COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 08-1 **NSF 08-502** **01/28/08**				FOR NSF USE ONLY	
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DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
01/28/2008	**2**	**11090000 DRL**	**7645**	**124726725**	**02/10/2008 4:16pm S**

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TITLE OF PROPOSED PROJECT **R&D: Cumulative Learning using Embedded Assessment Results (CLEAR)**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ **3,999,801**	**60** months	**09/01/08**	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW
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☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
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☐ VERTEBRATE ANIMALS (GPG II.D.5) IACUC App. Date ________
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Exemption Subsection ________ or IRB App. Date **Pending**
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PI/PD DEPARTMENT: **Graduate School of Education**

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CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the Authorized Organizational Representative or Individual Applicant is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), nondiscrimination, and flood hazard insurance (when applicable) as set forth in the NSF Proposal & Award Policies & Procedures Guide, Part I: the Grant Proposal Guide (GPG) (NSF 08-1). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

Conflict of Interest Certification

In addition, if the applicant institution employs more than fifty persons, by electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.A; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be dislosed to NSF.

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Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

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Certification Regarding Lobbying

The following certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

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The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

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Two sections of the National Flood Insurance Act of 1968 (42 USC §4012a and §4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the:

(1) community in which that area is located participates in the national flood insurance program; and
(2) building (and any related equipment) is covered by adequate flood insurance.

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant located in FEMA-designated special flood hazard areas is certifying that adequate flood insurance has been or will be obtained in the following situations:

(1) for NSF grants for the construction of a building or facility, regardless of the dollar amount of the grant; and
(2) for other NSF Grants when more than $25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME Patricia Gates	Electronic Signature	Feb 4 2008 11:59AM

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER
	pgates@berkeley.edu	

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Cumulative Learning using Embedded Assessment Results (CLEAR)

Summary. This is a full research and development project responding to the DRK12 solicitation NSF08502, focused on the contextual challenge of using assessment of relevant STEM content to improve K-12 teaching and learning.

CLEAR will take advantage of new technologies and research findings to investigate ways that science assessments can both capture and contribute to cumulative, integrated learning of key concepts in middle school courses. The project will research new forms of assessment that document students' accumulation of knowledge and also serve as learning events. CLEAR will use quasi-experiments (cohort comparisons) and randomized classroom comparisons to determine what combinations of instruction and assessment enable middle school students to gain cumulative understanding of energy concepts in science, and whether the project's approach when used in one course impacts progress in the next. The project will put design principles from across the field to the test, determining instruction and assessment strategies that encourage cumulative understanding and help learners develop integrated ideas about science.

Intellectual Merit. There is an urgent need to develop accurate student assessments that measure cumulative knowledge while eliminating the disruptions caused by tests. By measuring students' developing understanding as it is integrated with ideas from prior learning, the project will be able to foster coherent learning. The project will do this by making assessment an integral part of computer-based curricula. Because of prior and ongoing work, the partners are in a unique position to combine assessment with the best research-based instructional resources and tools to create unified electronic environments with unprecedented power to measure student learning.

The partners have a quarter-century record of important research and innovation that has made seminal contributions to research and practice in science education. This project is a logical continuation of their research, applying the results, technologies, and designs that were developed in prior work to the development of a new conception of curriculum and assessment that will foster cumulative learning.

Broader Impact. By aligning assessment and instruction around the goal of promoting understanding, the project will demonstrate how to improve learning outcomes for any STEM course while also making them more effective and efficient by converting assessment from a time-wasting, curriculum-limiting chore into an integral part of learning that fosters the accumulation of concepts across topics and grades. The results of the proposed research will have an important bearing on the design of effective all-electronic media, which are undoubtedly going to replace texts as technology continues to drop in price.

The project is designed to have a major impact by undertaking the kind of careful, statistically valid research design that leads to reproducible results that can support policy. The project will be able to tailor instruction to specific learners, increasing the impact on students at risk for failure. The partners will continue their practice of widely disseminating findings, materials, and open source software through reviewed and popular papers, talks, its website, and newsletters.

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*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

CUMULATIVE LEARNING USING EMBEDDED ASSESSMENT RESULTS (CLEAR)

Marcia C. Linn, Robert Tinker, Kathy Benemann, Hee Sun Lee, Ou Lydia Liu, & James Slotta

DESCRIPTION AND FRAMING

Cumulative Learning using Embedded Assessment Results (CLEAR) will take advantage of new technologies and research findings to investigate ways that science assessments can both capture and contribute to cumulative, integrated learning of key concepts in middle school courses. We will research new forms of assessment that document students' accumulation of knowledge and also serve as learning events. Aligning assessment and instruction around the goal of promoting understanding can improve learning outcomes and make any STEM course more efficient.

We define cumulative learners as students who build on the ideas they have learned and use the knowledge gained in one course when they take the next course. Cumulative learners maintain their science knowledge by applying it in their courses and everyday lives. Today most students are only tested on the topics they studied in the latest unit and often quite superficially; there is seldom the expectation of applying concepts learned in prior material.

This project builds on the partners' substantial prior research on the advantages of computer-based resources in teaching and learning. Because of prior and ongoing work, we are in a unique position to combine research-based instructional resources and tools into a unified electronic environment. This allows us to create learning opportunities of unprecedented power, to track in detail how individual students use these opportunities, and to assess their cumulative knowledge.

This work will be guided by a theoretical framework called Scaffolded Knowledge Integration, a constructivist view that has been refined in empirical studies over more than 20 years (Davis, 2003; Davis & Krajcik, 2005; Linn, 1995; Linn, Davis, & Bell, 2004; Linn & Eylon, 2006; Quintana et al., 2004). This framework draws on longitudinal case studies of students developing cumulative understanding (Linn & Hsi, 2000). The framework is the basis of design principles (Kali, 2006) that guide the development of software resources that promote integrated understanding (Linn, Clark, & Slotta, 2004) such as those used in the proposed work.

The National Science Education Standards (NRC, 1996; 2000) call for unifying concepts and processes that (a) provide connections between and among traditional scientific disciplines, (b) are fundamental and comprehensive, (c) are understandable and usable by people who will implement science programs, and (d) can be expressed and experienced in a developmentally appropriate manner during K-12 science education (p.115). Most science teachers endorse the notion of unifying or crosscutting concepts (Varma et al., in press). To test our own approach to this challenge, we will focus on the cross-cutting concept of energy, one of several possible unifying concepts that must be developed progressively over multiple grades.

CLEAR will study the impact of powerful, coherent assessments and instruction across middle school science classes in two- and three-year cohort studies. CLEAR will provide solid evidence for design principles that promote cumulative learning, develop an item bank of tested assessments items and tasks, and document the impact of context and experience factors. The research program will investigate assessments that improve cumulative learning by:

Developing valid and useful assessments to measure and promote cumulative learning. CLEAR will create assessments for energy concepts for 6th and 7th grade that capture cumulative accomplishments and also serve as learning opportunities. The assessments will take advantage of powerful technologies that are also features of the instructional materials. The online environment will administer the instruction and assessments, log student activities, and incorporate logged data into student guidance. The environment will track student progress in embedded, pre-post, and annual assessments. We will validate (Cronbach & Meehl, 1955; Embretson, 2007; Lissitz & Samuelsen, 2007; Messick, 1989; Mislevy, 2007) the new assessments by determining their ability to predict cumulative learning. We will compare the properties of the items by comparing them to widely used state and international tests.

Developing instructional materials to integrate energy ideas. CLEAR will create computer-based energy units for 6th and 7th grade that integrate core energy ideas across the relatively incoherent state standards. Informed by the knowledge integration framework, the curriculum will guide students to explore standards-based energy topics such as "when fuel is consumed, most of the energy released becomes heat energy," (CA 6th grade standards). Instructional materials will implement research-based strategies for promoting coherence and exploiting the electronic learning environment. Teachers will access student work in a portal that allows critical formative feedback and customization of the learning environment.

Testing strategies for encouraging cumulative learning. Research from the learning sciences has now demonstrated the impact of several instructional strategies in promoting cumulative understanding. We will test these strategies in the context of complex science learning: dynamic, interactive visualizations (Linn et al., 2006; Pallant & Tinker, 2004), distributed (rather than massed) instruction (Bjork, 1999), explanation questions (Richland et al., 2007), opportunities for students to represent their ideas about the links between concepts, inspired by research on concept maps (Novak, 1995; Schwendimann, 2007), multiple tests with or without feedback (Carpenter et al., in press; Roediger & Karpicke, 2006), and opportunities for students and teachers to debate a topic (Clark & Sampson, in press).

Establishing classrooms for formative testing and research. CLEAR will work with four middle schools that serve diverse students. One teacher-designer per grade level will participate in the design team to create the pilot version of the materials, enact the instruction, analyze student responses, help with revisions, and mentor new teachers.

Engaging teachers in supporting cumulative learning. CLEAR will interview teachers initially to gather their thoughts about cumulative understanding of science, energy as a unifying concept, and the impact of current assessments on their practice. CLEAR technologies have the capability of giving teachers regular summaries of student progress at varied levels of analysis We will track teacher views about assessment and cumulative understanding as they gain experience with CLEAR materials.

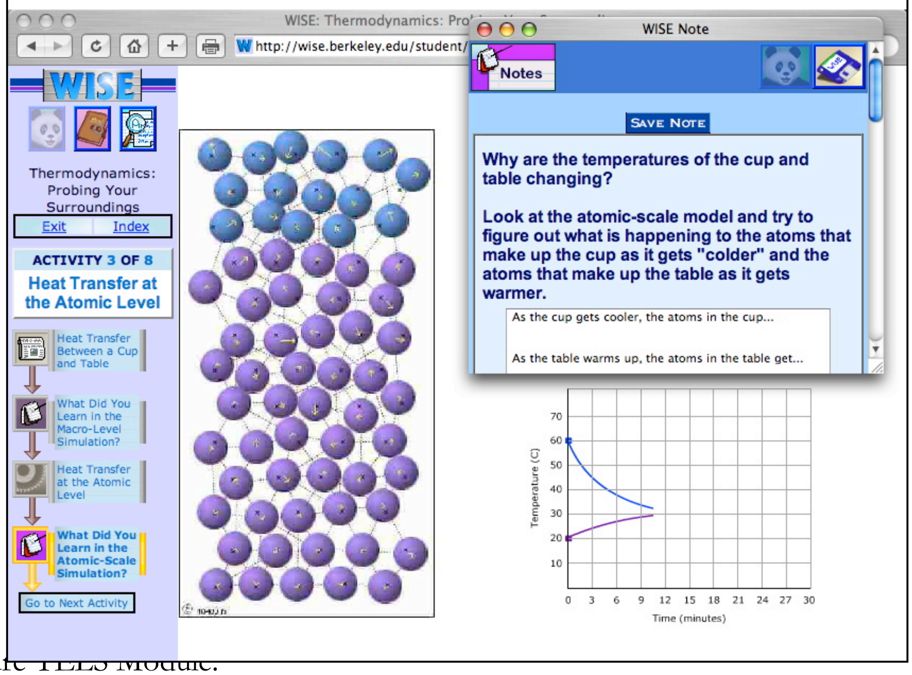
RATIONALE AND RESEARCH QUESTIONS

Science standards call for inquiry skills leading to cumulative understanding (AAAS, 2007) but most state, national, and international tests emphasize the topics and create very few items measuring connections across topics or ability to use science knowledge in new contexts (National Assessment Governing Board, 2004; Organization for Economic Co-operation and Development, 2005; Schmidt, Raizen, Britton, Bianchi, & Wolfe, 1997). Many researchers and policymakers complain that current assessments only ask for isolated science ideas rather than emphasizing the connections among ideas (Pellegrino et al., 2001; Shepard, 2000; Songer, 2006). As a direct consequence of the assessment design, teachers are motivated to emphasize details rather than connections and to drill students on multiple choice items (Au, 2007). To change this situation we need to align curriculum and assessment to promote cumulative learning and to demonstrate to teachers and policy makers that kind of instruction is efficient and engaging.

Strategies to promote cumulative learning. We will investigate six promising strategies for combining instruction and assessment to improve cumulative understanding:

- Dynamic, interactive software. Computational models and probeware will provide environments for guided inquiry that can help students build coherent understanding of complex topics (Casperson & Linn, 2006; Collela, Klopfer, & Resnick, 2001; diSessa, 2000; Edelson, 2001; Hegerty et al., 1999; Hegerty, 2004; Linn et al., 2006; Pallant & Tinker, 2004; Wilensky & Reisman, 2006) To enhance coherence, a limited set of tools will be used consistently (See Figure TELS Module.

Figure. TELS Module with Molecular Workbench Visualization and Note.



- Distributed (rather than one-shot) experiences. *Spacing*, rather than massing, learning materials increases long-term retention (Cepeda et al., 2005, in press; Pashler et al., 2007; Thios & Agostino, 1976; Tzeng, 1973).

- Activities that require respondents to generate an explanation rather than select a response from multiple choices. Answers *generated* by students based on their prior knowledge are retained much better than selected, listened, or read materials (Slamecka & Graf, 1978; Jacoby, 1978; deWinstanley, 1995; Pesta et al., 1999).

- Concept maps that challenge students to explore and represent their ideas about a topic (Novak, 1995; Schwendimann, 2007). Our approach, using a new tool called *MySystem*, will support cognitive or quantified relationships in student representations, drawing from the research on Model-It (Metcalf, 1999) and other systems modeling tools (Hogan & Thomas, 2001; Mandinach & Cline, 1996).

- Repeated opportunities for assessment with and without feedback. Some studies suggest that testing events without feedback are more useful that review of information or feedback (Roediger & Karpicke, 2006). Several research programs conducted with undergraduates and very short retention intervals suggest that prompt and corrective *feedback* can help students retain information (Butterfield & Metcalfe, 2001; Kulhavy, 1977; Kulik & Kulik, 1988; Pashler, Zarow, & Triplett, 2003; Schmidt, 1991; Schmidt, Young, Swinnen, & Shapiro, 1989;

Sloane & Linn, 1998; Winstein & Schmidt, 1990). CLEAR will be able to contrast these approaches to investigate the role of feedback in complex science learning.

- Opportunities for scientific argumentation. When students and teachers respond to each other's ideas about a topic they learn to distinguish among ideas. Students who commit to a view and critique the views of their peers using evidence from their investigations to support their ideas articulate integrated ideas (Clark & Sampson, in press).

Each of these strategies has been demonstrated in numerous empirical studies, set in a variety of laboratory and classroom designs. We will explore the conditions under which each of these interventions can grow in sophistication with the science topic as instruction progresses throughout any given science course or from course to course. For example, assessments using interactive visualizations offer great promise as both measures of student learning and instructional opportunities. We will log student interactions with the visualization and explore ways to provide feedback to students and teachers that promotes cumulative understanding. We will identify combinations of instructional activities, embedded assessments, and annual assessments that jointly encourage cumulative learning and provide valid, reliable indicators for students, teachers, and policy makers.

Focus Concept–Energy. We selected energy as a focus, because it is foundational to science and because it is opaque in the current curriculum. Our proposed research is equally applicable to other cross cutting topics such as evolution, atoms and molecules, or force and motion. Energy is a ubiquitous aspect of science and provides a powerful organizer for learning (see AAAS, 1994, 2001, 2007; NRC, 2000). Many characteristics of energy create confusion: it is intangible, difficult to measure, and cannot be given an absolute value in many contexts. Because it is difficult, the standards often treat energy superficially. A deeper understanding of energy could simplify learning of other topics that appear unrelated but can be understood through energy considerations.

Research Questions. To achieve a coherent curriculum that enables cumulative learning we need to understand how students integrate their ideas in science classes, how they use these ideas in the next class, and how their science classes impact their lives. CLEAR contributes to this challenge by addressing two research questions:

Research Question: What combinations of instruction and assessment enable students to gain cumulative understanding of science?

To address this question we will test the strategies described above for 6th and 7th grade topics of energy. We will collaborate with teachers to design materials and study how teachers interpret progress. We will test and refine our ideas in successive cohorts of students. We will compare cohorts using CLEAR materials to a cohort who studied the typical curriculum with the same teachers. We will use Item Response Theory (IRT) and Hierarchical Linear Modeling (HLM) to assess the impact of strategies intended to increase cumulative learning.

Research Question: How can instruction and assessment in one course impact the next?

We will design new item formats that ask students to connect energy ideas across topics in the curriculum, informed by our research on how students integrate their ideas. In prior studies we have identified ways that students connect ideas and developed items that tap this process for a few topics (Clark & Linn, 2003). CLEAR will build on these ideas and investigate technology-enhanced items to connect content from one topic to content from another topic. We will explore this question by studying how energy topics in 7th grade could benefit from treatment in 6th grade that anticipates future instruction. We will use IRT models to capture student trajectories and identify effective item formats.

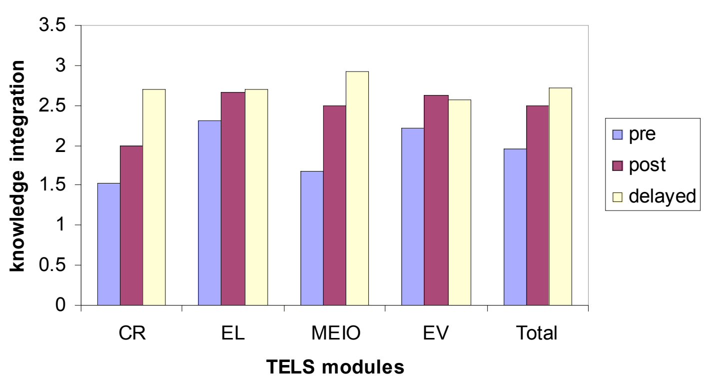
PRIOR SUPPORT

Our prior research in the Technology-Enhanced Learning in Science (TELS) Center for Learning and Teaching (NSF Grants ESI-0334199) has explored the development of instruction and assessments grounded in cognitive science research (Linn, Lee, Tinker, Husic, & Chiu, 2006) that is sensitive to inquiry instruction (Clark & Linn, 2003; Lee, Liu & Linn, 2008) and psychometrically rigorous (Liu, Lee, Hofstetter, & Linn, in press). Using the knowledge integration framework we created modules and assessments that tap the connections students make among their ideas. (See http://telscenter.org/). We have also created cyber-infrastructural resources that enable this work.

Impact of TELS modules. TELS benchmark assessments were used in a cohort comparison study to compare typical and TELS instruction for two key science concepts in six courses: middle school earth, life, and physical science; high school biology, chemistry, physics (Linn et al., 2006). The TELS cohort (N=4520) achieved over a quarter of a standard deviation improvement compared to the typical cohort (N=3712) with an effect size of .32 (p<.001). We used both multiple-choice questions, which were unable to detect this gain, and constructed response items, that were. We attribute these gains to the features of the TELS design, which include: guided inquiry based on interactive visualizations, models, and probeware; relevant contexts that interest students; ample time for reflection; a focus on integrating prior experiences with new observations, student collaboration, comprehensive activities, and easy implementation.

Student learning over time. TELS used pretest, posttest, and annual assessments to determine retention from TELS modules. High school students learned about unseen processes involving molecules (chemical reactions), electrons (electrostatics), population-based genetics (evolution), and chromosomes (meiosis). TELS followed these students (N=764) taught by 11 teachers from 6 schools in 3 states as they completed pretests and posttests immediately before and after the module enactment, and delayed posttests at the end of the school year. To track students over these three time points, TELS used explanations coded with the knowledge integration coding rubric (Lee et al. 2008). As shown at left, ANOVA results indicate that mean knowledge integration values significantly increased across tests for four different TELS curriculum units, $F(2, 1867) = 73.75$, $p < .001$. Considering that typical lab-based studies show a consistent drop at the delayed posttests, our results indicate that instruction with TELS modules can be highly effective and appear to foster post-instruction learning.

Figure. Delayed Posttest.
Results for the Chemical reactions (CR) module, Electrostatics module (EL), Meiosis module (MEIO), Evolution module (EV), and Total Group.



Combining assessment and instruction. The knowledge integration framework is ideal for combining instruction and assessment since many of the design principles call for students to provide evidence of their progress. CLEAR will design assessments that follow these principles, thereby creating activities that serve as both instruction and assessment. As our ability to track and monitor student progress during instruction increases we can establish student accomplishments more and more on evidence directly generated during instruction rather than on one-shot state and national tests that are often poorly aligned with either standards or instruction (Shepard, 1989, 2000).

Cyberinfrastructure. Over more than a decade of research (Buckley et al., 2004; Horwitz & Christie, 1999; Linn, Clark, & Slotta, 2003; Slotta, 2004), we have developed a unique technology infrastructure that is uniquely able to support the cumulative learning strategies, embedded assessments, and professional development proposed. Students learn through guided inquiry that is enhanced through rich computational resources.

TELS has created a new technology infrastructure for developing and delivering computer-based curricula that can include sophisticated applications such as probeware and computational models. This technology is called SAIL: the Scalable Architecture for Interactive Learning and represents refinements of WISE (Linn & Slotta, 2000; Slotta, 2004) and Pedagogica (Horwitz & Tinker, 2001). SAIL has enabled the development of new software that responds dynamically to student actions and provides formative feedback to teachers so they can adjust instruction as needed. This same technology enables researchers to collect detailed data from remote sites by logging and analyzing student actions and responses, and will support the dynamic assessment and feedback mechanisms required by CLEAR. A growing collection of applications can now be integrated in SAIL including the following that will be used in CLEAR: the Molecular Workbench, which uses molecular dynamics to generate exciting atomic-scale models and probeware software for real-time data acquisition and analysis.

RESEARCH AND DEVELOPMENT METHODOLOGY: ASSESSMENT DESIGN

CLEAR will design pretests, posttests, annual, and embedded assessments. The scaffolded knowledge integration framework and the cumulative learning strategies will guide the design of assessments and instruction. We will track progress in knowledge integration as well as trajectories of student energy conceptions and misconceptions.

The CLEAR technologies will allow us to provide multiple embedded assessment opportunities throughout each curriculum unit (Ball & Forzani, in preparation). All of the pretests, posttests, and embedded assessments will require students to

Figure. Rubric Comparison

A typical TIMSS explanation item (7th and 8th grade). TELS expanded the dichotomous scoring (left) of this item into five levels (right) increasing its sensitivity to knowledge integration (Linn et al., 2006).

Question: Electrical energy is used to power a lamp. Is the amount of light energy produced more than, less than, or the same as the amount of electrical energy used?
The amount of light energy produced is
(check one) __ more than __ less than __ the same as the amount of electrical energy used.
Give a reason to support your answer.

TIMSS Rubric (4)		
Category	**Description**	**Examples**
Correct	Choose "less than" with correct explanations.	Energy is transformed to heat; Energy is needed to warm up the lamp; Energy is lost to the surroundings.
Incorrect	Choose "more than" or "the same" with or without explanations. Choose "less than" with incorrect or no explanations.	
Off Task/Blank		

Knowledge Integration Rubric		
Link Levels	**Description**	**Examples**
Complex	Elaborate two or more scientifically valid links among relevant ideas.	Energy turns into heat and light energies under the conservation of energy framework.
Full	Elaborate a scientifically valid link between two relevant ideas.	Energy is transformed to heat; Energy is needed to warm up the lamp.
Partial	Elicit relevant ideas but do not fully elaborate the link between relevant ideas.	Energy is lost to the surroundings; Electrical energy is used as light energy.
No	Make invalid links. Have non-normative ideas.	Because the electricity is just flowing into the lamp. The same source could power more objects. Light travels faster than electricity.
Off Task/Blank		

TIMMS and KI scoring. For this item, students are asked whether the amount of light energy produced by a lamp compares to the amount of electrical energy used. The TIMSS dichotomous rubric on the left captures less information than the four-level KI rubric on the right. KI items are scored on the accuracy of the concepts and the number of meaningful links between them.

generate responses or artifacts as part of curriculum activities. Students will summarize their interactions with Molecular Workbench and probeware, create conceptual, quantitative, or qualitative representations of energy concepts with *MySystem*, write explanations of energy phenomena in embedded notes, as well as articulate energy stories and critique ideas of others in the CLEAR energy blog. Students will create portfolios of their work using the CLEAR Portal. The SAIL environment will log and evaluate student data so it can be used by teachers to improve instruction and by students to monitor their progress (e.g., Chiu & Linn, 2008; McElhaney & Linn, 2008). On the annual assessments, CLEAR will compare these new item formats to the knowledge integration items used in past research, and to the TIMSS items identified in the pilot study.

Pilot Study–TIMMS items. We analyzed 18 TIMSS items (TIMSS, 1995, 1999, 2003) measuring energy sources, transfer, transformation, and conservation that were administered in 6th to 8th grades (N=3500). We rescored the explanation items using the knowledge integration rubric and are using the Rasch partial credit model to obtain item parameters. We will use these TIMSS items along with project-designed items on annual assessments to calibrate new measures.

Knowledge Integration Rubric. To assess progress in knowledge integration, TELS researchers designed tasks that ask students to develop an explanation about a complex scientific phenomenon. The knowledge integration scoring rubric assesses the ideas students generate, whether ideas are normative and relevant, the existence and quality of links between ideas, and the number of elaborated, meaningful links. We compared the validity and sensitivity of multiple-choice and knowledge integration explanation items (see Figure Rubric Comparison). We used a Rasch Partial Credit Model (Liu et al., in press) to show that, as compared to multiple-choice items, explanation items exhibited better psychometric properties in terms of discrimination index, test-item consistency, and person separation reliability and, as a result, were more sensitive to the instruction aimed at increasing knowledge integration (Lee et al., 2008).

Scoring and interpreting student work. CLEAR will research three approaches to scoring on order to to assess sensitivity to cumulative learning, usefulness for monitoring progress, and consistency with state tests. We will apply the knowledge integration rubric to explanation, argumentation, concept mapping, and artifact items based on research by several TELS fellows (Chiu & Linn, 2008; McElhaney, 2008; Schwendimann, 2007; Zhang, 2008). We will capture trajectories in the repertoire of ideas that students articulate using the methods of Minstrell (diSessa & Minstrell, 1998; Hunt & Minstrell, 1994) and TELS collaborator Clark (Clark, 2006; Clark & Linn, 2003). We will continue to use rubrics and items from state and national tests (Lee et al., 2008). We will study how teachers and schools use CLEAR assessments for grading and other consequential decision and test the psychometric properties of CLEAR assessments and make revisions to increase validity and reliability.

ENERGY CURRICULUM DESIGN

Student ideas about energy. Learners hold disjointed, incoherent ideas about energy that are grounded in their observations of the natural world. Surveys of student (Duit, 1999; Driver et al., 1996; Galley, 2004; Goldring & Ogborn, 1994; Linjse, 1990; Liu & Keough, 2005) and teacher ideas (Kruger, Palacio & Summers, 1992; Trumper, 1997), instructional studies (White & Frederiksen, 2000), and a few longitudinal studies (Clark & Linn, 2003; Lewis, 1996; Linn & Hsi, 2000) all reveal that people develop a repertoire of contradictory, idiosyncratic, and complex ideas about energy. Students and their elementary and middle school teachers share similar views of energy. The best-characterized non-normative ideas about energy that have been reported include **vitalism** (Barak, Gorodetsky, & Chipman, 1997; Trumper, 1993, 1997, 1998), **energy-as-substance** (Chi, 2005;

Wiser & Carey, 1983; Linn & Hsi, 2000), and a **source-receiver model** (Driver et al, 1996). Other common ideas involve conflating similar ideas like energy transformation, transmission, and storage.

Curriculum strategies. To help students to develop ideas and build a coherent understanding that grows across grades, we will: 1) adopt a clear operational definition of energy, 2) focus on energy conversions, and 3) incorporate activity patterns that result in knowledge integration.

Energy definition. We will introduce energy as "a property that can be used to heat water." This sounds rather informal, but is, in fact, quite rigorous and avoids the problems of the typical definition—the ability to do work—which is accessible only to students who understand the scientific definition of work: an advanced concept based on the summation or integral of force over distance. By starting with such an inaccessible definition, the typical middle school treatment of energy sows confusion from the start.

Using the heating ability of energy is accurate because it is always possible to turn 100% of any form of energy into heat and use that heat to increase the temperature of water. Measuring their heating ability allows different forms of energy to be compared. It also provides a concrete, operational definitions that will be reinforced by actual experiments for each type of energy. Indeed, the Calorie and the British Thermal Unit are based on the energy required to heat water and probably persist because of their greater conceptual clarity, as compared to definitions based on work.

Energy conversions. To develop a solid, integrated understanding of energy, we will consistently use a set of four software tools: probeware to enhance lab experiments, molecular dynamics models for virtual experiments at the atomic level, *MySystem* for exploring energy systems, and the Energy Blog for reflection and collaboration. This multimodal approach will allow students to generate ideas, test them in real and virtual contexts, reflect on them, and communicate them. The following proposed topics, explored both with probes and atomic-scale models, are organized according to the ability of different forms of energy to heat water.

- Heating water with sunlight.
- Heating water with electricity.
- Heating water conduction from a warm aluminum slab.
- Cooling water conduction from a cool aluminum slab.
- Heating the aluminum slab by mechanical motion (friction).
- Heating the aluminum slab mechanical potential energy.
- Heating water with chemical energy.
- Cooling water with ice.

These experiments establish a way of measuring the amount of energy across its many forms, and of focusing on energy conversion. These experiments will naturally raise the question of whether each form can be converted to the others. Can sunlight be converted to electricity? Or kinetic energy to potential? The CLEAR curriculum will enable students to explore such conversions until they understand the idea that energy has many forms and can be converted from one form to another. In the curriculum, students will experiment with several alternatives, completing CLEAR reflections (which will also serve as formative assessments) as they move from experiment to experiment.

Instructional patterns. Students will follow four instructional patterns that have proven to succeed to knowledge integration: 1) eliciting ideas to clarify where students start their learning; 2) adding new ideas primarily through inquiry activities such as experimenting; 3) developing criteria for selecting among alternatives (criteria could be controlled experiments or coherence among scientific observations); and 4) reflection and sorting out of ideas (Linn & Eylon, 2006). Each instructional experience will feature many combinations of the four processes and relevant embedded assessments.

Development. A partnership of classroom teachers, technologists, discipline experts, learning scientists, and evaluators will design the CLEAR instructional materials informed by the knowledge integration framework. The partnership will align activities with state and national standards. We will use the American Association for the Advancement of Science Atlas (AAAS, 2007) representation of energy ideas for grades 6 to 8 as a basis for the integration of ideas (see Figure AAAS Energy Atlas Map). We will also select topics from the California and national standards (NRC, 1996).

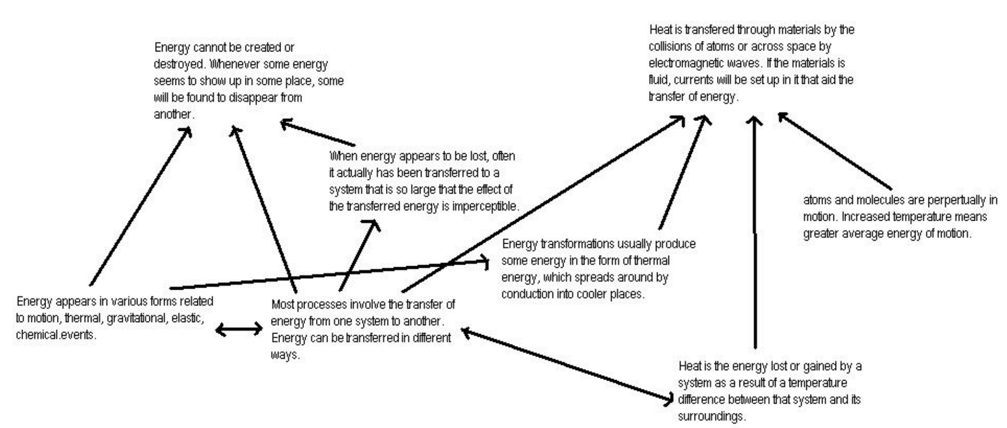
To build a cumulative understanding of energy will connect student experiments on energy conversions to related energy topics such as thermal equilibrium, electrical circuits, and work. This emphasis is also central to the California Standards (e.g., 6a, Students know the utility of energy sources is determined by factors that are involved in converting these sources to useful forms and the consequences of the conversion process.) By unifying their understanding of energy around conversions, students are ready to identify new forms of energy and to understand their connection to more familiar forms.

CLEAR TECHNOLOGIES

SAIL Learning Environment. CLEAR will use SAIL for materials development and deployment. SAIL is uniquely able to deliver sophisticated applications that run on student computers, provide scaffolding and persistence, and collect data on student performance. CLEAR will add features

CLEAR Energy Blog. The CLEAR Energy Blog will support collaboration, discussion, argumentation, and creation of community resources. Blogs are rapidly becoming one of the most common channels of information on the Web, and CLEAR will capitalize on this channel by challenging students to contribute blog entries that are relevant to the current energy topic within their curriculum. Students and teachers can contribute blog entries explaining energy situations relating to their own lives. They might discuss ideas for perpetual motion machines or explain the energy conversions necessary for them to ride a bicycle to school. Both students and teachers can add new situations, make comments to their peers' entries, and rate entries in terms of the energy claims. Blog assignments will be part of the curriculum and assessment. The Energy Blog will expand upon our prior efforts in designing the TELS portals and SAIL metadata. We will embrace Web 2 technologies, creating content and functionality from the participation of many users, and leveraging semantic metadata and social tagging or indexing to make the information accessible to everyone. We seek effective integration of social and collaborative technologies to promote cumulative learning.

Figure. AAAS Energy Atlas MAP.



Probeware. The Concord Consortium has a long history of research on educational applications of real-time data collection and analysis, now called probeware (see, for example, Metcalf & Tinker, 2004; Mokros & Tinker, 1987; Tinker, 2000). Their research required the development of flexible data collection and real-time graphing software that can work with any vendor's hardware or with parts assembled from parts. This package is open source, has been integrated into SAIL, and will be used in CLEAR. The primary sensor used will be a fast-response temperature probe available from two vendors and as a kit.

Molecular Workbench. The *Molecular Workbench (MW)* is a mature, open source molecular dynamics modeling engine already integrated into the SAIL system. It provides a highly interactive environment for student exploration at the atomic scale. It easily handles the evolution in time of systems of hundreds of Newtonian atoms and molecules acting under the Lennard-Jones and Coulomb forces. In CLEAR, *MW* will be used to provide a conceptual understanding of the atomic basis of heat, temperature, electricity, light-matter interactions, chemical energy, and the mechanisms of transformations among these. For access and information, see http://mw.concord.org and http://molo.concord.org .

MySystem. *MySystem* is a new application that will allow students to create or modify a system represented by objects connected by arrows. This will be introduced as a tool to help students represent the connections among their ideas about energy systems, but it will have a numerical underpinning that will be revealed when numbers are needed. Its broad applicability allows *MySystem* to be used consistently across topics and grades, connecting conceptual descriptions of systems with their qualitative and quantitative features. The *MySystem* user sees graphical objects that are connected by arrows. An intuitive and familiar set of drawing tools permits the user to create and edit systems.

In CLEAR, the graphical objects will represent energy producers, transformers, and sinks. More complex objects like a house or a power station can be "opened" to see constituent parts, made from objects interconnected by arrows. For instance, a power station might consist of an energy source such as oil, converters such as oil-to-heat and heat-to-electricity, and outputs such as electricity, heat, and CO_2. Mathematically, an object is a function or a sub-system with inputs and outputs and a graphical appearance, possibly animated. Arrows connect the output of one object to the input of another object and indicate that the two are equal. Running a *MySystem* model will calculate a consistent set of inputs and outputs if any exist for the values provided. If values change, *MySystem* will continue to resolve the system over time. To make the mathematics accessible, functions can be symbolic, qualitative, and/or textual. They can be as simple as "add one" or "increase" and as sophisticated as "integrate over time." A function can be defined quantitatively as in "when the input goes up a little, the output goes down a lot." In CLEAR most functions will be ratios or linear, corresponding to the mathematics they will be learning in these grades.

The following illustrates how MySystem could support student concept development. *One cold night Jan left the light on in her closet. Her father berated her the next day about the cost of wasted electricity. She objected, saying that the heat from the light saved them as much in heating costs. Her father claimed that light bulbs were not intended as heaters and besides, the light could not influence their room heater. Who is right?*

Two teams could use *MySystem* to model the various energy transformations. One team could model the home heating system and the other the light in the closet. The curriculum would supply a variety of objects, including light bulb object with electrical power input and both light and heat outputs. It would also provide an absorber that converts light energy to heat. Used without numbers, creating *MySystem* models helps organize students' thinking, scaffolded as needed by the software. By running numbers through their systems, they could make quantitative comparisons.

Open-ended problems like this generate animated debate because there is no right answer. Many assumptions need to be made to answer the question, including the location of the closet and the source of energy for heating. Naturally, the learning comes from the debates about the two models and the thinking that is generated (Bell & Linn, 2000; Osborne et al., 2004).

CLEAR Portal. All curriculum and assessment elements will be delivered through the CLEAR Portal. All technology-enhanced materials will collect student inputs and log them within the portal for use by the students, teachers and researchers. Building on our own prior systems, we will refine our abilities to deliver these data to the appropriate users at the opportune times. One feature of the Portal and other CLEAR materials is that of semantic metadata. Whenever a student makes any contribution, certain metadata (e.g., time and date, author name, class and period, curriculum topics and keywords) will automatically be added to a hidden file that is attached to that entry. Still other metadata will be added by students in the course of the activity (e.g., ratings or social tags or assessments). These metadata can be queried by teachers, or by other technology elements.

For example, to support students' reflections following the experiment on mechanical potential energy, the technology environment can provide students with a new window that includes all items that included "mechanical potential energy" from previous blog entries. The curriculum can encourage them to reflect on the new ideas that emerged from the experiment. The use of semantic metadata will greatly enhance our ability to build connections between curriculum topics and across science courses.

The Portal will draw upon the familiarity of students and teachers with online spaces and their expectations that such spaces should contribute to all aspects of their lives. The CLEAR Portal will provide a safe, personalized, permanent space for each student and teacher. Students will use this space for building a portfolio, preparing reports, and creating summaries that they can use in subsequent years. Portal documents will include runable *MySystem* and *MW* representations, annotated snapshots from these and probe software, and blog discussions about ideas of their own or their peers from previous years. Students will be able to see all of their own work, as well as selective access to that of peers, according to the design of the curriculum. Students will draw on these artifacts to revisit ideas, reflect, and monitor their progress.

Teachers will use the Portal to access succinct summaries of student progress, grade student work, and annotate curriculum materials. Teachers will receive well designed reports that include summaries of student data and links to specific student work in real time (i.e., during class). Researchers will be able to quickly and accurately query all data within and between any desired groupings of students.

RESEARCH DESIGN

CLEAR proposes to conduct cohort comparison studies and randomized classroom studies comparing alternative strategies for promoting coherence in four participating schools. These quasi-experimental (cohort comparison) and randomly assigned classroom comparison methods will be augmented with student interviews, video case studies, and classroom ethnographies.

Schools and Teachers. CLEAR is fortunate to have obtained the commitment of four middle schools from within the Mt. Diablo Unified School District. One of the largest school districts in California, Mt. Diablo serves over 35,000 K-12 students. The student body is diverse, including 30% Latino, 8% Asian, and 5% African American students. About 17% of the students are language learners. Three of the CLEAR schools enroll about 800 students each with about 18% receiving a free or reduced price lunch, and 8% classified as English language learners. The fourth CLEAR school enrolls about 650 students, of which 60% are socio-economically disadvantaged, over 82% receive free or reduced price lunches, and 35% are English language learners. (See School Support Letters for additional details). Altogether the four schools have a total of about 1000 students and 8 teachers at each grade level. Thus, each of the cohorts will include 1000 students followed for either 2 or 3 years, depending on the study. One teacher-designer at each grade level will be selected from each school to participate in the design team each summer. Teacher-designers will pilot test the materials within their own classroom and mentor other teachers within their school. We will follow four cohorts for up to three years (see CLEAR Timeline) :

Figure. CLEAR Timeline

Year	Assessment	Technology	Summer Design Workshop	Cohort Activities
1 **[Starting September 2008]**	Design and pilot test cumulative learning items for annual tests for 6th-8th grade.	Establish version 1.0 of CLEAR technologies.	6th grade teacher-designers and team draft the 6th grade materials.	**Control:** Administer annual tests to all 6th grade students in participating schools.
2 **[Starting September 2009]**	Design embedded and unit assessments. Calibrate pilot data using IRT models. Refine items based on psychometric properties. Equate tests.	Refine CLEAR technologies based on 6th grade trials. Refine SAIL to support design team.	7th grade teacher-designers from schools join team to draft 7th grade materials. Team refines the 6th grade materials.	**Control:** Administer annual tests in 7th grade. **Pilot:** Teacher-designers test 6th grade materials in their classes.
3 **[Starting September 2010]**	Refine embedded, unit, and annual assessments. Establish performance trajectory for Pilot cohort. Validity study using NAEP, TIMSS, and CLEAR items.	Refine CLEAR technologies based on 7th grade trials. Refine SAIL for design team.	Engage 6th and 7th grade teachers in refining CLEAR materials. Mentor new 6th grade teachers.	**Control:** Administer annual tests in 8th grade. **Pilot:** Teacher-designers test 7th grade materials. **Experiment and Spontaneous:** Conduct randomized trials of strategies.
4 **[Starting September 2011]**	Refine embedded and unit assessments. Refine items and annual assessments using IRT. Establish student performance trajectory for Experiment cohort.	Finalize technologies. Add features to SAIL based on findings from randomized trials.	Engage 6th and 7th grade teachers in refining CLEAR materials. Mentor new 7th grade teachers.	**Pilot:** Administer annual tests in 8th grade. **Experiment and Spontaneous:** Conduct randomized trials of strategies. **CLEAR Curriculum:** Enact final version in all 6th grades.
5 **[Starting September 2012]**	Refine items using IRT. Create item bank. Establish student performance trajectory for CLEAR Curriculum cohort.	Maintain CLEAR technologies. Add SAIL features for logging.	Engage 6th and 7th grade teachers in finalizing CLEAR materials and assessments.	**Experiment:** Administer annual tests in 8th grade. **CLEAR Curriculum:** Enact final version in 7th grade in all participating schools.

- **Control Cohort.** Students in all classes studying the typical curriculum. Cohort starts in 6th grade in year 1, followed for 3 years.
- **Pilot Cohort.** Students in classes of teacher-designers who helped design the first version of assessments and materials. Cohort starts in 6th grade in year 2, followed for 3 years.
- **Experimental Cohort.** Students in all classes studying randomly assigned alternative assessments and materials. Experienced teachers will mentor new teachers. Cohort starts in 6th grade in year 3, followed for 3 years.
- **CLEAR Curriculum Cohort.** Students in all classes studying the successful assessments and materials from experiments. Cohort starts in 6th grade in year 4, followed for 2 years.

We will conduct additional experimental comparisons by working with teachers who spontaneously locate the CLEAR materials and agree to participate in annual assessments. CLEAR materials will be open source and available for free on the Internet starting in year 3. Currently about 500 teachers spontaneously use the WISE library of projects every month.

Cohort methods. All four cohorts will complete annual assessments. In addition, the Pilot, Experimental, and CLEAR Curriculum cohorts will take pretests and posttests and respond to assessments embedded in instructional materials. These cohorts allow us to iteratively refine the materials and test alternative approaches while gathering indicators of cumulative learning every year.

The Pilot Cohort will test the first version of the materials and assessments; we will analyze students' progress in generating explanations, arguments, and artifacts during the academic year. The team will refine the piloted materials using evidence from this cohort. The team will use the refined materials to design comparison studies of promising strategies for promoting coherence.

The Experimental Cohort classes will study randomly assigned strategies to promote cumulative learning, including alternative forms of feedback, varied formats for explanation items, and alternative uses of *MySystem* and the Energy Blog. These studies will typically employ a pretest, followed by a single experimental curriculum unit, then a posttest – an approach that has proven successful in comparison studied using technology-enhanced materials (Chiu & Linn, 2008; McElhaney & Linn, 2008; Tate, 2008; Zhang & Linn, 2008).

For the CLEAR Curriculum Cohort we will combine the most successful instructional strategies based on the comparison studies from the Experimental Cohort. This cohort will include all teachers. The CLEAR Curriculum Cohort is the best comparison to the Control Cohort.

These three cycles of curriculum development, testing, and item revision will allow us to eliminate unsuccessful approaches and strengthen fruitful ones. Using evidence from these studies we will create design principles describing ways to design assessments and instruction to promote cumulative learning.

Measurement and evaluation techniques. Advanced measurement and evaluation techniques including item response models, multi-level models, and test equating techniques will allow us to interpret the results of these investigations. We will use item response models to establish reliable estimates of student cumulative science learning and characterize stable performance trajectories. Multi-level models will help us understand the role of both student and teacher level characteristics when comparing cohorts. By combining these methods with interviews, video case studies, and ethnographies we will be able to identify main impacts as well as nuanced effects.

We will conduct three types of analyses: Cohort trajectory studies, Within grade comparison studies, and Cohort Comparison Studies. *Cohort trajectory studies* track student trajectories in understanding energy from 6^{th} grade to 8^{th} grade. We will establish a performance trajectory for students in the Pilot, Experimental, and CLEAR Curriculum cohorts. We will take advantage of the multiple assessment opportunities to understand student strengths and weaknesses at each testing point. We will also explore how the cumulative learning trajectories vary among the three cohorts as they receive incrementally improved energy instruction. The multiple evaluation opportunities improve the accuracy of estimates of student performance before, during, and after instruction. In addition, we will study how information gathered at multiple instruction points helps teachers identify strengths and weaknesses in student understanding.

Within grade comparisons will compare alternative instructional strategies randomly assigned to classes within the Experimental cohort and determine which succeed. We will analyze the cumulative learning of the 6th graders and 7th graders separately. We will also be able to compare classes in the Control, Pilot, Experimental, and CLEAR Curriculum cohorts.

The *Cohort comparison studies* allow us to compare the Control cohort to the Pilot cohort and the CLEAR Curriculum cohort to assess impact of instruction on cumulative understanding. With these 3 cohorts we can investigate how implementation of the CLEAR materials, modification of the materials, or variation in teacher practice affects the way students make progress in understanding scientific phenomena.

We will investigate the impact of various implementation variables on student cumulative learning using a multi-level model. For example, participating teachers are likely to become more adept as they teach more energy units. They may identify concepts students find difficult and come up with teaching strategies. To tease out the impact of the various factors on student success, this hierarchical model will use individual students as the basic unit of analysis. The second level analyses include the cohort variables. Performance of the control cohort and the pilot and CLEAR Curriculum cohort will be evaluated. The third level analyses add teacher characteristics such as demographic variables, years of teaching experience, and most importantly how they implement the CLEAR energy activities. This three-level model has the potential of clarifying how students become cumulative learners.

Item bank and design principles. After analyzing the data collected from all sources, we will establish a comprehensive and validated item bank for the use of the science assessment community. By the end of year 5, we will have developed, tested, and analyzed a large number of cumulative learning items. Item response modeling techniques will be used to calibrate all of the items in terms of item difficulty and discrimination power. We will also compare items that follow our assessment design principles with those designed by large scale standardized assessments as TIMSS and NAEP. All of the items with complete psychometric properties will be made available to interested users including assessment professionals, administrators, and teachers. We will also identify principles associated with successful items to add to the design principles database.

Expertise, Evaluation, and Dissemination

Project Expertise and Management. The CLEAR leaders will balance flexibility and accountability. At the start of the project a detailed, task-based work plan will be developed that reflects the timeline sketched above. The project leaders will monitor project progress through biweekly teleconferences and quarterly meetings (in conjunction with professional activities including AERA, AAAS, the Summer Design Workshop, and PI meetings). The PIs will tap the expertise in the project advisory board regularly and meet with them at the Summer Institute. CLEAR will communicate results regularly and cooperate fully with any NSF program reviews and requests for project data. Important parts of the project will be accomplished by sub-awardees who have successfully collaborated in the past. CLEAR will use the Berkeley monitoring process requiring annual negotiation of a Statement of Work. Each leader will have a primary responsibility and will work closely with the other leaders:

Marcia Linn, the Principal Investigator, has overall responsibility for the project and will lead the research activities, drawing on her background in learning sciences, technology, and psychometrics.

Robert Tinker, President of the Concord Consortium, will lead the technology activities. Tinker has produced powerful simulations and visualizations for energy topics across the curriculum (Pallant & Tinker, 2004; Tinker, 1996).

Jim Slotta, at the University of Toronto will lead the curriculum design activities. Slotta has a background in Engineering, completed his doctorate in Cognitive Psychology under Michelene Chi (Slotta, 1997) studying the implications of students' ontological understanding of energy, and leads the learning environment design team.

Kathy Beneman will coordinate with the schools and lead the professional development activities. Beneman is the TELS manager and has experience in classroom teaching and technology leadership.

Hee Sun Lee, Berkeley and Tufts, will lead the assessment design and rubric construction activities. Lee has extensive assessment experience (Linn et al., 2006; Songer et al., 2002).

Ou Lydia Liu, ETS, will lead the quantitative analysis activities, review all research plans, and coordinate the external evaluation. Liu studied with Mark Wilson and collaborated on design and analysis of the TELS assessments (Liu, Lee, Hofstetter, & Linn, in press).

Advisory Board. CLEAR will be ably advised by leaders in the field who have agreed to both meet formally with the project annually and evaluate the project in their areas of expertise on a regular basis. Advisors and areas of expertise include: Jane Bowyer, Mills College (educational leadership and professional development); Derek Briggs, University of Colorado, Boulder (assessment, HLM, IRT,); Michelene Chi, University of Pittsburgh (cognitive psychology); Doug Clark, Arizona State University (biology, conceptual change, language learners); Yael Kali, Technion, Israel Institute of Technology (earth science and design principles); Rich Lehrer, Peabody College, Vanderbilt University (modeling and student learning); Min Li, University of Washington, Seattle (assessment, applied measurement); Senta Raizen, WestEd (physical science and assessment); Nancy Songer, University of Michigan (life science, inquiry learning, learning technologies); Elisa Stone, Berkeley (CA) High School (life science, biology teaching). CLEAR will benefit from disciplinary expertise in physical and earth science (Horwitz, Kali, Raizen, Tinker), life science (Clark, Slotta, Songer, Stone), professional development (Bowyer, Clark, Lehrer, Songer, Stone), and assessment (Briggs, Lee, Linn, Li, Liu, Raizen).

Project Evaluation. CLEAR will take advantage of the expertise of the advisory board to carry out the external evaluation of the project. The external evaluation will be coordinated for the advisory board by Paul Holland of the Paul Holland Consulting Corporation. Holland holds the Frederic M. Lord Chair in Measurement and Statistics (retired) in the Research & Development Division at the Educational Testing Service in Princeton, NJ. The board will evaluate the project based on the research questions and the detailed work plan. Lydia Liu, ETS, will coordinate the data collection plan, Holland will review the plan, and CLEAR will prepare the information. The board will meet in closed session, develop recommendations, and report to the project as well as NSF.

Synthesis and Dissemination. To synthesize our findings for future designers we will identify evidence-based design principles for instruction and assessment and to add to the design principles database (Kali, 2006). We will develop an item bank of assessments and tag them with information about the principles they illustrate.

CLEAR will use a website, articles, presentations, congressional visits, and workshops to disseminate progress to multiple audiences, including: researchers, curriculum designers, professional developers, precollege teachers, principals, industry leaders, and policy makers. The website will feature free curriculum materials, policy briefs, links to papers and presentations, design principles, design patterns, and opportunities to participate (see http://WISE.berkeley.edu for past practices). CLEAR assessment items, curriculum materials, and technologies will be open source, available free on our website, and widely publicized at meetings of elementary and middle school science teachers.

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Stone, E. M., Slotta, J. D., & Linn, M. C. (2003, December 15). *Using Technology to Promote Cell Biology Learning: A Web-Based Inquiry Science Environment (WISE).* Paper

presented at the The American Society for Cell Biology 43rd Annual Meeting, San Francisco, CA.
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Vosniadou, S. (Ed.). (in press). *Handbook of Research on Conceptual Change*. Mahwah, NJ: Lawrence Erlbaum Associates.
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White, B. Y., & Frederiksen, J. R. (2000). Technological tools and instructional approaches for making scientific inquiry accessible to all. In M. J. Jacobson & R. B. Kozma (Eds.), *Innovations in science and mathematics education* (pp. 321-359). Mahwah, NJ: Lawrence Erlbaum Associates.

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Wilensky, U., & Reisman, K. (2006). Thinking like a wolf, a sheep or a firefly: Learning biology through constructing and testing computational theories – An embodied modeling approach. *Cognition and Instruction, 24*(2), 171-209.

Williams, M., & Linn, M. (2003). Collaborating with WISE Scientists. *Science & Children, 41*(1), 31-35.

Williams, M., Linn, M., Ammon, P., & Gearhart, M. (2004). Learning to Teach Inquiry Science in a Technology-Based Environment: A Case Study. *Journal of Science Education and Technology, 13*(2), 189-206.

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Wiser, M., & Carey, S. (1983). When heat and temperature were one. In D. Gentner & A. L. Stevens (Eds.), *Mental models* (pp. 267-298). Hillsdale, NJ: Lawrence Erlbaum Associates.

Zhang, Z. (2007). *Learning Energy Through Inquiry: Hydrogen Fuel Cell Cars* (TELS Report): University of California, Berkeley.

Zhang, Z. (2008). *Using Drawing Activities to Improve Student Learning Through Visualizations.* Paper to be presented at the annual meeting of the American Educational Research Association, New York, NY.

Zhang, Z. (2007). *Using Scaffolded Visualizations to Support Student Understanding of Energy Concepts at Molecular and Macroscopic Levels* (TELS Report): University of California, Berkeley.

Zhang, Z., & Linn, M. C. (2008). *Using Drawing Activities to Promote Student Understanding of Chemical Reactions from Dynamic Molecular Visualizations*: TELS Report.

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EDUCATION

Stanford University, B.A., Psychology (Advisor: R. C. Atkinson), Minor: Statistics, 1965
Stanford University, M.A., Educational Psychology (Advisor: L. Cronbach), 1967
Stanford University, Ph.D., Educational Psychology (Committee: L. Cronbach, R. Snow, E. Hilgard), 1970

EMPLOYMENT

1989–present	Professor, Graduate School of Education, University of California at Berkeley (UCB)
2007	Fellow, Rockefeller Foundation Study Center, Bellagio, Italy
2006-2008	Chair, Studies in Engineering, Science, and Mathematics Education (SESAME), Graduate School of Education, UCB
2003-2006	Chancellors Professor, UCB
1996-1998	Chair, Cognition and Development Area, UCB
1995-96; 2001-02	Fellow, Center for Advanced Study in the Behavioral Sciences, Stanford, California
1989–1996	Director, Instructional Technology Program, UCB
1985–1989	Adjunct Professor, Graduate School of Education, UCB
1986–1989	Associate Director, Instructional Technology Program, UCB
1983	Fullbright Professor, Weizmann Institute, Israel
1970–1987	Research Psychologist, Lawrence Hall of Science, UCB
1977–78; 79-80	Visiting Associate Professor, School of Education, Stanford University
1974–1975	Visiting Fellow, University College, London, England
1967–1968	Visiting Fellow, Institute J. J. Rousseau, Geneva, Switzerland (worked with Jean Piaget)
1965–1970	Teaching Assistant, Research Assistant, Stanford University
1965–1970	Statistical Consultant, Stanford, California
1965–1968	Computer Programmer, Programming Instructor, Statistical Advisor, Information Processing Corporation, Palo Alto, California

RELATED PUBLICATIONS

Hyde, J. S. & Linn, M. C. (2006). Gender Similarities: Implications for Science and Mathematics Education. Science, 314, 599-600.

Linn, M. C. (2006). The Knowledge Integration Perspective on Learning and Instruction. In R. K. Sawyer (Ed.), The Cambridge Handbook of the Learning Sciences (pp. 243-264). New York: Cambridge University Press.

Linn, M. C., Davis, E.A., & Bell, P. (Eds.) (2004). Internet Environments for Science Education. Mahwah, NJ: Lawrence Erlbaum Associates.

Linn, M. C. & Kyllonen, P. (1981). The field dependence-independence construct: Some, one, or none. Journal of Educational Psychology, 73, 261-273.

Linn, M.C., Lee, H.-S., Tinker, R., Husic, F., & Chiu, J.L. (2006). Teaching and Assessing Knowledge Integration in Science. Science, 313, 1049-1050.

ADDITIONAL PUBLICATIONS

Clark, D., & Linn, M. C. (2003). Designing for Knowledge Integration: The Impact of Instructional Time. The Journal of the Learning Sciences, 12(4), 451-494.

Linn, M. C. (2005). WISE design for lifelong learning—Pivotal Cases. In P. Gärdenfors and P. Johansson (Eds.), Cognition, Education, and Communication Technology (pp. 223-256). Mahwah, NJ: Lawrence Erlbaum Associates.

Linn, M. C. & Eylon, B.-S. (2006). Science Education: Integrating Views of Learning and Instruction. In P. A. Alexander & P. H. Winne (Eds.), Handbook of Educational Psychology, (2nd Ed., pp. 511-544). Mahwah, NJ: Lawrence Erlbaum Associates.

Linn, M. C. & Hsi, S. (2000). Computers, Teachers, and Peers: Science Learning Partners . Hillsdale, NJ: Lawrence Erlbaum Associates.

Richland, L. E., Linn, M. C., & Bjork, R. A. (2007). Chapter 21: Instruction. In F. T. Durso (Ed.), Handbook of Applied Cognition (2nd Ed., pp. 555-583). West Sussex, England: John Wiley & Sons, Ltd.

SYNERGISTIC ACTIVITIES

- American Psychological Association (APA), Math and Science Education Task Force, 2007-2009.
- Institute of Education Sciences, Science Education Curriculum Research and Evaluation Working Group, 2007-2008.
- American Association for the Advancement of Science (AAAS), Board 1996-2000; Chair, Education Section (Chair-Elect 2005-2006, Chair 2006-2007, Retiring Chair 2007-2008).
- American Association for University Women (AAUW), Commission on Technology and Gender, 1998-2000.
- Graduate Record Examination Board (GREB), Educational Testing Service, 1990-1995; Technical Advisory Committee (TAC) for the GREB, Member; Chair, 1992-1997

COLLABORATORS

- Ammon, P. Univ. of California, Berkeley
- Bell, P. Univ. of Washington
- Bjork, R. A. Univ. of California, Los Angeles
- Bransford, J. Vanderbilt University
- Brophy, S. Vanderbilt University
- Burbules, N. Univ. of Illinois, Champaign
- Casperson, J. M. Univ. of California, Berkeley
- Cherniavsky, J. C. National Science Foundation
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- Peterson, A. Kellogg Foundation
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- Roseman, J. AAAS
- Ryan, C. Los Medanos College
- Seethaler, S. Univ. of California, San Diego
- Shear, L. SRI
- Singer, J. Univ. of South Carolina
- Slotta, J.D. Univ. of Toronto
- Spitulnik, M. W. Univ. of California, Berkeley
- Songer, N. Univ. of Michigan, Ann Arbor
- Tate, E. D. Univ. of California, Berkeley
- Tinker, R. D. Concord Consortium
- Titterton, N. Univ. of California, Berkeley
- Zhang, H. Univ. of California, Berkeley
- Williams, M. Michigan State University

ADVISORS AND SPONSORS

Post Doctoral

J. Piaget University of Geneva – *deceased*

Graduate

L.J. Cronbach Stanford University – *deceased*
R.E. Snow Stanford University – *deceased*
E.R. Hilgard Stanford University – *deceased*

Sponsors

Post-Doctoral Scholars: Eric Baumgartner, John Bell, Sean Brophy, Hsin-Yi Chang, Stephanie Corliss, James Gray, Jeffrey Holmes, Yael Kali, Hee-Sun Lee, Dalit Levy, Ou Lydia Liu, Ji Shen, James Slotta, Michele Spitulnik, Michelle Williams, Keisha Varma

Graduate Students: Thomas Aswell, Philip Laverne Bell, Kathy Benemann, Janet Casperson, Britte Cheng, Jennie Chiu, Doug Clark, Helen Clark, Alex Cuthbert, Paul Daubenmire, Elizabeth Anna Davis, Kristina Duncan, Megan Dueck, Jennifer Esterly, Matthew Fishbach, Andrew Fisher, Brian Foley, Oliver Grillmeyer, Amy Holloway, Tara Higgins, Christopher M. Hoadley, Sherry Hsi, Samantha Johson, Michael Katz, Nathan Kirk, Alton Lee, Hee-Sun Lee, Brian Levey, Eileen Lewis, Alan Li, Ernie Lo, Jacquie Madhok, Lydia Mann, Paul Mazzei, Matthew Mc Hugh, Kevin McElhaney, Lawrence Muilenburg, Abbey Novia, Sandhya Rao, Dawn Rickey, Kristine Romano, Patricia Schank, Christina Schwarz, Beat Schwendimann, Sherry Seethaler, Michelle Shaver, Linda Shear, Stephanie Sisk-Hilton, Elisa Stone, Ricky Tang, Erika Tate, Laura Telep, Eric Terual, Lori Tewksbury, Mark Thomas, Lydia Tien Richard Weinland, Michelle Williams, Jully Yi, Helen Zhihui Zhang, Tim Zimmerman.

Paul Horwitz

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(A) Professional Preparation

Undergraduate Institution:	Harvard College	Major: Physics	Degree & Year: AB, 1960
Graduate Institutions:	Columbia University	Major: Physics	Degree & Year: MS, 1963
	New York University	Major: Physics	Degree & Year: Ph.D., 1967
Postdoctoral Institutions:	Cornell University	Physics	Years: 1967- 1969
	University of Oregon	Physics	Years: 1969- 1971

(B) Academic / Professional Appointments

The Concord Consortium, Concord, MA; Senior Scientist; 1997–Present
Educational Network Services, Concord, MA; President and CEO; 2003 -Present
BBN, Inc., Cambridge, MA; Principal Scientist; 1992–97
BBN, Inc., Cambridge, MA; Senior Scientist; 1979–92
Massachusetts Institute of Technology; Ctr for Policy Alternatives, Research Associate, 1978-79
Avco Everett Research Laboratory, Everett, MA; Senior Scientist; 1976–19 78
Congressional Fellow (American Physical Society), Office of Senator E. Kennedy; 1975-76
Avco Everett Research Laboratory, Everett, MA; Scientist; 1971–19 75

(C) Publications

Publications most closely related to the proposed project

Horwitz, P. and Christie, M.A. (2000) *Computer-Based Manipulatives for Teaching Scientific Reasoning: An Example,* in Innovations in Science and Mathematics Education: Advanced Designs for Technologies of Learning, Lawrence Erlbaum Assoc., Mahwah, NJ

Hickey, D.T., Kindfield, A.C.H. Horwitz, P., and Christie, M.A. (1999) *Advancing Educational Theory by Enhancing Practice in a Technology-Supported Genetics Learning Environment,* Journal of Education, 181 (2)

Horwitz, P. and Christie, M.A. (1999) *Hypermodels: Embedding Curriculum and Assessment in Computer-Based Manipulatives,* Journal of Education, 181 (2), 1 – 23

Horwitz, P. (1999) *Designing Computer Models that Teach,* in Computer Modeling and Simulation in Pre-College Science Education, pp. 179 – 196, Nancy Roberts and Wallace Feurzeig, eds., Springer Verlag, Berlin

Horwitz, P (1996) *Linking Models to Data: Hypermodels for Science Education,* The High School Journal, 79 (2), 148 - 156.

Other significant publications

Horwitz, P (2007) Computers and Clean Slates: Creating Interactive Learning Experiences, @Concord, 11 (1)

Horwitz, P. (2005) What do students need to know to achieve ICT fluency?, Proceedings of the Workshop on ICT Fluency and H gh School Graduation Outcomes, National Academy of Sciences, Washington, DC

Horwitz, P. and Barowy, W. (1994) Designing and Using Open-Ended Software to Promote Conceptual Change, Journal of Science Education and Technology 3 (3),161 – 185

Horwitz, P., Taylor, E.F., and Barowy, W. (1994) Teaching Special Relativity with a Computer, Computers in Physics 7 (1)

Horwitz, P and Feurzeig, W. (194) Computer-Aided Inquiry in Mathematics Education, Journal of Computers in Mathematics and Science Teaching 13(3), 265 - 301

(D) SYNERGISTIC ACTIVITIES

Testified before the House Subcommittee on Science, Research and Technology on the Computer Literacy Act and the National Educational Software Act, 1984

Winner, EDUCOM Higher Education Software Awards for Best Design and Best Physics Software for the RelLab Program, 1992

Developed and promoted the concept of scripting models for educational purposes ("hypermodels")

Initiated and experimented with the remote collection of performance data from hypermodels for assessment purposes.

Consulted to National Research Council Panels on Science of Learning and Learning Research and Education Practice

Contributed to the National Conference on Achieving High Educational Standards for All, 2002

(E) COLLABORATORS & OTHER AFFILIATIONS

(i) Collaborators and Co-Editors

Buckley, Barbara, retired
Chamberlain, John, Center for Occupation Research and Development
Dede, Chris, Harvard University
Garik, Peter, Boston University
Gobert, Janice, Worcester Polytechnic Institute
Koon, Al, Tidewater Community College
Linn, Marcia, University of California at Berkeley
Rogers, Chris, Tufts University
Wilensky, Uri, Northwestern University
Willet, John, Harvard University

(ii) Graduate Advisors and Postdoctoral Sponsors

Hans A. Bethe, deceased
Michael J. Moravcsik, deceased
Malvin A. Ruderman, Columbia University

(iii) Thesis Advisor and Postgraduate Scholar Sponsor

N/A

Ou Lydia Liu

Professional Preparation

University of Science and Technology of China	Science and English	B.S., 2001
University of Science and Technology of China	Business Law	B.A., 2001
University of California at Berkeley	Quantitative Methods and Evaluation	M.A., 2004
University of California at Berkeley	Quantitative Methods and Evaluation	Ph.D., 2006

Appointments

Associate Research Scientist, August 2006 – Present
Center for Validity Research
Educational Testing Service, Princeton

Summer Intern, Summer 2006
Psychometric Research Group
Law School Admission Council

Research Assistant, 2002-2006
Berkeley Evaluation and Assessment Research Center
Graduate School of Education
University of California at Berkeley

Summer Intern, Summer 2005
Teaching and Learning Group
Educational Testing Service, Princeton

Publications

Publications Most Closely Related to the Proposed Project

Liu, O. L., Lee, H.S., & Linn, M.C., (in press, 2008). Assessing knowledge integration in science: Construct, Measures, and Evidence. *Educational Assessment*.

Lee, H.S., **Liu**, O. L., & Linn, M.C. (under review). Construct validity of inquiry assessments: role of multiple choice and explanation item format. *Applied Measurement in Education.*

Liu, O. L., Wilson, M., & Paek, I. (in press, 2008). A multidimensional Rasch analysis of gender differences in PISA mathematics. *Journal of Applied Measurement*.

Liu, O. L., & Rijmen, F., (in press, 2008). A Modified Procedure for Parallel Analysis for Ordered Categorical Data. *Behavior Research Methods*.

Liu, O. L., Minsky, J., Ling, G.M., & Kyllonen, P. (conditionally accepted). Using the Standardized Letter of Recommendation in Selection: Results from a Multidimensional Rasch Model. *Educational and Psychological Measurement*.

Other Significant Publications

Liu, O. L., & Wilson, M. (conditionally accepted). Sources of self-efficacy belief: Development and Validation of two scales. In M. Wilson (ed.). *Handbook of the 13th International Objective Measurement Workshop.*

Liu, O. L., Minsky, J., Ling, G., & Kyllonen, P. (2007). Using standardized letter of recommendation. *ETS research report series (RR-07-038)*. Princeton: NJ.

Liu, O.L., Jackson, T, & Ling, G. (in press, 2008). An Initial Field Trial of an Instrument for Measuring Learning Strategies of Middle School Students. *ETS research report series.* Princeton: NJ.

Liu, O.L. & Wilson, M. (under second review). Gender differences in large-scale mathematics assessments: PISA trend 2000 & 2003. *Applied Measurement in Education*.

Synergistic Activities

Committee Chair, Planning the 5th Spearman Conference in China (2007-Present)

Doctoral Student Mentor, psychometric program sponsored by Morgan State University and Educational Testing Service (2007-Present)

Collaborators & Other Affiliations

Collaborators

Brent Bridgeman, Principal Research Scientist, Educational Testing Service
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Frank Rijmen, Psychometrician, Educational Testing Service
Mark Wilson, Professor, University of California at Berkeley
John Young, Senior Research Scientist, Educational Testing Service

Graduate and Postdoctoral Advisors

Mark Wilson, Professor, University of California at Berkeley