaningful declarative XML-based language. The symbiosis between OTrunk and SAIL is a fruitful

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[3] The software is at http://sail.sourceforge.net. The community uses http://encorewiki.net

one. SAIL provides OTrunk with network-enabled data persistence and OTrunk provides SAIL the flexibility and agility associated with specifying activities using a declarative language.

Our integration of SAIL, OTrunk, and Pedagogica has been designed from the outset to be easily scalable and accessible to teachers and developers alike. Its extensibility provides for dynamic evolution and its open source design offers a ready response to the sustainability issues plaguing many software learning environments. The LOOPS project will continue the development of this powerful architecture and will contribute to its continued vitality and sustainability.

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