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Brian L. Zuckerman
Abigail R. Azari
William E. J. Doane

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POLICY INSTITUTE
1899 Pennsylvania Ave., Suite 520
Washington, DC 20006-3602

About This Publication

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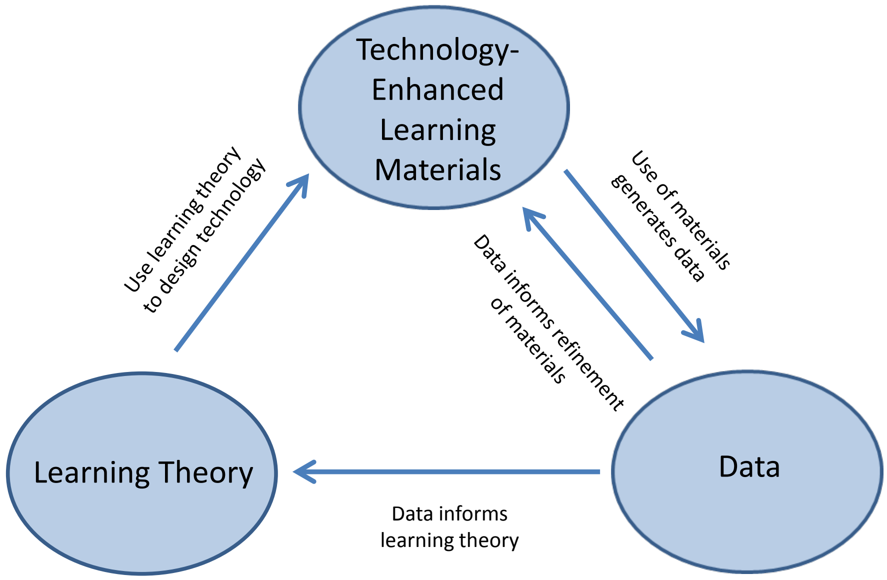
Executive Summary

On July 29, 2013, the National Science Foundation (NSF) hosted a workshop on technology-enhanced education that brought together nearly 100 participants, including representatives of Federal agencies and 2- and 4-year degree-granting institutions as well as experts in key areas related to technology-enhanced education, assessment, and learning. The purpose of the workshop was to invite community input to inform Federal agencies, the White House Office of Science and Technology Policy (OSTP), and the NSF about how to effectively create U.S. Government strategies to promote advances in undergraduate education in light of rapid progress in online learning tools and research on learning.

Workshop participants began by identifying an overall vision for the future of post-secondary education in the United States: *computer-mediated learning, anytime, anywhere.* Participants also identified a research-oriented vision in support of the overall one: *from learning science to learning engineering.* Plenary session presenters discussed advances in the fundamental science of learning—the underlying research base as to how individuals learn—and called for the development of a new applied discipline—termed *learning engineering*—which was intended to translate these fundamental insights into new learning environments and tools.

Technology-enhanced learning environments provide a mechanism for translating fundamental principles of the learning sciences into curricula. These environments offer a cycle of continuous improvement through the collection and analysis of participant data. Learning engineers can quickly identify the strengths and weaknesses of particular environments and refine them through analyses of the large quantities of data produced through participant interactions (e.g., clickstream data, data on problems addressed correctly and incorrectly, and potentially audio or film data intended to measure participant engagement). Finally, the collection and analysis of data may lead to new fundamental hypotheses that can be tested through the learning sciences, which further can be fed back into instructional materials development and teaching practice. This cycle is depicted in the figure on the next page.



Learning Engineering Paradigm

Workshop participants identified three groups of grand challenges related to realizing the workshop participants' long-term and short-term visions:

- One group of challenges is related to the development of the technologies themselves. This group includes the upfront challenges in the development of new technologies; issues related to dissemination, access, and quality; and concerns regarding balancing intellectual property, data ownership, and privacy considerations.
- A second group of challenges is specific to the university context, regarding the complexities of embedding technology-enhanced learning environments into undergraduate education.
- A third group of challenges is related to the short-term vision, namely, the need for the further development of learning sciences to the point where they can be used in the genesis of learning engineering as a full-fledged discipline.

Workshop participants also discussed challenges associated with developing competencies, including their definitions, measurement issues, and privacy-related challenges specific to assessment. Similarities and differences in challenges associated with developing competencies for industry and military training and those associated with university-based learning were an integral part of the conversations.

Participants suggested a four-part action plan for future Federal efforts to advance technology-enhanced learning:

RECOMMENDATIONS TO ADVANCE TECHNOLOGY-ENHANCED LEARNING ENVIRONMENTS

1. *Develop a research agenda for technology-enhanced learning at the post-secondary level:* The learning sciences and learning technology communities are at the cusp of catalyzing potentially transformative change. Convening these communities to pose research challenges and develop priorities that could be used as the basis for action by Federal agencies and others will maximize the usefulness of research resources.
2. *Support centers of excellence*: Center-mode research facilitates large-scale, in-depth research in particular topical areas and industry-university cooperative research efforts in developing and implementing learning technologies. Centers could serve as hubs for connecting academia with venture capital and emerging small businesses in the educational learning technology arena, which was considered by participants to be a priority as they could help emerging technologies successfully traverse the “valley of death” between academic research and commercialization.
3. *Conduct collaborative research calls*: Many Federal agencies fund learning science and educational technology research in post-secondary settings. Conducting joint calls in areas of interest (e.g., educational games and digital tutors) both facilitates the transmission of best practices among awardees and assists Federal policy-makers in setting and realizing larger priorities in technology-enhanced learning.
4. *Identify opportunities for public-private partnerships*: Developing a research agenda, supporting centers of excellence, and conducting collaborative research is not merely a Federal challenge; industry, State and local governments, and foundations have a role to play, especially in scaling up successful demonstrations.

Contents

1. Workshop Rationale and Design

A. Introduction

Community input is needed to inform Federal agencies and the White House Office of Science and Technology Policy (OSTP) about creating effective U.S. Government strategies to promote advances in undergraduate education in light of rapid progress in online learning tools and research on learning. Many public and private sector organizations are exploring specific areas without benefit of being informed by relevant work in other sectors and are often biased by their own experiences and interests in these ventures. For example, many of the online courses that are proliferating in higher education are not well informed by research on how undergraduates learn. Platforms for online delivery are springing up without knowledge of major Federal investments in open access platforms, including the National Training and Education Resource (NTER). Competency versus credit-based determination of success has major policy implications, and current investments in high-quality, technology-based tools could be an important asset in the implementation of effective competency-based assessment. The goal of these efforts is to transform education and training from volume-based to value-based enterprises.

B. Background

OSTP staff initiated conversations with the National Science Foundation (NSF) about community-building workshops around the issue of leveraging technology-enhanced education to improve science, technology, engineering, and mathematics (STEM) learning and workforce outcomes, which is a concern across the Federal Government.[1] The consensus of these conversations was that the expertise of government, industry, and academics need to be brought together in an objective manner to inform government policies and programmatic decisions. A broad cross-section of different agencies, institutions of higher learning, and corporate entities needed to be involved given the complexities of technology-enhanced education and provider-proprietary tools, as well as the varied interests of the stakeholders. On July 29, 2013, NSF hosted the workshop on technology-enhanced education in conjunction with OSTP and other mission agencies. The workshop brought together nearly 100 participants that included representatives from Federal agencies and 2- and 4-year degree-granting

[1] Refer to the glossary for definitions and examples of technology-enhanced learning environments.

institutions as well as experts in technology-enhanced education, assessment, and learning. Appendix A lists the participants and their affiliations.

C. Workshop Design

The workshop was designed to maximize opportunities for interaction and community-building with three plenary sessions and three breakout sessions. Appendix B provides details of the workshop agenda.

After welcoming remarks from Henry Kelly of the Department of Energy on behalf of OSTP, Joan Ferrini-Mundy and Pramod Khargonekar, the NSF Assistant Directors for Education and Human Resources and Computer and Information Science and Engineering, respectively, set the stage for presentations that followed.

Professor Candace Thille of Stanford University presented on the first plenary session topic, Integrating Technology into Undergraduate Education to Advance Learning, and Professor Beverly Woolf of the University of Massachusetts presented on the second plenary session topic, Computer-Assisted Adaptive Learning. Appendix C and Appendix D provide their presentation slides. Frank DiGiovanni from the Department of Defense stimulated discussion through question-and-answer sessions that carried into the first breakout session, What Are the Grand Challenges in Education and How Can New Educational Technologies Address Them?

A mid-day demonstration session, where 14 participants presented educational technologies and research results, allowed for informal discussion and knowledge sharing among the participants.

The afternoon was devoted to three further breakout sessions:

- How Should Learning Outcomes Be Defined and Measured?
- How Can Validated Technologies and Methods Best Be Disseminated and Adapted to Others' Needs?
- Future Directions—What Should the Federal Government's Role Be?

Discussions begun during the morning sessions continued during these afternoon sessions. The breakout groups then reported the outcomes of their discussions to all attendees and began the process of formulating action steps.

2. Future Vision

Workshop participants began by identifying a specific vision for the future of the post-secondary education system in the United States: *computer-mediated learning, anytime, anywhere*. This concise vision is intended to serve both as a guide to action and a starting point for identifying the stakeholder communities who will need to be involved in realizing the vision. Work towards realizing this vision is already occurring in universities and community colleges across the country with participation of industry, foundations, and government organizations. Today, Federal research and development (R&D) agencies have an opportunity to accelerate and shape the revolution that is coming.

The five-word vision encompasses several key concepts that require explanation. Workshop participants agreed that “learning” was the best term to use in the vision statement, as it avoids creating a false dichotomy between “education” (which was perceived as connoting general-purpose skills and metacognitive behaviors useful in a variety of situations) and “training” (which was perceived as connoting specific skills, often for a particular task or job). Participants identified three implied goals of the vision as requiring deeper explication, as follows.

A. Providing Learning for All Levels and Needs

Because workers in the twenty-first century are more likely to have multiple careers, there is a growing need for adaptable training programs and lifelong learning. The need for STEM-informed learning spans community college, undergraduate, graduate, and lifelong learners. Technology-enhanced learning should encompass formal and informal modes of providing for critical thinking and analytical skills needed for the workplace and beyond as workers change fields and existing fields evolve.

Transferability of skills and knowledge needs to be emphasized, given the wider range of career paths individuals potentially possess. Transitions to universities from formal education to the workplace, or between military and civilian careers may require transferring existing skills to new situations as well as adding new skills. Learning environments specific to particular situations will not be sufficient to meet the skills needed of a twenty-first-century workforce. The flexibility of technology-enhanced learning environments allows for personalized instruction and exploration based on individual interests and needs.

Learning for all levels and needs also implies that learning environments need to be accessible to learners across many domains with a broad range of skill levels. Efforts focused on specific populations or a particular set of skills—whether foundational or advanced—will fall short of the vision. Given the range of needs and the diverse population of the United States, no single learning approach will suffice. A diversity of approaches will allow learners to be matched to those approaches best suited for their learning styles and needs.

B. Providing Learning over All Time and Space

Efforts to improve educational access to twenty-first-century skills and learning among U.S. citizens must reach populations that are currently underserved. Broadening participation by getting effective learning materials to people outside of the traditional education sphere is increasingly important. Technology-enhanced learning environments, therefore, must be accessible across a variety of platforms so that technological access and cost do not serve as barriers to universal access.

A second aspect of this goal is that learning should not be confined to traditional fixed locations (e.g., universities, classrooms, and libraries), but instead should be accessible where people work, live, and play. Mobile devices (e.g., Internet-enabled cellular phones) have the potential to become computer-based, portable, personal learning accessories. Similarly, learning environments should not be restricted by time, as traditional courses are, but instead can be accessed as needed, regardless of the time of day or year. Technology-enhanced learning environments offer the promise to meet the challenges of reaching learners without regard to geography or time.

C. Providing Blended Learning

Workshop participants identified technologically enhanced approaches as a means for speeding the movement from generalized approaches towards individualized instruction. While technology offers the future promise that fully computer-mediated learning environments will become standard and effective, trained instructors remain the "gold standard" of educational practice for the foreseeable future. Workshop participants, therefore, suggested the goal of "blended learning"—a hybrid of human-taught and computer-taught modalities for learning and the incorporation of twenty-first-century skills with technology—for providing high-quality individualized instruction. This approach allows education to be personalized so educators have greater ability to reach individual learners.

While the vision of *computer-mediated learning, anytime, anywhere* laid out by workshop participants represents the desired end state for technology-enhanced learning, the discussions identified an intermediate-term vision for the field. Plenary session presenters discussed advances in the fundamental *science of learning*—the underlying research base as to how individuals learn and the biological and psychological principles behind memory formation, cognition, and interaction in learning situations. They called for the development of a new applied discipline, which was termed *learning engineering,* intended to translate these fundamental insights into new learning environments and tools. Presenters used the analogy that as the fundamental principles of physics are embodied in machines and bridges through the activities of mechanical and civil engineers, so too the discipline of learning engineering is required to bring these new scientific advances into the classroom, workplace, or Internet-enabled learning application of the future.

One presenter argued that learning engineering and technology-enhanced learning environments go hand in hand, as shown in Figure 1. Technology-enhanced learning environments represent a mechanism for translating fundamental principles of the learning sciences into curricula, offering the particular advantage that through the collection and analysis of participant data, a cycle of continuous improvement can occur. Learning engineers can quickly identify the strengths and shortcomings of particular environments and refine them using the large quantities of data (e.g., clickstream data, analyses of problems addressed correctly and incorrectly, and potentially even technologies for measuring engagement such as cameras) that are produced as participants interact with them. Finally, the collection and analysis of data may lead to new fundamental hypotheses that can be tested through the learning sciences, which further can be fed back into instructional materials development and teaching practice.

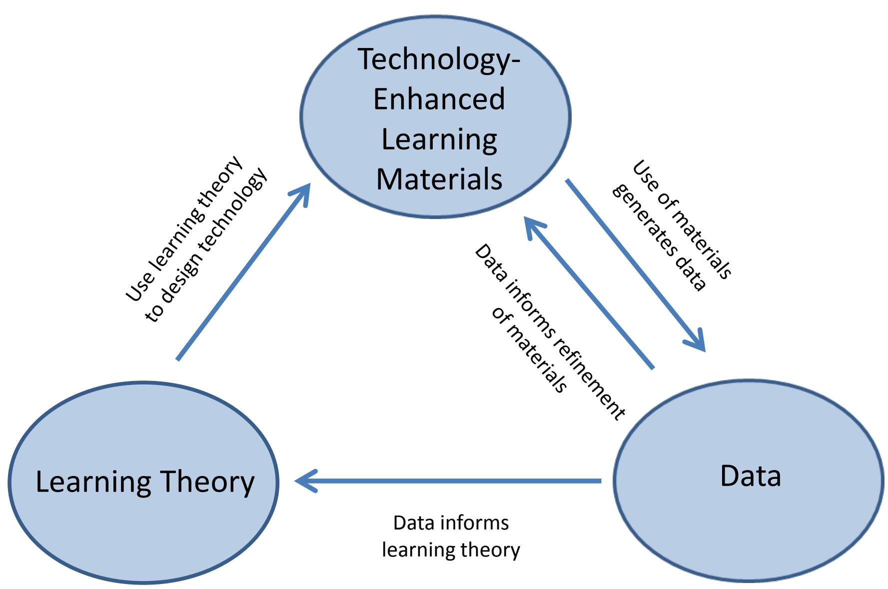


Figure 1. Learning Engineering Paradigm

A second linkage between the short-term and long-term visions is that, without well-developed learning engineering principles, it will remain expensive to deliver the quality and depth of education envisioned, especially because the potential of computer-mediated learning will remain unmet. Currently, large-scale randomized controlled trials (RCTs) are the gold standard for the validation of new approaches; these trials require a large number of participants, sites, and learners, as well as direct comparisons of educational outcomes between intervention and control groups. Moves toward personalized learning in a computer-mediated environment, whereby the nature of the education delivered varies based on each individual's learning style and engagement with the material, renders large-scale RCTs overly cumbersome and expensive to conduct. Harnessing the big data produced by technology-enhanced learning environments allows for rapid assessment both of the environments themselves and the learning engineering principles that underlie them, feeding back information for discovery and refinement of fundamental principles. Emerging methods, such as propensity score analysis and learning curve analysis—and wholly new methods still to be developed—will become increasingly necessary and important given the shift toward personalized learning technologies.

An analogy to this vision of personalized learning was drawn from the use of genomics and proteomics in biological science to launch a new era of personalized medicine. Biomedical science uses big data derived from genomic and proteomic studies to discover disease pathways and suggest new therapeutic targets. This use of big data is moving biomedical research towards observational studies in large populations (e.g., Phase IV post-approval studies to identify side effects and the use of tools like Google Flu to detect disease outbreaks) to complement RCTs. The use of technology-enhanced learning environments will allow for secondary data analyses that will complement large-scale trials of wholly new approaches and tools to discover new principles and develop new instructional approaches.

3. Grand Challenges to Realizing Future Vision

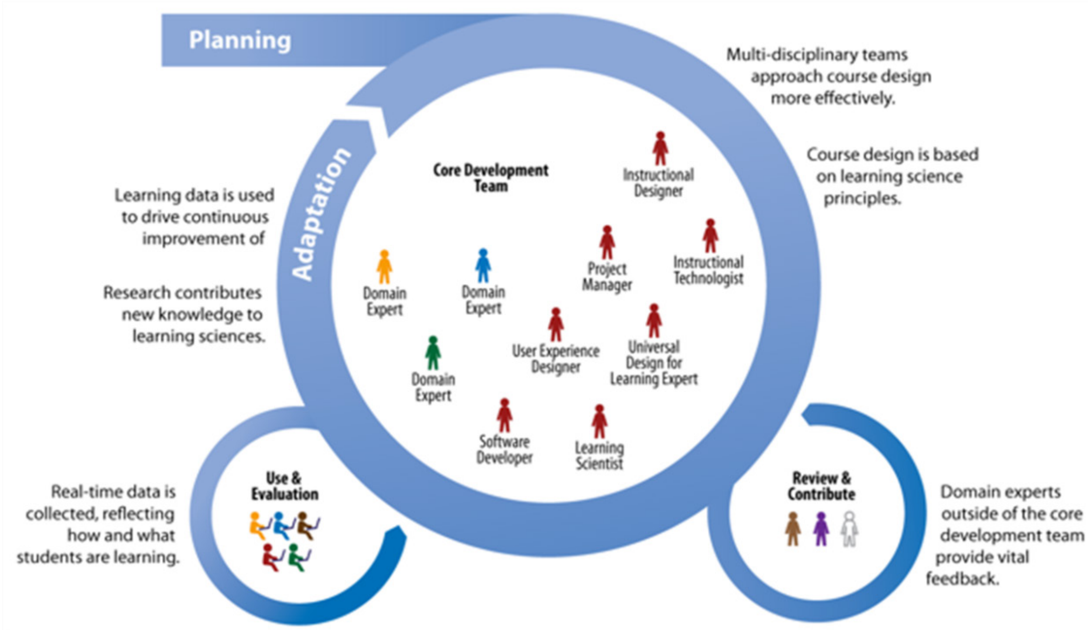
The workshop was balanced between identifying the challenges that hinder the fulfillment of the vision for post-secondary education and some potential ways to meet those challenges. Two groups of challenges related to realizing the long-term vision of *computer-mediated learning, anytime, anywhere* were identified. One of those groups relates to the development of the technologies themselves, and another involves the implementation of the resulting technology-enhanced learning environments into existing institutions. A third group of challenges relates to the short-term vision, namely, the need to further develop learning sciences to the point where they can be used in the genesis of learning engineering as a full-fledged discipline.

A. Developing Technologies Themselves

1. Upfront Development Challenges

Workshop attendees agreed that the process for development of innovations faces steep challenges due to the time and resources required to develop quality products. One concern is that large multidisciplinary teams, comprising skills in instructional design, learning science, domain expertise, and technology development, are required for effective development of technology-enhanced learning environments, as depicted in Figure 2. If some of these skills are not present during the design process, the likelihood that the resulting learning environment will be effective is lessened. The challenge is heightened when creating digital materials for blended learning. In addition to the complexities of developing the software, the in-person components of the physical environment need to be designed together with the virtual components.

Another concern in developing innovations is that the instructors implementing new technology-enhanced learning environments need to be personally involved in upfront design. Currently, materials often are not created with the instructor interface in mind and design decisions are often made far away from the classroom, resulting in products that are difficult to implement effectively. Yet, while the goal of including instructors in design is laudable, doing so is difficult when materials are intended to be used in a wide variety of settings. Correctly identifying the eventual users and implementers of a particular approach may not be feasible in this scenario.



Source: Diagram from keynote presentation by Candace Thille, which is reproduced in Appendix C.

Figure 2. Multidisciplinary Course Development Team and the Learning Engineering Paradigm

Another challenge created by the need for multidisciplinary team-based efforts is that substantial funding is required to start and continue any particular innovation that is developed. Without strong financial backing, promising ideas may never mature to successful innovation; many startup companies involved in learning technology development cease operations before innovative efforts are completed because funding becomes unavailable.

2. Dissemination, Access, Quality, and Sustainability of Approaches

Workshop participants further agreed that even when high-quality materials are created, substantial barriers to disseminating and sustaining them remain. Educational technologies, especially those intended for a post-secondary or lifetime learning audience, are disseminated into a complex, disaggregated marketplace where few standards exist. Innovations often are disseminated by word of mouth. Although there are many mini-repositories, there is no central repository of validated technologies that either instructors or learners can access and to find learning objects, curricula, users' or instructors' guides, and journal articles describing the technologies and results from their use. As a result, finding quality materials may be difficult. Dissemination of technologies may be even more difficult for individual investigators or small firms than for larger publishers, because large companies would be expected to have more capacity for wider distribution of new materials. Participants noted that in some cases there are "firstmover" advantages whereby materials of acceptable quality continue to be used even after improved approaches are developed.

A second concern participants identified related to the sustainability of technology-enhanced learning environments, especially those developed by individual faculty or small firms. Many participants were concerned that the high-quality learning environments that are developed do not include sufficient information for instructors and learners to easily adopt them. This lack of high-quality implementation guides creates an access barrier for educators who do not have information on how to effectively use these novel materials. As a result, promising efforts may remain underutilized because the cost and time to adopt them and to train educators in their proper use is prohibitive. Online professional development materials may mitigate these access barriers, and workshop participants were excited by the potential of this approach. Development and dissemination of standards (e.g., the Sharable Content Object Reference Model known as SCORM) may facilitate interoperability.

Workshop participants identified computer hardware and Internet connectivity as additional barriers to adopting technology-enhanced learning environments. Participants mentioned that these concerns are especially acute in rural areas, where not all community colleges and universities are fully connected to national Internet backbones. Recent results from an NSF National Center for Science and Engineering Statistics (NCSES) survey point to a continuing disparity in connectivity between doctoral research institutions and smaller colleges. In fiscal year 2012, the percentage of doctorate-granting institutions with bandwidth of 2.5 gigabits per second was ten times that of institutions that do not grant doctorates (53 percent versus 5 percent).[2]

3. Intellectual Property of Materials and Open Access Concerns

Because learning takes place in a variety of settings and at different levels, the ability for educators and learners to customize approaches to meet their particular needs was considered by panelists to be highly valuable. At the same time, participants identified the practicalities of navigating intellectual property and access concerns as a barrier to realizing desired goals. To the extent to which high-quality materials are controlled by particular organizations (whether private or nonprofit), it may be expensive to purchase—and difficult to modify and customize—those learning environments. Combining materials developed by multiple organizations, for example, may be difficult. Recently, open access organizations, such as Creative Commons, have begun to develop approaches to overcoming the barriers to sharing and modifying educational materials.

[2] Michael Gibbons, "Computing and Networking Capacity Increases at Academic Research Institutions," *InfoBrief* (July 2013, NSF 13-329) Arlington, VA: National Science Foundation.

CREATIVE COMMONS

Creative Commons is a nonprofit provider of copyright licenses. Licenses provide free and easily accessible legal tools to allow public access, sharing, and alteration of materials in six different levels of restriction. Ranging from basic “Attribution,” which allows for distribution, sharing, and alteration of original work as long as credit is provided, to “Attribution Non Commercial, No Derivatives,” which allows others to download original works as long as the originator is credited and does not allow for commercial dissemination. Other licenses between these extremes restrict variations to be credited to the originator or require that commercially profitable dissemination provide compensation back to the originator.

Creative Commons has licensed several open educational resources (OERs) as an alternative to private educational resources. OERs provide the option of educators and learners being able to “revise, reuse, remix, and redistribute” various educational materials. Examples follow.

Peer 2 Peer University (https://p2pu.org/) is a website that uses OERs to provide the ability of building courses, study groups, and design challenges.

OER Commons (http://www.oercommons.org/) is a database of over 31,000 openly licensed content modules evaluated by users and developed to match Common Core State Standards.

MIT OpenCourseWare (ocw.mit.edu) provides publication of most of MIT’s course content.

Carnegie Mellon Open Learning Initiative (OLI), (http://oli.cmu.edu) provides course redesign to community colleges for free by using learning science, online learning, and cognitive tutoring.

Source: Creative Commons website, http://creativecommons.org.

A related interoperability concern mentioned by workshop participants was that of data portability. Learners who over time are involved with multiple providers (e.g., Coursera and Udacity) may want to link their accounts or otherwise make known the learning objectives attained through one provider to another. To the extent to which each approach has its own siloed record formats, measurement of learning objectives, and record of learner attainment, opportunities will be lost for educators, learners, and learning scientists to understand the overall attainment of participants.

Without interoperability across courses designed by different institutions and abilities to perform meta-analyses across data collected from a variety of courses and to combine successful interventions, the true potential of computer-mediated education likely will not be reached. The use of big data techniques to speed analysis and foster innovation requires researchers in academia and industry to share data without regard to protecting intellectual property.

One particular concern workshop participants identified was sharing data collected across multiple platforms for the purpose of large-scale analyses. Thus far, efforts at data collection across platforms have been complicated by issues of privacy and informed consent from the standpoint of those whose data were collected, as well as concerns regarding intellectual property of those who created the data sets. The Family Educational Rights and Privacy Act (FERPA) in particular protects the privacy of student education records and restricts the collection and sharing of data. Open sourcing data provides a potential option for resolving these concerns, but also raises the question of balancing the rights and responsibilities of all parties.

The broader question of data ownership was also mentioned by workshop participants. If data generated through the use of learning environments are owned by the providers, it raises the specter of improper use and ethical concerns. On the other hand, if data are purely owned by the study subjects, gaining consent for secondary use and analysis may be complex, hampering learning science research and slowing the rate of innovation. As with the issue of open sourcing data, participants agreed that careful discussion and balanced standard-setting will be required. It was suggested that the National Institute of Standards and Technology, given its measurement and standard-setting mission, may be the proper convener in this domain.

B. Implementing Technology-Enhanced Learning Environments into Existing Educational Institutions

Workshop participants agreed that even if technology-enhanced learning environments can be created effectively, there may be institutional barriers to their full adoption and implementation. They identified the nation's universities and other institutions of higher education as a particular set of organizations where adoption challenges may be found. Universities and institutions of higher education exist in a conservative environment that is not conducive to large, sweeping, dynamic changes. Barriers to change may be still greater with respect to educational materials.

One concern identified by workshop participants is that institutions, especially leading universities, value research more than teaching. In such institutions, there are few incentives for graduate students to seek out and receive training in instruction and curriculum design, hindering the development of a new generation of well-trained professors. University-level policies and procedures provide few incentives to developing new approaches to pedagogy, such as technology-enhanced learning environments, nor are there incentives for university faculty to engage in professional development around their pedagogy. Moreover, individual departments and faculty members control curriculum development. In primary education, State or national standards encourage the adoption of new approaches wholesale. In the university setting, however, diffusion of innovations may occur one department, or even one faculty member, at a time.

A second barrier identified by workshop participants is that there is a mismatch between the goal of a team-based approach to technology-enhanced learning environments and the organization of institutions of higher education. University teaching, curriculum development, and refinement are considered a singular pursuit that is the individual responsibility of each faculty member. In many tenure and promotion systems, co-teaching courses and investing time and effort into the development of new techniques is neither acknowledged nor valued. Developing new learning environments requires a large investment of time and resources and therefore may be feasible only in rare cases, even when faculty are interested in becoming educated in instructional design principles and technology development. Dedicated expert resources at department or university levels are required. These resources would need to be supported by long-term revenue streams—likely taken from overhead funds otherwise encumbered for the support of research, equipment, and physical plant—to ensure continuity and sustainability of efforts.

A third barrier mentioned was that emerging approaches to blended learning and online education have not yet been fully accepted into academia. Online platforms are often thought of as devaluing or replacing faculty (perhaps in an effort to cut costs or replace tenure-track faculty with adjuncts), rather than providing a new capability for educators to enhance their instructional practices and to facilitate their students' learning. Overcoming the difficulties of navigating the cultural challenges associated with introducing technology-enhanced learning environments into the university will require continuing attention from university leadership, faculty, and developers.

C. Developing Learning Sciences to Advance Learning Engineering as a Discipline

Workshop participants agreed that while advances have been made in the fundamental science of learning and teaching, there is not yet a well-developed set of theoretical principles that can be translated into general practice—and without a science of learning, developing learning engineering is not possible. The current state of learning science, participants judged, depends heavily on individual theories rather than validated general principles. Without robust learning science-based principles, curriculum development and teaching is a craft rather than a science; best practices are tacit rather than clearly stated and validated and are difficult to transmit from individual to individual. Development of learning engineering is hindered by this lack of a well-established discipline, and is a fundamental barrier to the realization of the vision. Without well-developed principles, delivering the quality and depth of education envisioned will remain difficult and expensive, leaving the potential of computer-mediated education unfulfilled. A related discussion concerned the need to develop standard data elements and methodological approaches for measuring learning.

4. Challenges Related to Competencies

In addition to the grand challenges described in the previous section, workshop participants wrestled with fundamental questions regarding how learning might be specified in the form of competencies, and how attainment of those competencies might be measured. While participants were unable to definitely address this vital question over the course of the single-day meeting, they did lay out the fundamental challenges associated with developing and measuring competencies.

A. Defining and Developing Competencies

Participants pointed to vocational training as an area where competency development has been successful (see *Welding: A Competencies Success Story* on the next page). In these cases, industry and academia have worked cooperatively to define the range of job-specific tasks, analytical skills, and workplace-readiness "soft skills" that employees require at each level of expertise. For the job-specific tasks, appropriate tests have been created that require workers to demonstrate necessary skills. Tightly defined competencies and requirements facilitate the development of technology-enhanced learning environments that are designed to supplement instructors' efforts.

While successes have been identified in these domains, they have not been replicated broadly in the university setting. There is little agreement on what constitutes competency in physics at an undergraduate or graduate level, for example, or on the set of skills that comprise "cognitive readiness" for lifelong learning. Participants argued that a barrier to developing competencies associated with undergraduate and graduate education is the fundamental reliance on imparting skills in *critical thinking*, *model building*, and *problem solving*. These constructs have not been operationalized in a way that would allow for the definition of tight competency statements, and there is fundamental disagreement as to whether doing so is desirable or even possible. It was suggested during the workshop that there may be value in pursuing this approach and that introductory-level STEM courses would be the most appropriate starting point for such an effort. Another suggestion was that scientific societies convene to discuss the definition of competencies. The American Physical Society, for example, might be the locus of activity to define competencies in physics, perhaps under the aegis of its Physics Education program.

WELDING: A COMPETENCIES SUCCESS STORY

Development of welding competency models

Based upon the Advanced Manufacturing Competency Model, the welding industry and education certification stakeholders worked together to build industry-based competency standards for welding certification. The NSF-funded National Center for Welding Education and Training (Weld-Ed), the American Welding Society (AWS), and industry experts worked together to define the skills needed by employers and how to provide them in current certification programs. They defined three levels of certification—welder, welder technician, and welding engineer—complete with knowledge areas and skills required. The certification standards are reviewed every 2 to 3 years.

Source: http://www.careeronestop.org/competencymodel/info_documents/WeldingCMInAction.pdf.

Use of simulators to teach welding competencies

As part of the curriculum in welding certification courses, welding simulators are utilized to provide a realistic and hands-on, yet inexpensive and safe, alternative. One such welding simulator, the VRTEX 360, is able to simulate realistic puddles (areas of molten metal required for welding)and an arc welding sound to provide a fully immersive environment. The VRTEX 360 uses virtual reality goggles and a traceable welding electrode to track the welding task. The instructor is able to build welding scenarios and the machine records student assessment based on speed, angle, and coordination. Given real-world limitations on materials, the simulator allows for multiple practice sessions.

A welding student courtesy of Associated Press Images.

Sources: Weld-Ed, Welding Course for Educators at http://www.weld-ed.org/curriculum/ and "The New Face of Technical Education," *Minnesota State Colleges & Universities Foundation Magazine* 6(1), http://www.mnscu.edu/media/publications/pdf/mnstate_magazine_fall2010.pdf.

Future directions

Workshop participants mentioned that while simulators are being used effectively today by expert instructors in assisting students to develop competencies, the data collected through these technology-enhanced learning environments can be leveraged further in support of learning engineering principles. Because simulators collect fine-grained data for each use, for example, regarding the angle at which the welder is held and the time the virtual flame is applied, data mining-based techniques can identify the specific "knowledge components" involved in welding. Once such models have been developed, they provide feedback to instructors regarding whether students have mastered particular welding principles and identify common areas of difficulty, which instructors can use to improve their own teaching.

B. Measuring Learning

Workshop participants agreed that a competency-based set of learning measures is superior to metrics that are activity based. Completion and accreditation data for programs are weak measures of success, for a variety of reasons. One reason is that merely counting degrees completed or student-hours of instruction delivered provides little insight as to whether any learning has occurred. Even negative measures such as dropout rates may not provide much insight, participants argued, as many learners do not complete programs for various reasons. One example mentioned was that many programs online and in community colleges reach lifelong learners who do not complete courses, but who still gain knowledge or become more engaged with or confident in their ability to work in a subject area. Completion measurements alone do not reflect learning, let alone more subtle considerations such as the learners' satisfaction with their experience. A similar challenge was described in the context of industry and military training, which sometimes focuses on running the requisite numbers of people through courses at minimum cost with insufficient attention to quality. Participants described four particular challenges relative to competency measurement:

- *Sufficient Approximations:* All measurements of learning are essentially approximations. Balancing the value of increasing rigor and specificity of testing against the burden associated with the testing process itself on learners, educators, and assessors is a complex challenge. What level of approximation is sufficient to measure each class of learning outcomes? How can cognitive skill development be measured in real time? Can high-fidelity, low-cost simulation tools be developed to assess practical skills?
- *Measurement beyond Cognitive Skills*: Additional questions were raised with respect to measurement of domains beyond subject-matter knowledge. How can skills such as critical thinking or interpersonal skills be measured? How can and should learner properties such as engagement, interest, or confidence be measured?
- *Interactions and Assessment*: Many STEM fields are moving towards a greater reliance upon interactivity and interdisciplinarity with investigators from multiple backgrounds (and often in multiple locations) working collaboratively to solve problems. Technology-enhanced learning environments allow for greater peer-to-peer and learner-to-learner interactions. For example, online courses often have a discussion forum, where students can help others. Workshop participants identified that most current assessment strategies, however, ares administered individually. How can the value of interaction be identified and measured? Can and should assessments be designed that measure not only individual learners' efforts but also the scope and value added by interaction and peer production?

- *Scale:* Competencies can be defined and measured at many levels, ranging from the specific fact, through particular concepts, to an entire discipline or field of study. While technology-enhanced learning environments offer the promise of collecting massive quantities of granular data, using these data to measure competencies depends upon the competencies that are defined such that collected data can be applied to them, and upon analysis tools that can use collected data to assess whether competencies have been met. How to handle big data, accurately analyze it, and scale data up and down effectively for measurement are challenges.

C. Privacy Issues

Privacy issues and their applicability to competency development and assessment issues was a recurring theme of the workshop. Given the call for large shared assessment data sets, student privacy becomes a concern.

Workshop participants described two current approaches to measuring competencies: large population studies and small population studies. Large population studies tend to use general measures such as standardized test scores, which provide a sense of overall achievement but little insight into what learners actually understand. Small population studies allow measurement of detailed information about the learning process, but results are difficult to generalize beyond the specific population assessed. Workshop participants identified a niche between these two approaches, where learning in medium-sized populations can be assessed in detail, using technology-enhanced learning environments. Formative assessment performed in this fashion has the potential to provide detailed feedback to learners and educators while generating data that can influence education theory and drive innovation. In addition to the limitations on research of this type stemming from FERPA, participants stressed that a National Institutes of Health-led reassessment of human subjects and privacy rules threatens to increase regulatory burden associated with learning science research, potentially requiring advanced consent for all secondary data analyses such as those envisioned in these mesoscale analyses. It was suggested there may be a need for NSF (or others) to convene a working group to develop an approach for balancing human subject protection and privacy issues with research needs in this domain.

5. Action Plan for Future Federal Effort

Participants agreed that attainment of the long-term and short-term visions developed at the workshop, and the approach to curriculum design and deployment that they suggest, will require extensive modifications to Federal Government efforts in the educational technology arena. Historically, many Federal agencies have invested in technology and learning sciences for use in post-secondary settings, but often these efforts have been uncoordinated, so that best practices and successful results have not been fully leveraged. Especially at a time of budgetary stringency, coordinated efforts and government-wide knowledge sharing are vital to ensure that the most pressing issues are addressed and maximal results obtained. Participants suggested a four-part action plan for future Federal efforts to advance technology-enhanced learning.

1. *Develop a research agenda for technology-enhanced learning at the post-secondary level.* The learning sciences and learning technology communities are at the cusp of catalyzing potentially transformative change in post-secondary education. At the same time, there are many unknowns regarding the fundamental science of learning, the translation of those fundamental ideas into curriculum design and technology development, and the best use of technology to enhance learning at all post-secondary levels. Convening stakeholders will be required—potentially under the aegis of the National Science and Technology Council's Committee on Science, Technology, Engineering, and Mathematics (CoSTEM)—to pose research challenges and develop priorities that could be used as the basis for action by Federal agencies and others. The President's Council of Advisors on Science and Technology actively works on STEM issues and could develop recommendations in this area.
2. *Support centers of excellence.* The National Science Foundation, the Department of Defense, and the Department of Education have supported centers of excellence in learning science and educational technology research. Centers allow for large-scale, in-depth research in particular topical areas. Participants called for continuing investment in these centers while expanding their scope and breadth to include "learning engineering" as well as learning sciences and industry-university cooperative research efforts in developing and implementing learning technologies. Such centers could serve as hubs for connecting academia with venture capital and emerging small businesses in the learning technology arena, which was considered by participants to be a priority as they could help emerging technologies successfully traverse the "valley of death" between

academic research and commercialization. Commercialization-related programs (e.g., Small Business Innovation Research and NSF Innovation Corps) also may play a role in moving technologies forward.

3. *Conduct collaborative research calls.* Many Federal agencies fund learning science and educational technology research in post-secondary settings, including the National Science Foundation, the Department of Defense, and the Department of Energy. Conducting joint calls on areas of interest (e.g., educational games and digital tutors) both facilitates the transmission of best practices among awardees and assists Federal policy-makers in setting and realizing larger priorities in technology-enhanced learning. Interagency support for cybersecurity (e.g., the CyberCorps: Scholarship for Service program funded by NSF in coordination with Department of Homeland Security) may offer models for other collaborative activities.

4. *Identify opportunities for public-private partnerships.* Developing a research agenda, supporting centers of excellence, and conducting collaborative research is not merely a Federal challenge; in all three areas industry, State and local government, and foundations have a role to play, especially in scaling up successful demonstrations. Given current budgetary constraints, identifying opportunities whereby Federal investments can leverage other support through public-private partnerships is essential in realizing the vision. Whether the goal is setting standards, sharing data, or supporting promising interventions, public-private partnerships offer a route to leveraging investments.

Appendix A.
Workshop Participants

Name	Affiliation
Adams, Bernadette	Department of Education
Alfano, Kathleen	College of the Canyons
Atkinson, Robert	Arizona State University
Awadelkarim, Osama	Pennsylvania State University
Baker, Eva	University of California, Los Angeles
Blumenthal, Marjory	Office of Science and Technology Policy
Bonvillian, William	Massachusetts Institute of Technology, Washington, D.C.
Branan, Daniel	Colorado Community College System
Breslow, Lori	Massachusetts Institute of Technology
Carter, V. Celeste	National Science Foundation
Cherniavsky, John	National Science Foundation
Cohen, Alex	Department of Energy
Cooper, Kevin	Indian River State College
DiCerbo, Kristen	Pearson
DiGiovanni, Frank	Office of the Deputy Assistant Secretary of Defense (Readiness)
Elmore, Donna	Orangeburg-Calhoun Technical College
Feser, Jason	AAAS Fellow
Fletcher, J. Dexter	IDA Studies and Analyses Center
Ford, Knatokie	AAAS Fellow
Fox, Michelle	Department of Energy
Fu, Xiang	Hofstra University
Gates, S. James	University of Maryland
Goroff, Daniel	Sloan Foundation
Green, Cheryl	Prince George's Community College
Hardy, Darcy	Department of Education
Hill, Randall	University of Southern California
Hodge-Clark, Kristen	Association of American Universities
Hooper, Thomas	Department of Labor
Jackman, John	Iowa State University
Jones-Davis, Dorothy	AAAS Fellow
Katchova, Ani	University of Kentucky—AAAS Fellow USDA
Kelly, Henry	Office of Science and Technology Policy
Knowles, Tracy	Bluegrass Community and Technical College
Kramer, Bruce	National Science Foundation
Laitinen, Amy	New America Foundation
Larsen, Glenn	National Science Foundation/Small Business Innovation Research
Lathe, Warren "Trey"	AAAS Fellow
Law, Kim	National STEM Consortium
Lester, James	North Carolina State University
Leu, Sharon	Department of Labor

Name	Affiliation
Lurie, Howard	EdX
Mack, Kelly	Association of American Colleges and Universities
Maldonado, Theresa	National Science Foundation
McKnight, Steven	National Science Foundation
Muench, Matthew	Joyce Foundation
O'Connor, Sally	National Science Foundation
Olson, Rebecca	McGraw-Hill
Perez, Ray	Office of Naval Research
Perkins, Katherine	University of Colorado
Peterson, Bruce	Bemidji State University
Plotkin, Hal	Department of Education
Porter, Sandra	Biolink ATE
Preston, Jon	Southern Polytechnic State University
Proctor, David	AAAS Fellow
Qaissaunee, Michael	Brookdale Community College
Rajan, Rahim	Bill and Melinda Gates Foundation
Riley, Donna	National Science Foundation
Rollins, Evette	National Science Foundation
Sanders , James	Department of Education
Sarma, Sanjay	Massachusetts Institute of Technology
Saxberg, Bror	Kaplan, Inc.
Shilling, Russell D.	Defense Advanced Research Projects Agency
Singer, Susan	National Science Foundation
Smith, Richard	National Science Foundation
Soo, David	Department of Education
Spalter-Roth, Roberta	American Sociological Association
Stacey, Paul	Creative Commons
Stepanek, Laurie	AAAS Fellow
Tanner, Michael	Association of Public and Land-grant Universities
Teese, Robert	Rochester Institute of Technology
Tennen, Ruth	Department of State–AAAS Fellow
Thille, Candace	Carnegie Mellon University
Vigeant, Margot	Bucknell University
Weber, Jerry	College of Lake County
Whitmeyer, Steven	James Madison University
Woolf, Beverly	University of Massachusetts Amherst/National Science Foundation

Appendix B.
Workshop Agenda and Breakout Questions

Advancing Technology Enabled Education Workshop Agenda

July 29th, 2013

National Science Foundation, Room 375

4201 Wilson Boulevard, Arlington VA

8:15-9:00: Welcome and Setting the Stage

8:15-8:30 Henry Kelly (White House Office of Science and Technology Policy/Department of Energy)
8:30-8:45 Joan Ferrini-Mundy (National Science Foundation)
8:45-9:00 Pramod Khargonekar (National Science Foundation)

9:00-9:40: Plenary Session 1: Integrating Technology into Undergraduate Education to Advance Learning

9:00-9:20 **Candace Thille (Carnegie Mellon University/Stanford University)**
9:20-9:40 **Questions and Discussion**

9:40-10:20: Plenary Session 2: Computer-Assisted Adaptive Learning: Tutors, Games, and More

9:40-10:00 **Beverly Woolf (University of Massachusetts/National Science Foundation)**
10:00-10:20 **Questions and Discussion**

10:20-11:00: Plenary Session and Discussion 3: Using Technology Enhanced Approaches to Measure Competency: Defining Appropriate Metrics and Developing Assessments

10:20-10:40 **Frank DiGiovanni (Department of Defense)**
10:40-11:00 **Questions and Discussion**

11:00-11:15: Break

11:15-Noon: Breakout Session 1: What Are the Grand Challenges in Education and Training and How Can New Technologies Address Them?

Noon-1:30: Lunch and Demonstration Session/Networking

Demonstrators: **Dr. Daniel Branan, Colorado Community College System**
Dr. Lori Breslow, Massachusetts Institute of Technology
Ms. Kim Law, National STEM Consortium
Dr. James Lester, North Carolina State University
Ms. Rebecca Olson, McGraw-Hill
Dr. Ray Perez, Office of Naval Research
Dr. Katherine Perkins, University of Colorado
Dr. Jon Preston, Southern Polytechnic State University
Mr. Paul Stacey, Creative Commons
Dr. Robert Teese, Rochester Institute of Technology
Dr. Candace Thille, Carnegie Mellon University
Dr. Jerry Weber, College of Lake County
Dr. Steven Whitmeyer, James Madison University
Dr. Beverly Woolf, University of Massachusetts

1:30-1:45: Setting Stage for Afternoon Breakout Sessions: **Susan Singer & Steven McKnight (NSF)**

1:45-2:30: Breakout Session 2: How Should Learning Outcomes Be Defined and Measured?

2:30-3:15: Breakout Session 3: How Can Validated Technologies and Methods Best Be Disseminated and Adapted to Others' Needs?

3:15-3:30: Break

3:30-4:00: Breakout Session 4: Future Directions—What Should the Federal Government's Role Be?

4:00-5:00:Report Backs and Discussion

Breakout Session Questions

<u>Breakout Session 1: 11:15am-12:00pm</u>

What are the Grand Challenges in Education and Training and How Can New Technologies Address them?

- What are the grand challenges in education and training?
- How can technologies help address these challenges?
- What are technologies that have shown promise in improving learning?
    - How are these technologies being used?
    - Are they pilots or being used at a large scale?
    - Have they been evaluated?
- Are there commercial technologies with a potential to help with the challenges if applied to learning?
- What management strategies are best suited to encouraging development of instructional systems based on sophisticated technology and facilitating continuous improvement and evaluation?

<u>Breakout Session 2: 1:45pm-2:30pm</u>

How Should Learning Outcomes Be Defined and Measured?

- What are current challenges in measuring educational outcomes? How can competency best be defined and measured?
- How can new technologies help measure desired competencies? Can they measure complex intellectual skills?
- How can we ensure that measured competencies correlate with desired outcomes (as measured by success in later courses or success in job settings)
- How can we collect data needed for continuous improvement of courses and for research and ensure that privacy, and privacy laws, are respected?
- How can new metrics of competency be broadly accepted (accreditation, widely accepted certificates)?

<u>Breakout Session 3: 2:30pm-3:15pm</u>

How Can Validated Technologies and Methods Best Be Disseminated and Adapted to Others' Needs?

- What are the largest barriers to widespread use of new technologies? (cost, training, lack of validation, institutional conservatism, lack of information) What can be done to overcome these barriers?
- Are there examples of widespread replication and dissemination of successful new education and training technologies?
- How were these technologies scaled up? How could this be improved?

- Are there examples where education technologies have been adopted by wholly different communities? Are there or have there been missed opportunities?
- What management techniques are best suited for encouraging innovation and successful development and management of sophisticated learning technology? How can new efforts to leverage educational technologies at large institutions go beyond individual courses and instructors? What are the necessary components (e.g. personnel, administrative structure) to ensure success?

Breakout Session 4: 3:30pm-4:00pm

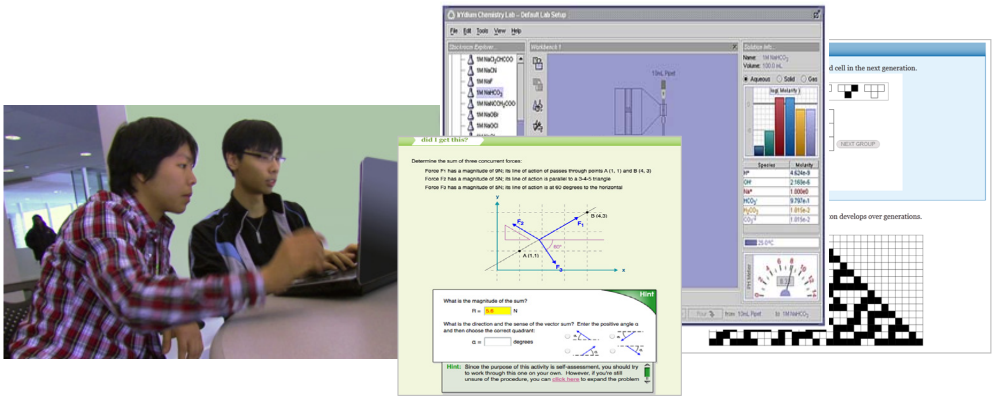
Future Directions - What Should the Federal Government's Role Be?

- Given the diverse opportunities available, what should be the priorities of Federal R&D programs? How can they best be managed to encourage innovation and adoption of innovation?
- What is the role for government support in overcoming regulatory, legislative and cultural barriers to advancing educational technologies?
- How should the Federal Government best facilitate communication among the many communities involved in educational technologies?
- How can the Federal Government ensure that it is using the best tools available for its own education and training? Can Federal procurements help drive innovation?

Appendix C.
Plenary Session Presentation by Candace Thille: Integrating Technology into Undergraduate Education to Advance Learning

What is the Open Learning Initiative?

Open online learning environments based on the **integration** of technology and the science of learning with teaching. OLI is **designed** to simultaneously improve learning and facilitate learning research.



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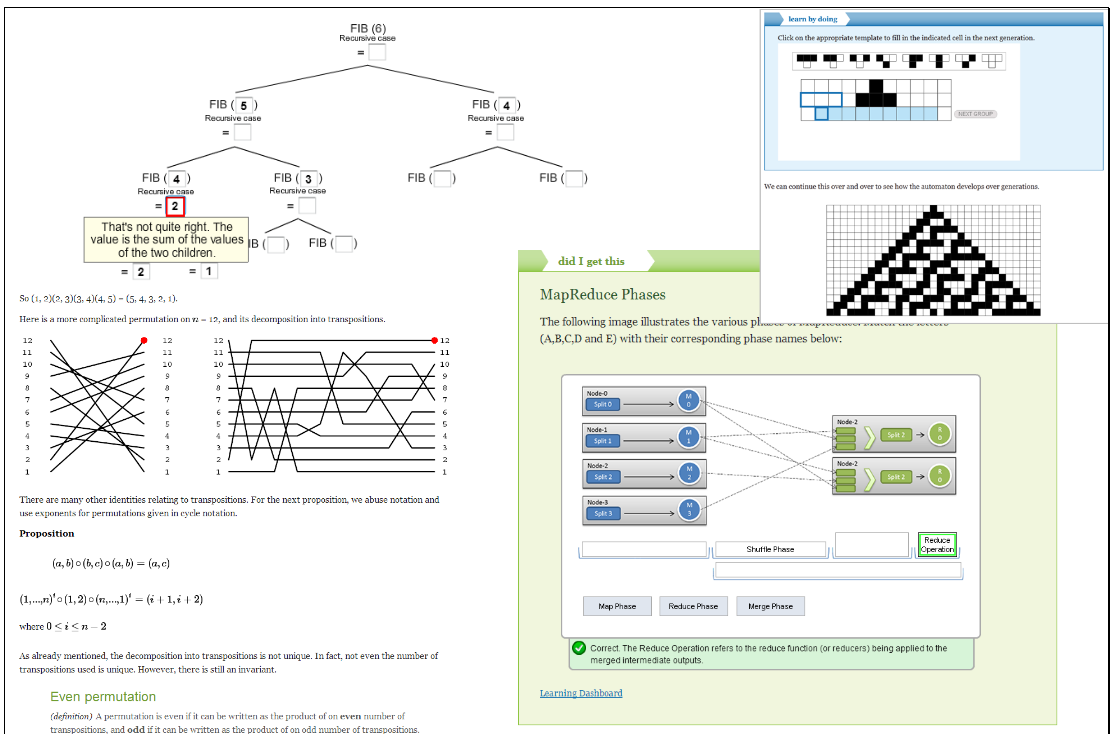

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What is a Cognitive Tutor?

A computerized learning environment whose design is based on cognitive principles and whose interaction with students is based on that of a (human) tutor—i.e., making comments when the student errs, answering questions about what to do next, and maintaining a low profile when the student is performing well.

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The *mini tutors* used throughout OLI courses such as the ones we just saw, are built on the 20 years of work that has been done at Carnegie Mellon on cognitive tutors. The mini-tutors in OLI courses are not full cognitive tutors in that they do not have full production rule sets or student models but their behavior is similar to a cognitive tutor for the given problem they are intended to tutor.

Chemistry - Stoichiometry

My Courses | Syllabus | Outl

Unit 1 :: Stoichiometry I

Introduction | The mole | The arsenic problem in Bangladesh

Module 3 / Arsenic in Bangladesh

To show how stoichiometry is used in practice, much of this course is set in the context of arsenic contamination in the ground water of Bangladesh. The following video introduces this context and why stoichiometry plays an important role in this environmental problem.

Is this well sample toxic? - 1

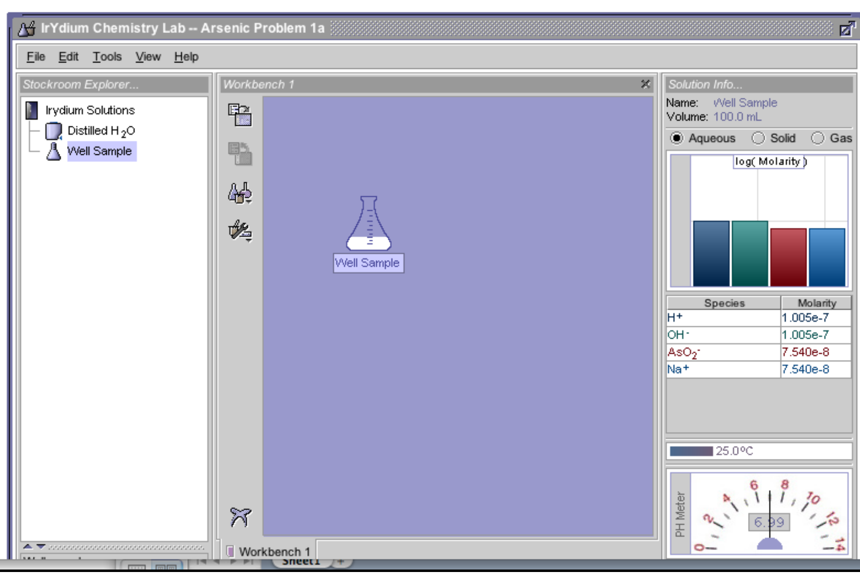
Acording to the WHO, the recommended limit for arsenic in drinking water is 10 micrograms per liter. While is not easy to answer if a well is toxic or not, a simpler question that can be answered is: Is the concentration of arsenic larger than the WHO recommendation?

If so, we may consider toxic this water source. If not, we may say that is arsenic-wise safe to drink this water.

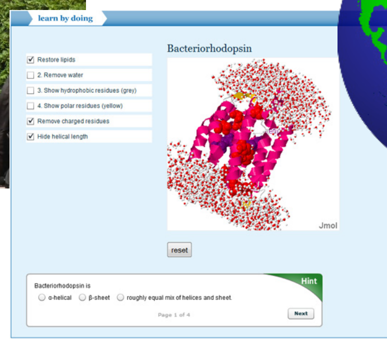
Activity 1: How many micrograms per liter of As is in the sample? (Please give your answer to 3 significant figures) Check Hint

56.4 micrograms/L

The virtual lab shows solution information in moles, grams or molarity. Remember to pay attention to what quantity is currently being shown. Please try again



What Are the Affordances of the Technology?



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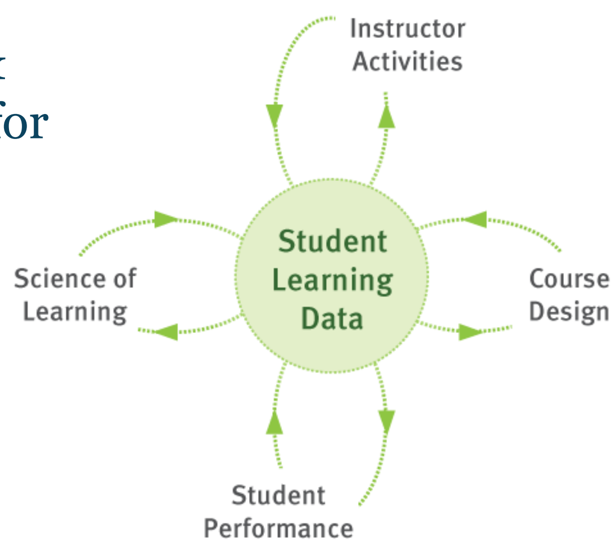
Data Collection & Feedback Loops for Continuous Improvement



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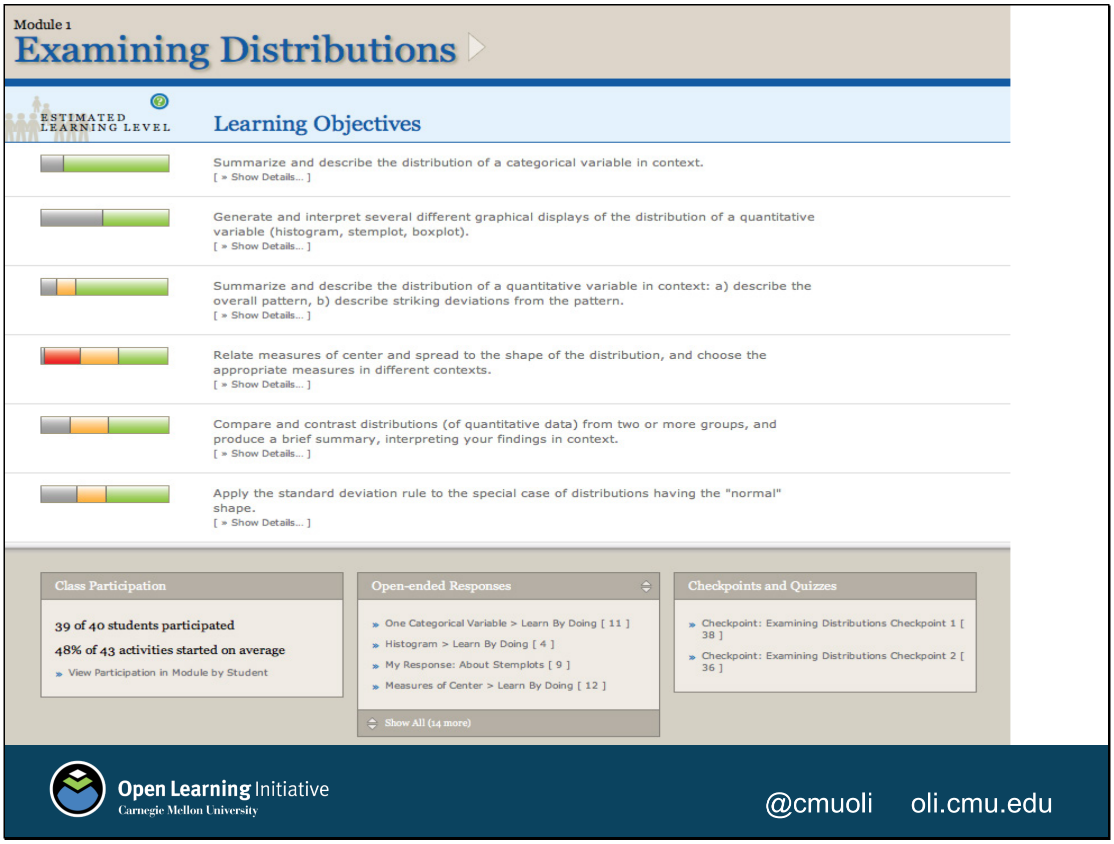
Module 1
Examining Distributions
ESTIMATED LEARNING LEVEL
Learning Objectives
Summarize and describe the distribution of a categorical variable in context.
[» Show Details...]
Generate and interpret several different graphical displays of the distribution of a quantitative variable (histogram, stemplot, boxplot).
[» Show Details...]
Summarize and describe the distribution of a quantitative variable in context: a) describe the overall pattern, b) describe striking deviations from the pattern.
[» Show Details...]
Relate measures of center and spread to the shape of the distribution, and choose the appropriate measures in different contexts.
[» Show Details...]
Compare and contrast distributions (of quantitative data) from two or more groups, and produce a brief summary, interpreting your findings in context.
[» Show Details...]
Apply the standard deviation rule to the special case of distributions having the "normal" shape.
[» Show Details...]
Class Participation
39 of 40 students participated
48% of 43 activities started on average
» View Participation in Module by Student
Open-ended Responses
» One Categorical Variable > Learn By Doing [11]
» Histogram > Learn By Doing [4]
» My Response: About Stemplots [9]
» Measures of Center > Learn By Doing [12]
Show All (14 more)
Checkpoints and Quizzes
» Checkpoint: Examining Distributions Checkpoint 1 [38]
» Checkpoint: Examining Distributions Checkpoint 2 [36]
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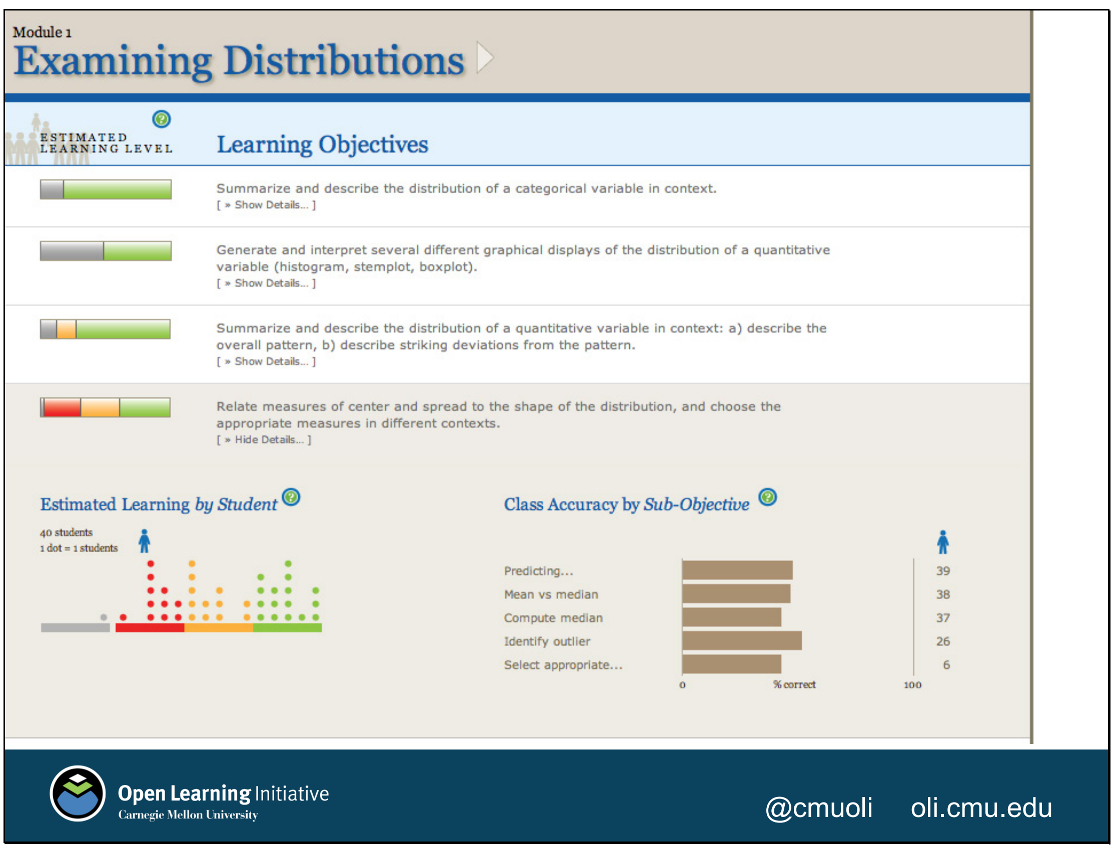
Module 1
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[» Show Details...]
Generate and interpret several different graphical displays of the distribution of a quantitative variable (histogram, stemplot, boxplot).
[» Show Details...]
Summarize and describe the distribution of a quantitative variable in context: a) describe the overall pattern, b) describe striking deviations from the pattern.
[» Show Details...]
Relate measures of center and spread to the shape of the distribution, and choose the appropriate measures in different contexts.
[» Hide Details...]
Estimated Learning by Student
40 students
1 dot = 1 students
Class Accuracy by Sub-Objective
Predicting...
Mean vs median
Compute median
Identify outlier
Select appropriate...
39
38
37
26
6
0
% correct
100
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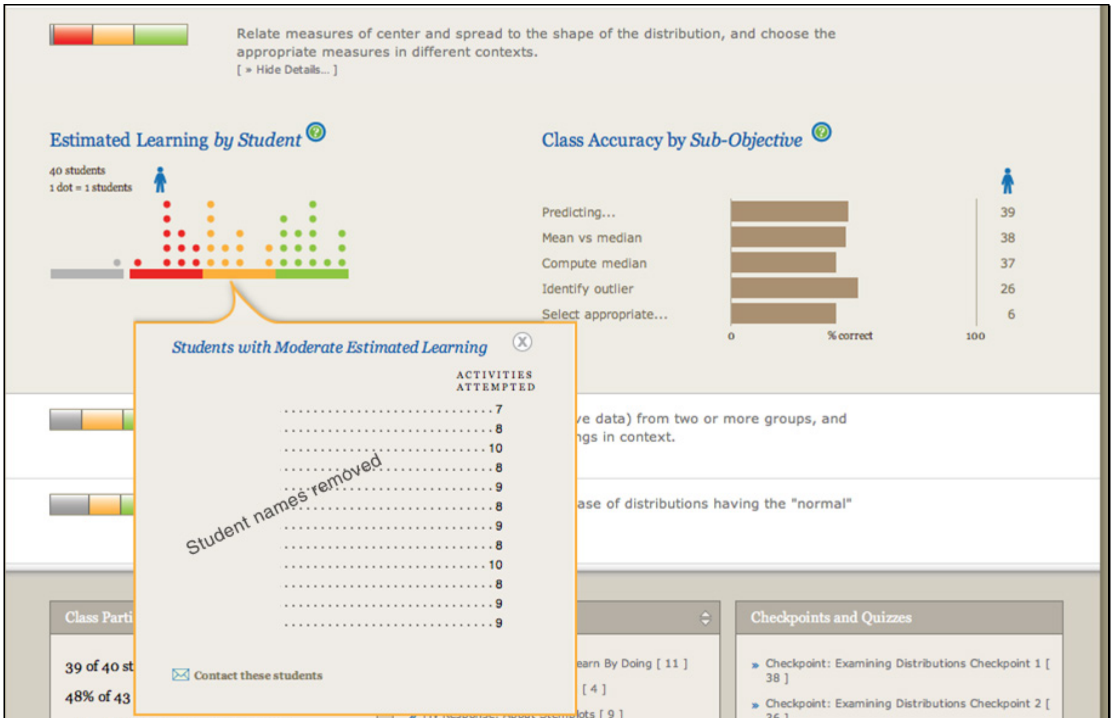

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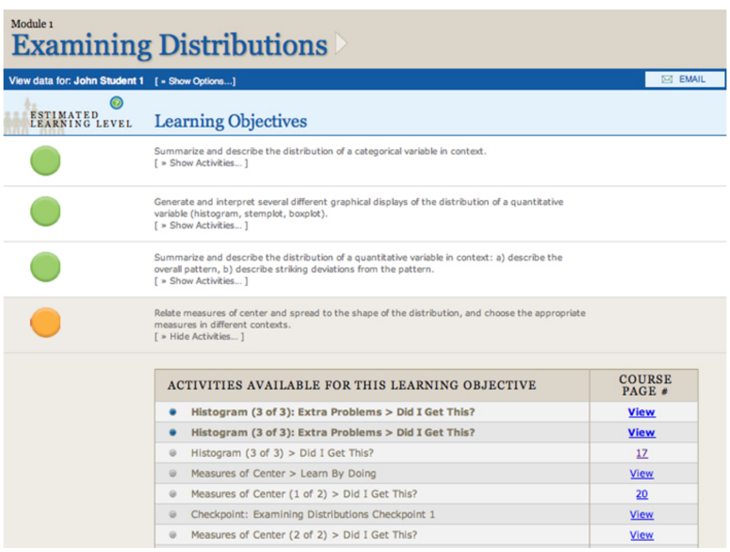
Single Student View



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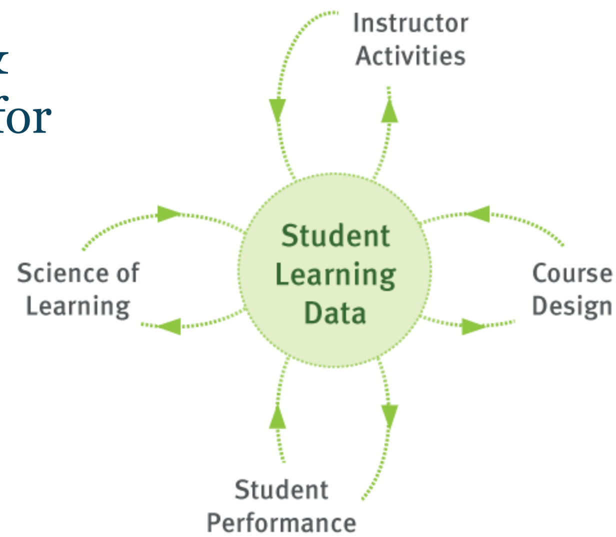

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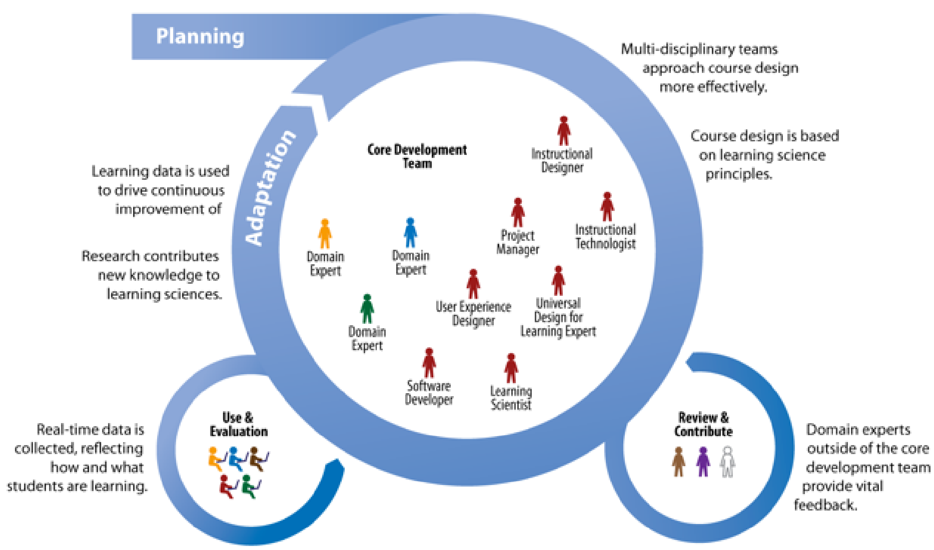
Community-based Research



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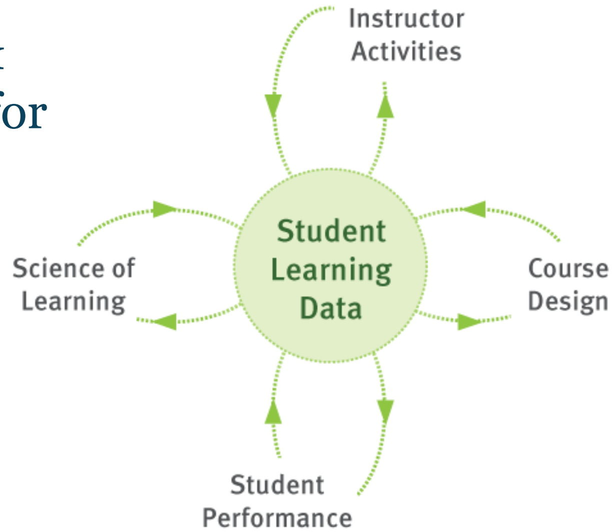
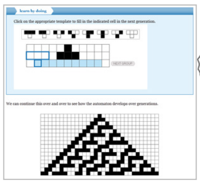


Pasteur's Quadrant

Stokes argues basic/applied goals need not trade off

	Low Emphasis on Applied Work	High Emphasis on Applied Work
High Emphasis on Basic Science	How to translate to real world? (**Bohr**)	☺ (**Pasteur**)
Low Emphasis on Basic Science	X	What principle can be derived? (**Edison**)

LearnLab: Transforming Education Research



LearnLab
Pittsburgh Science of Learning Center

Ed tech + wide use = "Basic research *at scale*"

NSF Science of Learning Center

- 10 years, ~$50 million
- Tech enhanced courses, assessment, & research
- School cooperation for data collection

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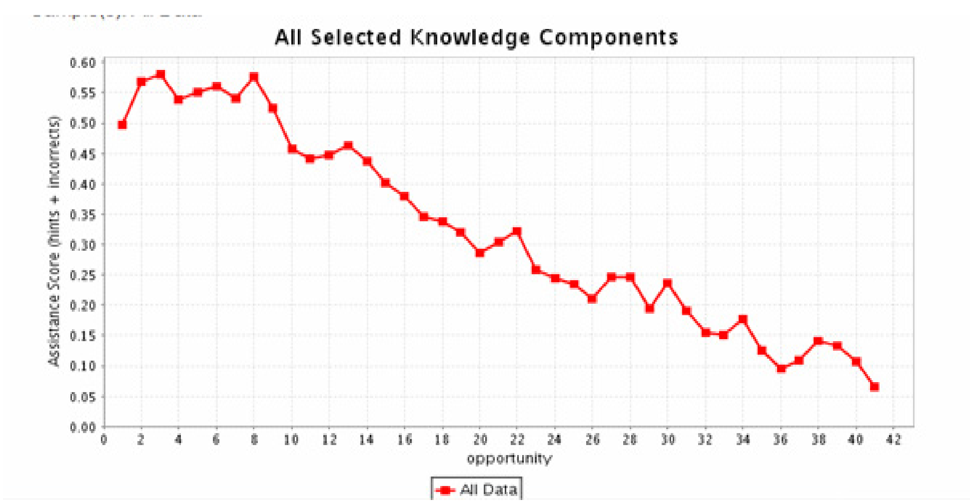
Learning Curve Analysis



DataShop: Pittsburgh Science of Learning Center

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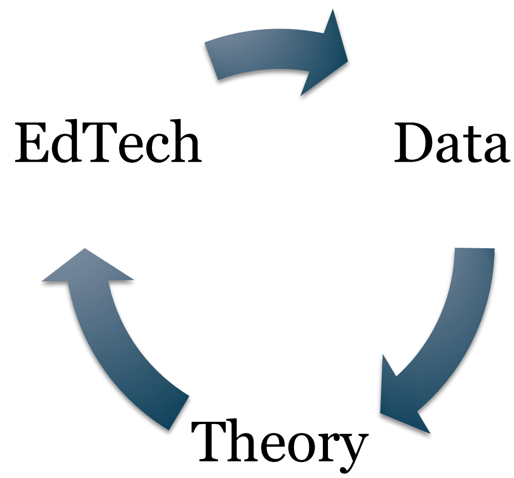
Strategy for Educational Improvement



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Open Data and Data Formats

Share Alike and Share Data

(This doesn't exist, but we think it should.)

We need to build and promote communities of research.

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Learning Science & Engineering

20th Century	21st Century
Intuitive Design	Evidence Based Design
Isolated Development	Connected Development
Flying Blind	Data Driven
Oversimplification	Managing Complexity

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"Improvement in Post Secondary Education will require converting teaching from a 'solo sport' to a community based research activity."

The late Herbert Simon,
Nobel Laureate & CMU Professor

cthille@cmu.edu cthille@stanford.edu

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OLI Funders

THE WILLIAM AND FLORA HEWLETT FOUNDATION

BILL & MELINDA GATES foundation

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THE KRESGE FOUNDATION

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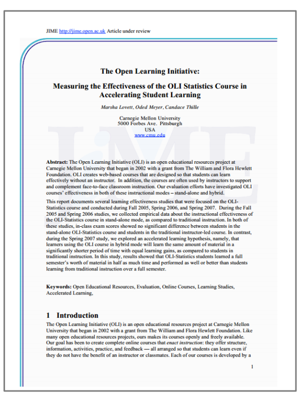
LearnLab is funded by The National Science Foundation award number SBE-0836012.

NSF

Proven Results



JIME http://jime.open.ac.uk Article under review

The Open Learning Initiative:

Measuring the Effectiveness of the OLI Statistics Course in Accelerating Student Learning

Marsha Lovett, Oded Meyer, Candace Thille

Carnegie Mellon University
5000 Forbes Ave. Pittsburgh
USA
www.cmu.edu

Abstract: The Open Learning Initiative (OLI) is an open educational resources project at Carnegie Mellon University that began in 2002 with a grant from The William and Flora Hewlett Foundation. OLI creates web-based courses that are designed so that students can learn effectively without an instructor. In addition, the courses are often used by instructors to support and complement face-to-face classroom instruction. Our evaluation efforts have investigated OLI courses' effectiveness in both of these instructional modes – stand-alone and hybrid.

This report documents several learning effectiveness studies that were focused on the OLI-Statistics course and conducted during Fall 2005, Spring 2006, and Spring 2007. During the Fall 2005 and Spring 2006 studies, we collected empirical data about the instructional effectiveness of the OLI-Statistics course in stand-alone mode, as compared to traditional instruction. In both of these studies, in-class exam scores showed no significant difference between students in the stand-alone OLI-Statistics course and students in the traditional instructor-led course. In contrast, during the Spring 2007 study, we explored an accelerated learning hypothesis, namely, that learners using the OLI course in hybrid mode will learn the same amount of material in a significantly shorter period of time with equal learning gains, as compared to students in traditional instruction. In this study, results showed that OLI-Statistics students learned a full semester's worth of material in half as much time and performed as well or better than students learning from traditional instruction over a full semester.

Keywords: Open Educational Resources, Evaluation, Online Courses, Learning Studies, Accelerated Learning,

1 Introduction

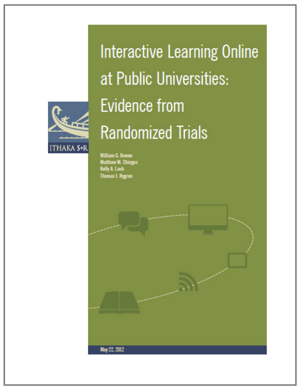
The Open Learning Initiative (OLI) is an open educational resources project at Carnegie Mellon University that began in 2002 with a grant from The William and Flora Hewlett Foundation. Like many open educational resources projects, ours makes its courses openly and freely available. Our goal has been to create complete online courses that *enact instruction*: they offer structure, information, activities, practice, and feedback — all arranged so that students can learn even if they do not have the benefit of an instructor or classmates. Each of our courses is developed by a

1

This study, conducted at Carnegie Mellon University, shows that students using the OLI statistics course at Carnegie Mellon achieved the same or better learning outcomes as students in the traditional course in **half the time**.

Lovett, M., Meyer, O., & Thille, C. (2008). *The Open Learning Initiative: Measuring the effectiveness of the OLI statistics course in accelerating student learning.* Journal of Interactive Media in Education.

Proven Results



"The results of this study are remarkable; they show comparable learning outcomes for this basic course, with a promise of cost savings and productivity gains over time."

Deanna Marcum
Managing Director, Thaka S+R

Bowen, W.G., Chingos, M.M., Lack, K.L., & Nygren, T.I. (2012). *Interactive Learning Online at Public Universities: Evidence from Randomized Trials.* ITHAKA.

Open Learning Initiative
Carnegie Mellon University

@cmuoli   oli.cmu.edu

Appendix D.
Plenary Presentation by Beverly Woolf: Computer-Assisted Adaptive Learning: Tutors, Games, and More

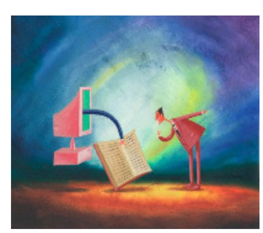
We stand on the threshold of a very disruptive time in education.

Conversations about teaching and learning across the country have been recatalyzed.

2

Education is a Game-changer for Society

Technology is a Game-changer for Education



3

Agenda

- Motivation
- → Current Education is boring and ineffective
- Intelligent Tutors; User Models, Mobile Tools, Serious games
- Two Example Intelligent Tutors
  - Adaptable Mathematics Tutors
  - Inquiry Biology Game
- Discussion and Further Work

Learning is Different with Technology

Students learn at / with:

Twitch speed vs. conventional speed

Parallel processing vs. linear processing

Graphic vs. text based

Connected vs. stand alone

Active vs. passive

Fantasy vs. reality

No wonder students are bored in school !

(Catherine Beavis, Digitel Conference, 2010)

The Child's Experience with Technology

All information is instantly available.

Change is constant and rapid.

Distance and time do not matter.

Powerful tools are taken for granted

Multimedia entertainment is omnipresent

Multi-tasking is how people work
(not effectively).

No wonder students are bored in school !

Chris Dede, Keynote Speech, Digital Conference, Taiwan, 2010

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❖ Technology to Support
A Teacher for Every Student

User models with machine learning techniques:

Track student skills, cultural preferences, personal interests, and knowledge

Identify who learns, when they learn and which pedagogies worked.

Recognize student misconception, off task behavior

7

Big Data Example:

- Big Data can be used by researchers to learn about learning. (Big privacy issues)
- Big Data was used to develop and test a model of learning and to predict student performance. How do students learn? What makes items easier or harder for students? How should lesson design and curriculum be modified?
- Worldwide competition: KDD Cup (Knowledge Discovery and Data Mining). The best model of learning was awarded a prize.

8

❖ Research Issues
Discovery about Teaching and Learning

Intelligent tutors now:

record and analyze interaction data;
induce automatic features from educational log files;
develop real-time dynamic assessment tools;
automatically measure cluster relationships.

9

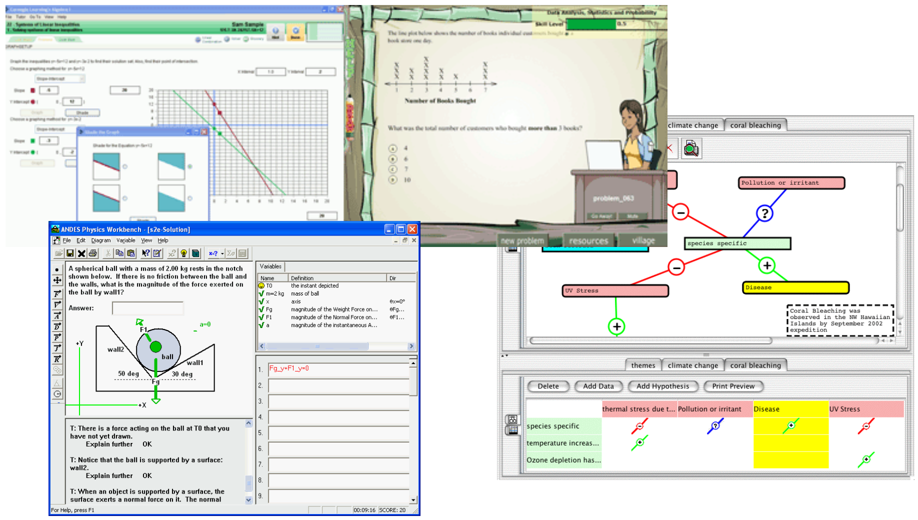
Educational Goals

- Match the needs of individual students. Tutor measures student behavior, amount of effort, quick guesses, and correctness.
- Move away from 'one-size-fits-all' education, away from passive lecture style teaching
- Tutor supports active learning and customizes instruction by providing each student with alternative
  - representations of content
  - paths through material
  - means of interaction.

10

Intelligent Tutors

- Intelligent Tutoring Systems have demonstrated ability to provide learning gains to students.



Agenda

- ➢ Motivation
- ➢ Current Education is boring and ineffective
- ➢ Intelligent Tutors; User Models, Mobile Tools, Serious games
- ➢ Two Example Intelligent Tutors
  - → o Adaptable mathematics Tutor: Wayang
  - o Inquiry Biology Game: Rashi
- ➢ Discussion and Further Work

Wayang

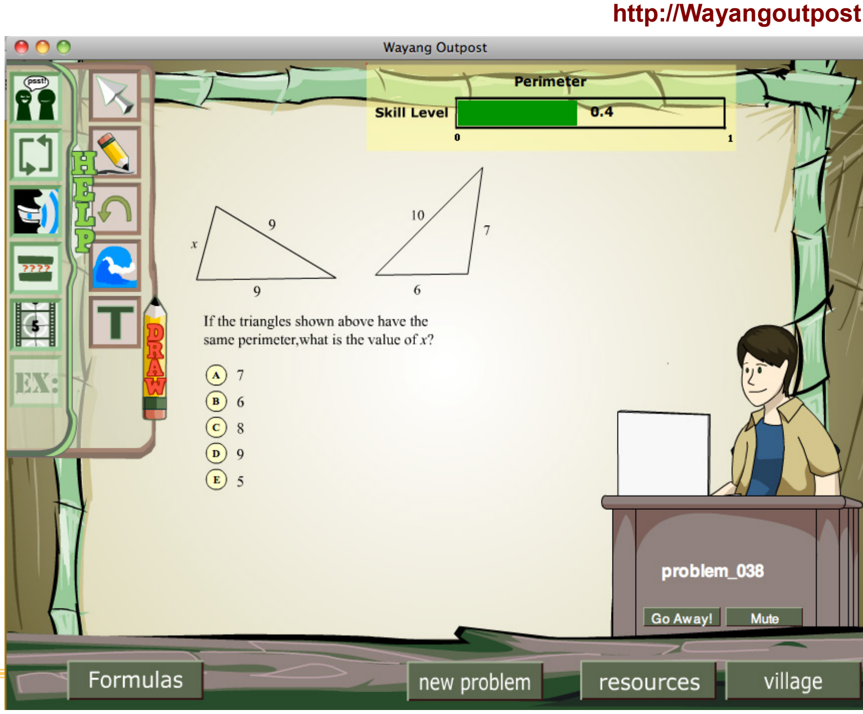
A <u>computational tutor</u> developed at UMass that:

- improves learning of mathematics by (20%)
- detects and responds to student emotion
- has been evaluated with thousands of students at dozens of middle and high schools
- Wayang will be used in the Instructional Van in Pakistan

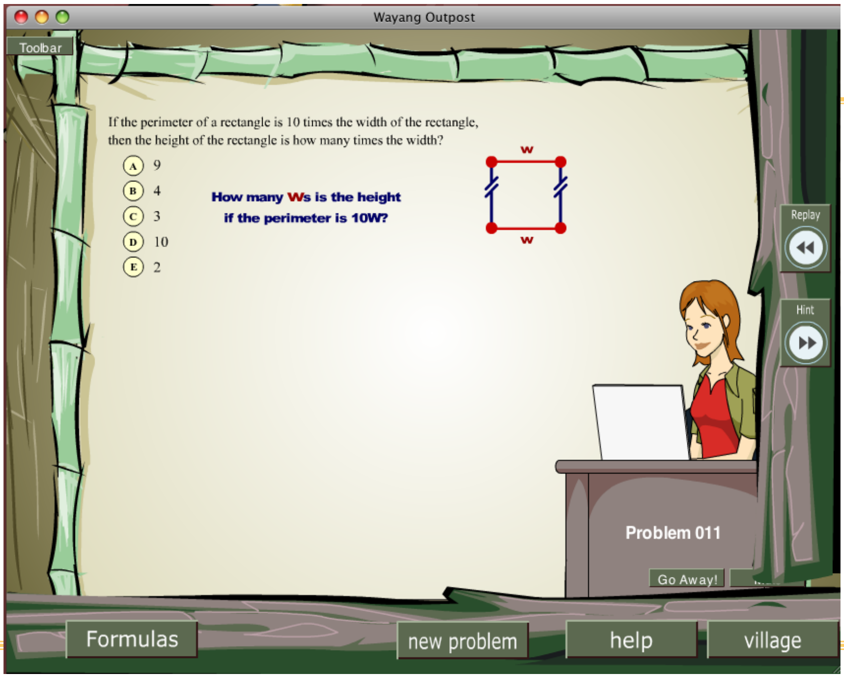
Wayang Outpost --Math Tutoring System

Grades 7,8,9,10 and community colleges

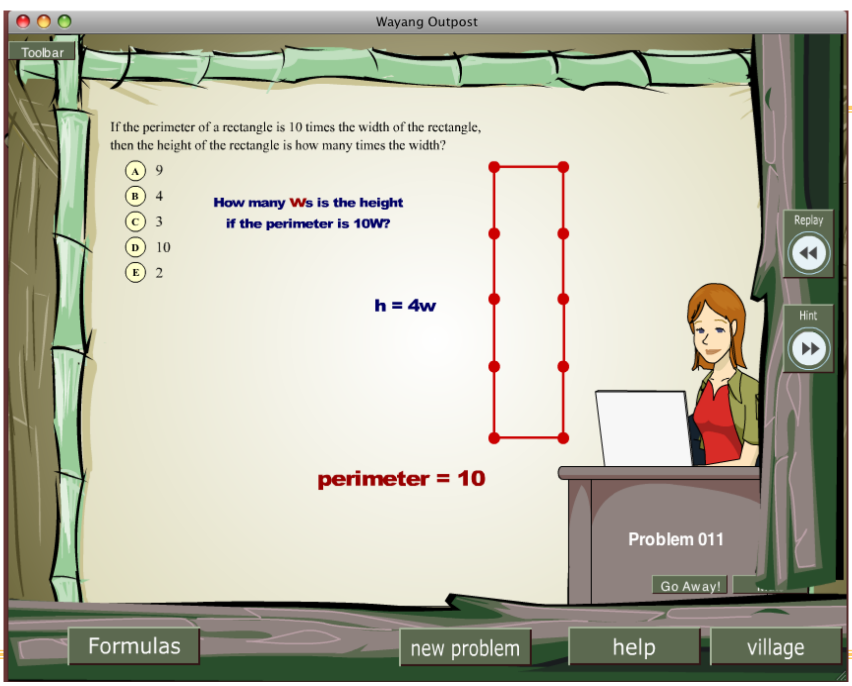
http://Wayangoutpost.com



The Tutoring System



The Tutoring System



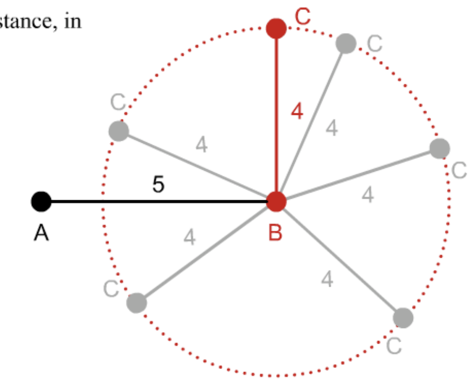
Wayang Outpost--Math Tutoring System

Standardized-test math problems with multimedia help

http://Wayangoutpost.com

The distance from town A to town B is 5 miles and the distance from town B to town C is 4 miles. Which of the following could NOT be the distance, in miles, from town A to town C?

- (A) 1
- (B) 4
- (C) 8
- (D) 9
- (E) 10



Modality
Contiguity
Animation

More Help

Mayer, R. E. & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. Educational Psychologist, 38, 43-52.

Sensors to Detect Emotion

Pedagogical Agents

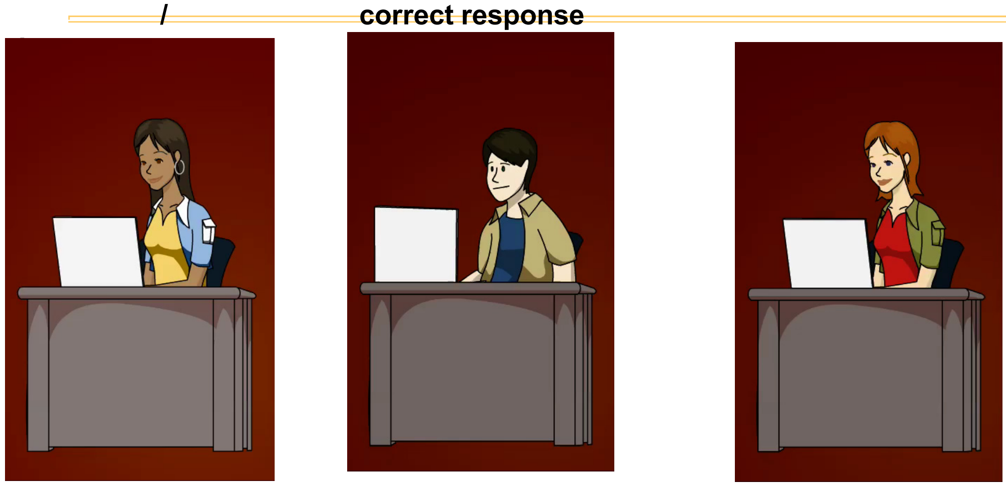
<u>Build student's self-esteem and self-worth.</u> Agents are gendered, African, Hispanic and White.

<u>Help students develop a positive emotional</u> environment. Offer advice and encouragement.

<u>Empathize with students.</u> Express full sentences of cognitive, meta-cognitive, emotional feedback.

Agent Emotion

Student effort shown / | **Student effort shown/ correct response** | Incorrect Response



Frustrated students are supported by helpful companions.

→ Arroyo et al., AIED2009

Affirmation Theory Messages

Affirmation Theory: Propose that students' motivation is rooted in their beliefs about why they succeed or fail. Students can be taught to understand that failure is the result of a lack of effort instead of a lack of ability.

Example Messages

Over 300 problems from standardized tests

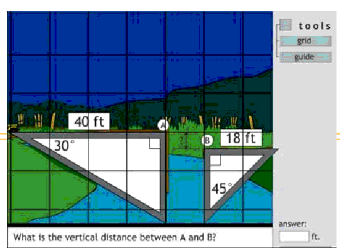
Whole number word problems
- Negative numbers (and absolute value)
- Exponents and square roots
- Fractions
- Decimals and percents (including discounts, etc.)

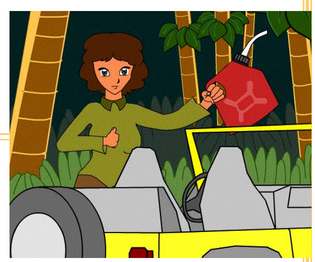
- Expressions (including distributive property, etc.)
- Expressions with variables
- One and Two step equations of 1 variable
- Inequalities
- Linear Equations
- Systems of Equations

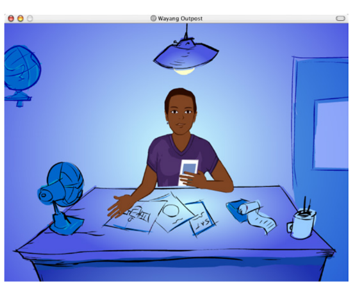
Other topics:
- Data Analysis, Statistics and Probability
- 5 geometry topics, from perimeter through special triangles and volumes.

Provide Rewards to Students

Fantasy Adventures







Students solve real-world problems, e.g., rebuild an orangutan infirmary (top left), calculate the possibility of driving a jeep (top right) over a broken bridge to enhance their understanding of mathematics.

Results of Use in K-12 Classes

Year	LEARNING (posttest – pretest) / (100-pretest)
Spring 2003 N~50 *South Deerfield, MA*	**13%**
Fall 2003 N~50 *South Deerfield, MA*	**7.6%**
Fall 2004 N=119 *Orange&Springfield*	**10%**
Spring 2005 N=34 *Springfield, MA*	**17%**
Fall 2005 N=120 *Springfield, MA*	**18%**
Spring 2006 N=116 *Springfield, MA*	**13%**
Winter 2007-2008 *Holyoke, MA* N~50	**16%**
Fall 2008 N=67 Belchertown/Amherst	**25%**
Spring 2009 N=250 *TurnersFalls/S.Deerf*	**13%**
Spring 2009 N=250 *S. Deerf. Middle Sch*	**14%**
College level 2008-10 *UMASS Amherst and ASU Arizona (N=94)*	**33%**

Improved Passage of State Standardized Tests

After short exposure (3-4 hours)

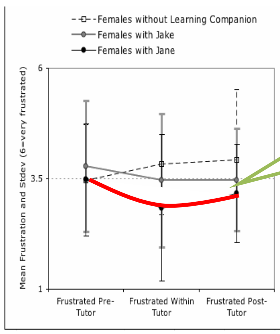
MCAS passing% WITH Wayang	MCAS Passing% NO Wayang
77%	60% **
34%	24% *
d=0.25	
d=0.24	
92%	76% *

Wayang Posttest	Control No Wayang
76%	67% **
d=0.52	

College-Level Classes

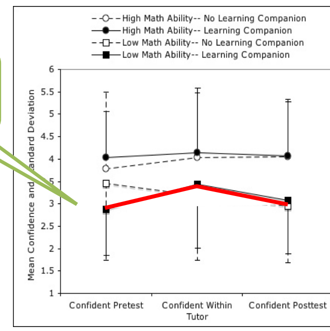
Teach Every Student

Tutor Reduces Math Anxiety and Frustration



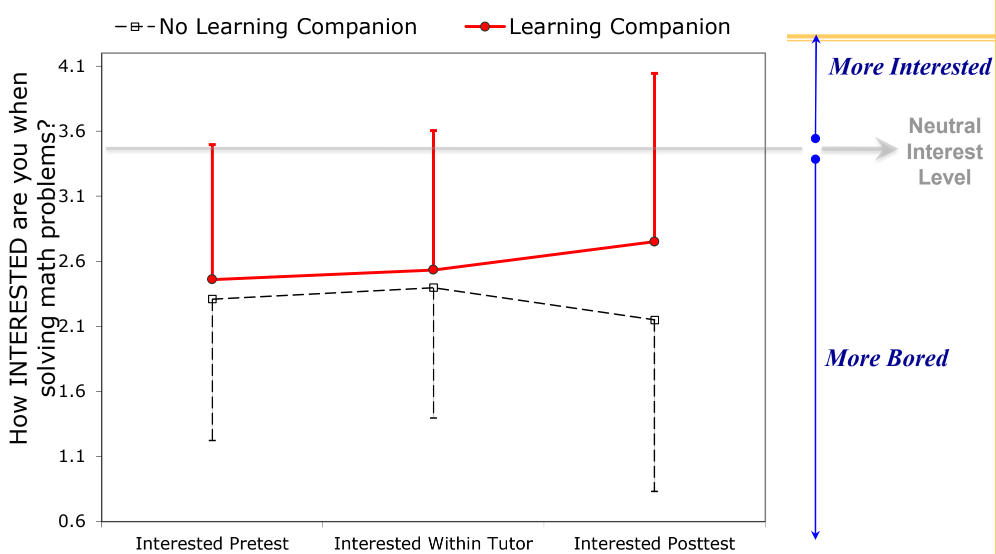
Reduced Frustration with Tutoring

Increased Confidence with Tutoring



Increased Interest

Less ***boredom*** *for math* at post-test time in LC condition. **+F(94,1)=3.4, p=.07**

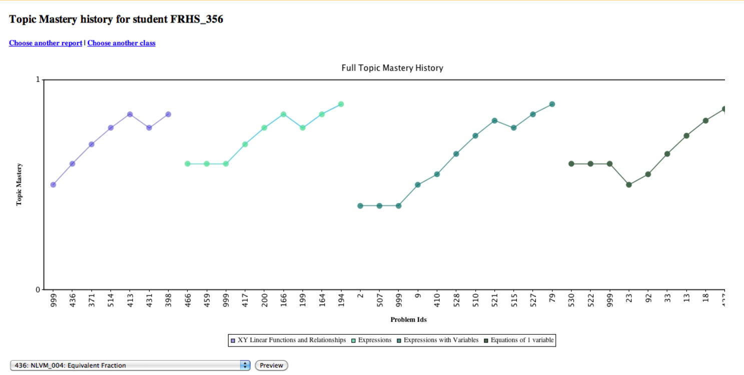


Intelligent Tutors Support Teachers

Reduced time grading homework

Increased time for individual mentoring

New diagnostic information about each student



Instant feedback on student mastery for four topics (color) and each problem (dots). Our team works closely to support instructors and students during its use.

New insight into curriculum materials

Detail Problem Info for Main High School - MCAS Prep

Skills that your students found really hard
Skills that your students found challenging

Choose another report | Choose another class

Skill name	# problems	% solved in the first attempt	Avg # of hints requested per problem	Seconds "thinking" out the time to first action (hint o
SQUARES: Square sides and angles, identify square from a picture or definition, what are the diagonals	1	0.0	0.0	55.0
LINES: Understanding the concept of parallel lines and perpendicular lines forming four 90 degree angles	3	0.0	0.0	47.6
CIRCUMFERENCE: Circle perimeter formula as a function of the diameter. Semicircle perimeter as half of this.	1	0.0	0.0	20.0
VOLUMES: Volume of cubes and cones	7	0.0	0.0	141.0
SHORTEST/LONGEST ROUTES: Finding the full Length of Shortest and Longest Routes	1	0.0	0.0	13.0
EXPONENTS: Working with exponents	1	0.0	0.0	24.0
LAWS OF EXPONENTS: Laws for combining terms that have exponents	1	0.0	0.0	44.0
SIMPLE FRACTION ARITHMETIC: Adding/subtracting simple fractions (like denominators or involving mixed numbers and whole numbers)	1	0.0	0.0	44.0
ANGLE ESTIMATION: Estimating angles of 30, 45 degrees. Understand angles > 90, < 90 etc.	1	100.0	0.0	14.0
PROPORTIONAL REASONING: Seting up and solving proportion problems, similar triangles, etc.	3	100.0	0.0	46.3
SURFACE AREA: Area of cubes and cones	7	14.2	0.0	28.4
EXPRESSIONS WITH VARIABLES: Distributive Property, plugging in values for variables	6	16.6	0.0	66.8
AREA OF A SQUARE: Find the area of a square from one side, or the side from the area	8	25.0	0.0	35.3
STEM&LEAF PLOTS: Interpret/Construct Stem and Leaf Plots	4	25.0	0.0	75.2
MAKE A SKETCH: Create a sketch/picture/drawing to represent the information given in the problem	12	25.0	0.0	38.5

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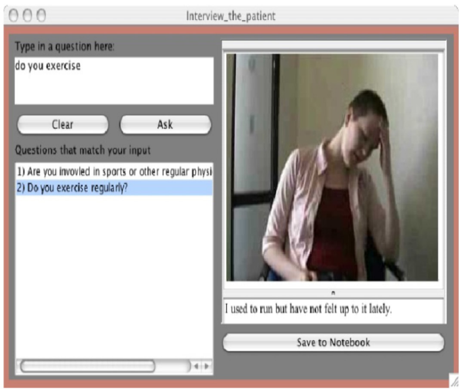
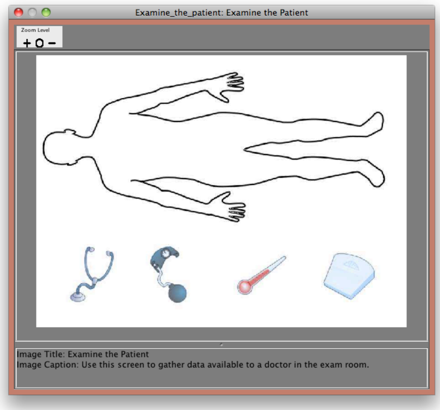
Rashi Environment

Data Collection Tools



Interviewing the Patient



Examining the Patient

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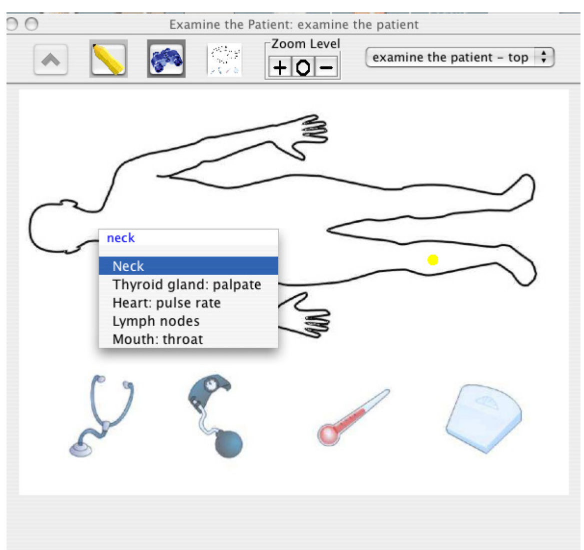
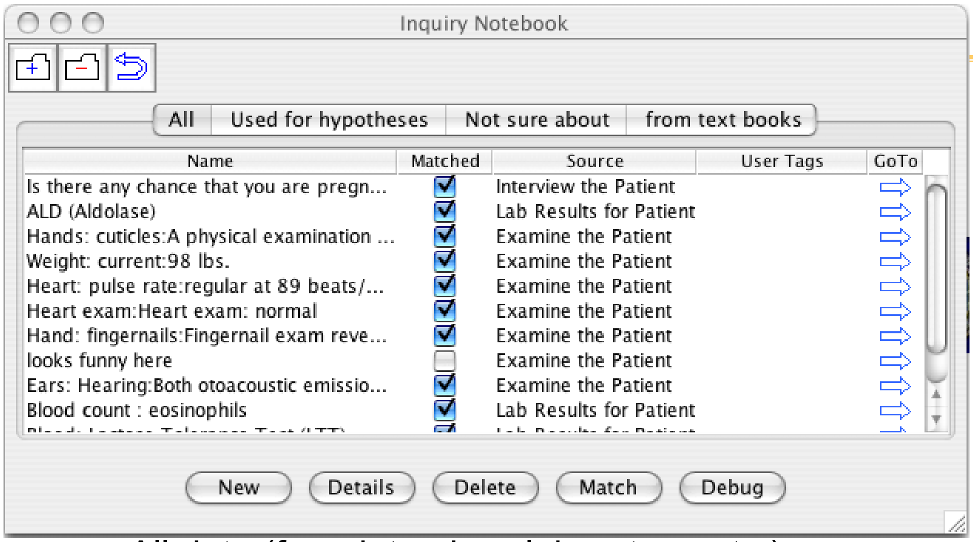
Patient Examination Tools

Students measure weight, pulse, blood pressure, etc. By selecting, the head the user can then examine eyes, ears, neck, etc.



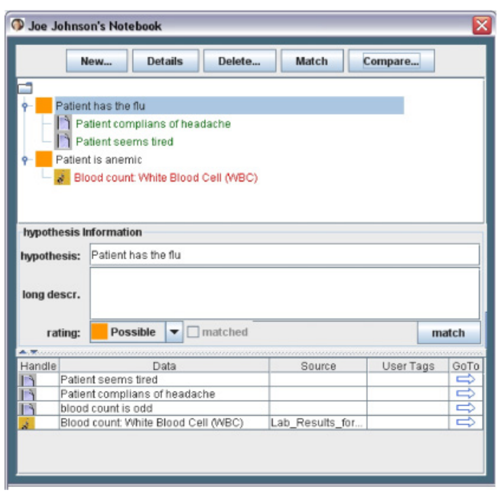
Student edits statements in the Inquiry Notebook



All data (from interview, laboratory, etc.) are automatically recorded.

Rashi Environment

Organization



The Notebook

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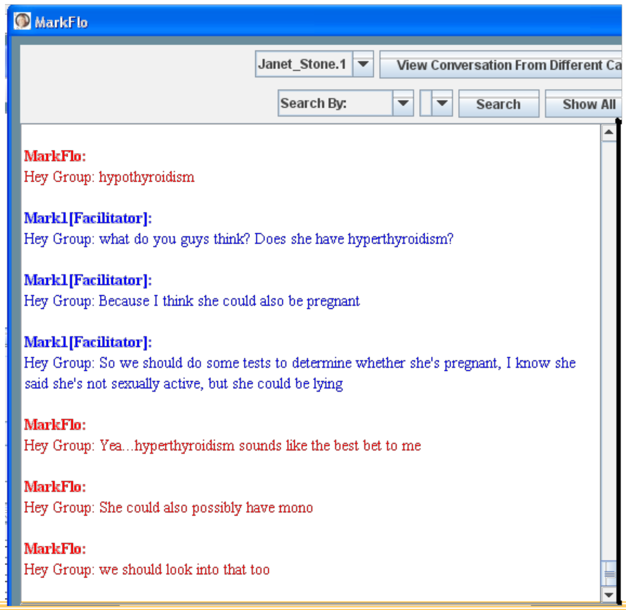
Rashi Environment

Collaborative Features



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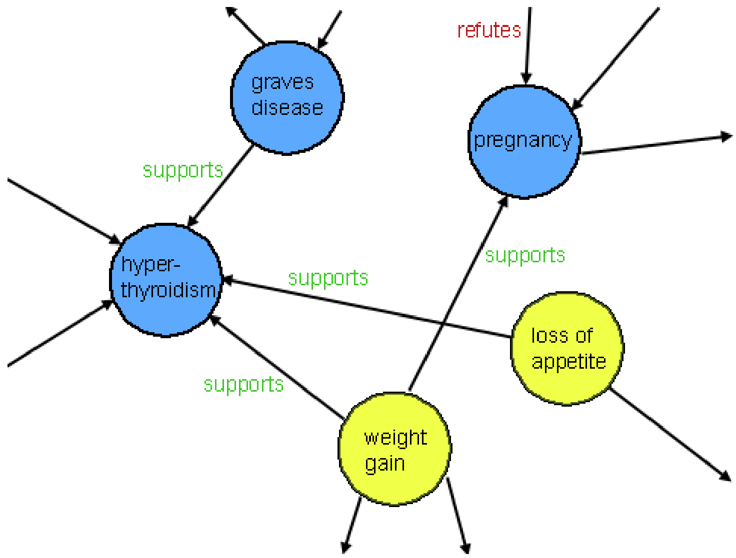
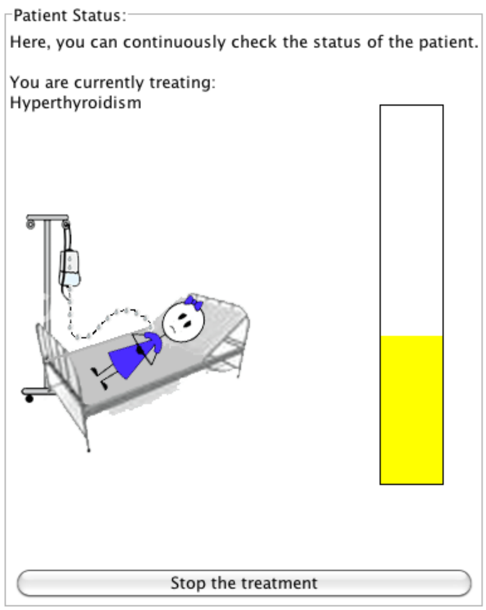
Automated Content Recognition

- A tutoring system can accurately determine the domain content of student dialogue in the majority of cases by using an expert knowledge base.
- The knowledge base structure and creation process are important to the success of this endeavor.

Rashi: Expert Knowledge Base



Rashi: Some New Features



The Data

- Approx 650 Rashi accounts used in past month
  - UMass Intro Biology Course
  - Tufts Univ. Intro Biology Course
- > 4000 hypotheses created
- > 7000 data nodes / relationships created

Crowd Sourcing used to define knowledge base

- *Knowledge defined:*
  - *A set of Nodes*
  - *A set of Relationships*
- *Node = (desc, type, conf) where:*
  - *desc is a string representation of the description of this node*
  - *type ε NodeTypes is the type of node (e.g. evidence, data, etc…)*
  - *$0 \leq$ conf ≤ 100 is the confidence that Node is true for domain D*
-

More detail available in proposal document

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One Policy Perspective

Education should be a civil right for all people. A knowledge society requires all people to have knowledge and learn rapidly. A global repository is needed with numerous teaching modules available for free for all people.

However, it is naive to think that policy reforms as customarily understood will result in the needed changes.

We need to think in terms of systemic, broadly-based changes, in terms of social movements.

If society is to embrace the scope and scale of needed changes, social movements must be launched and sustained over protracted periods of time. For example, in the USA, **disability assistance** and **smoking bans** each took around **40 years** to achieve.

John King, U Michigan, CCC Councilor, *Roadmap* 45

ONR STEM Challenge

As part of an ONR Challenge Grant

we are integrating two well vetted mathematics tutors:

ASSISTment and **Wayang**

Enhance student learning with:

Relational learning companions

Stealth assessments

Machine learning to customize curriculum

EdRank to judge the impact of Web resources

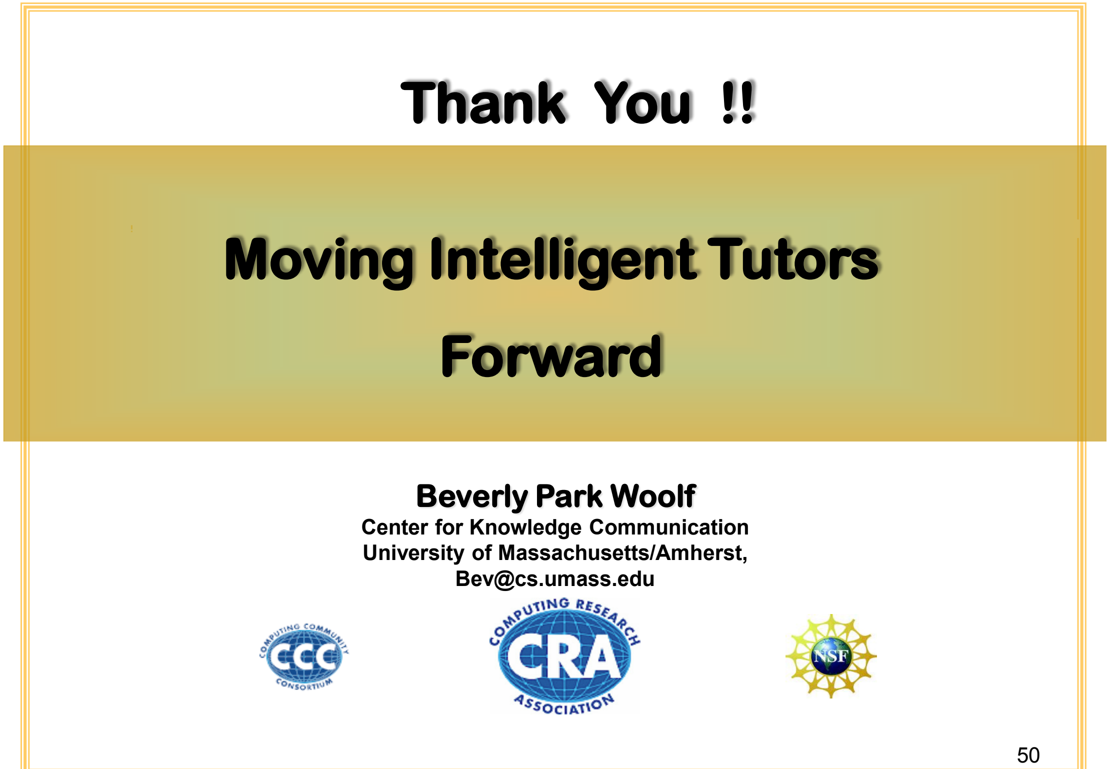
Specific Challenges

- Achieve 2 Ω improvement in student learning;
- Develop efficient methods to author content;
- Create a tutor that learns to customize curriculum and responses;
- Evaluate stealth assessments.

Prior Data

- <u>ASSITment</u>: used **daily** by 2,500 students across the country and **weekly** by 100 to 200 teachers;
- <u>Wayang:</u> used by thousands of students with improved learning behavior (increased interest and confidence, reduced frustration and ‘gaming’)

ASSISTment: <u>2,500 students</u>/daily


Thank You !!
Moving Intelligent Tutors
Forward
Beverly Park Woolf
Center for Knowledge Communication
University of Massachusetts/Amherst,
Bev@cs.umass.edu
CCC
COMPUTING RESEARCH
CRA
ASSOCIATION
NSF
50

Glossary

Technology-enhanced learning environments

Digital textbooks: Digital textbooks are online or computerized versions of traditional textbooks. They often are a lower cost option than traditional textbooks and sometimes provide interactive or personalized features.

Example: *College Open Textbooks* is a group of 29 educationally focused for profit and nonprofit organizations which hosts a resource pool of open textbooks. The project's goal is to disperse open textbooks to community and other 2-year post-secondary education providers. The group also provides training in how to use open resources and peer review of open textbooks. College Open Textbooks has identified more than 550 textbooks available for use and has peer reviewed over 100 that are free to use without restriction.

Source: http://collegeopentextbooks.org

Educational games: Educational games are games that have a learning component. Technology-enhanced educational games, such as video or computer games, usually have an interactive component and sometimes an assessment portion at various intervals within the gaming environment.

Example: *Games and Professional Simulations (GAPS):* GAPS is a collaboration of six research groups in the United States working on epistemic game development. One current project is Nephrotex, a learning game focused on engineering skill development that assigns engineering tasks to undergraduate students working at a simulated company called Nephrotex.

Source: http://edgaps.org/gaps/projects/nephrotex/

Example: *360Ed* develops learning games and other educational products. One of the games, Conspiracy Code, was developed to provide American history education though two adventure characters.

Source: http://www.360ed.com/

Intelligent tutoring systems/cognitive tutors: Intelligent or cognitive tutors walk students through a learning goal while recording and analyzing interaction data and provide individualized learning and feedback to each student. Some tutors are designed to be able to measure level of effort, delineate between guesses and well-considered answers, and understand how student mood influences accuracy of response.

Example: *Wayang Mathematics Tutor* is a free intelligent machine tutoring system that uses multimedia to interact with students interested in reviewing or learning basic math skills. The tutor learns along with the student and adapts to each student's personal learning style and pace.

Source: http://wayangoutpost.com/ and Beverly Woolf

Massive open online course (MOOCs): MOOCs are online courses that are open access to the public and provide course materials through online means. Often they have an interactive community of learners and instructors and include multimedia content.

Example: *EdX* is a nonprofit MOOC provider created by founder institutions Harvard University and the Massachusetts Institute of Technology (MIT). It supplies certificates of completion through their courses.

Source: https://www.edx.org/

Real-time feedback devices: Real-time feedback devices provide learner response through technology to the instructor. The instructor can use these responses to better tailor the course material.

Example: *Clickers* are classroom response systems that allow students to provide individual responses to multiple choice questions via a wireless connection. Each student with a clicker can provide a response to a question posed to the class.

Source: http://cft.vanderbilt.edu/teaching-guides/technology/clickers/

Clicker in use, courtesy of Associated Press Images.

Simulations/immersive environments: Simulations and immersive environments provide a safe way to gain skills by eliminating any dangerous consequences or visualizations to provide greater understanding of topics. Simulators are often used in areas where mistakes would cause injury or damage. Simulators have proved useful for skill building and training in educational settings and in military exercises.

Example. *TeachWELD* is a welding simulator that provides a safe way to learn the skills necessary for quality welding. TeachWELD is owned by Realityworks, an educational simulation company.

Welding simular in use, courtesy of Associated Press Images.

Source: http://realityworks.com/categories/welding-simulation

Example: *PhET Interactive Simulations* is a source of simulations for science and mathematics at the University Colorado, Boulder. PhET provides 113 different simulations that are interactive, based on research, and user tested with about 60 million simulations run. PhET is licensed by Creative Commons.

Source: http://phet.colorado.edu

Virtual laboratories: Virtual laboratories give students access to laboratory experiments and other learning opportunities without the infrastructure necessary for a traditional laboratory space. Virtual laboratories use technology to provide remote access to real laboratories or simulations of actual laboratory experiments.

Example*: ChemCollective* is an online resource run by a group of Carnegie Mellon University faculty and staff that provides virtual laboratories and online chemistry lesson materials. ChemCollective is sponsored by the National Science Foundation and the Department of Education.

Source: http://www.chemcollective.org/

Other Terms

Clickstream data: data relating to the use of web browsing or Internet activity, or more broadly, data captured from individual keystrokes or movement through a technology-enhanced learning environment

Interoperability: capability of multiple different organizations, systems, or educational platforms to work together and share information as well as operate together

Open source: agreements allowing materials to be accessible free of charge to the general public

Post-secondary education: learning that occurs after secondary (high school) education at community colleges, universities, graduate schools, and vocational centers for example

Valley of death: period between development of an innovative research idea (or prototype) to implementation in a product where ideas often fail to progress

Abbreviations

CoSTEM	Committee on Science, Technology, Engineering, and Math Education
FERPA	Family Education Rights and Privacy Act
FY	fiscal year
GAPS	Games and Professional Simulations
IDA	Institute for Defense Analyses
I-CORPS	Innovation Corps
MOOC	massive open online course
MIT	Massachusetts Institute of Technology
NCSES	National Center for Science and Engineering Statistics
NSF	National Science Foundation
NTER	National Training and Education Resource
OER	open educational resource
OLI	Open Learning Initiative
OSTP	White House Office of Science and Technology Policy
R&D	research and development
RCT	randomized controlled trial
SCORM	Sharable Content Object Reference Model
STEM	science, technology, engineering and mathematics
USDA	U.S. Department of Agriculture

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	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Zuckerman, Brian L. Azari, Abigail R. Doane, William E. J.	**5d. PROJECT NUMBER**
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14. ABSTRACT

On July 29, 2013, the National Science Foundation (NSF) hosted a workshop on technology-enhanced education that brought together nearly 100 participants from Federal agencies, 2- and 4-year degree-granting institutions, and experts in key areas related to technology-enhanced education, assessment, and learning. The purpose of the workshop was to invite community input to inform Federal agencies, the White House Office of Science and Technology Policy, and the NSF about how to effectively create U.S. Government strategies to promote advances in undergraduate education in light of rapid progress in online learning tools and research on learning. This document describes the results of the workshop.

15. SUBJECT TERMS

technology-enhanced education, educational data mining, learning science, intelligent tutors, educational games

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