CENTER FOR INNOVATIVE LEARNING TECHNOLOGIES

Six Years of Knowledge Networking in Learning Sciences and Technologies

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PREFACE

This report presents a series of in-depth reflections about the work of the Center for Innovative Learning Technologies (CILT) from 1997 until 2004. Each member of the CILT team (Principal investigator, postdoctoral scholar, project coordinator and manager) provided their personal reflections on what they, and all of us as a group, have learned from the attempt to stimulate the development and implementation of important, technology-enabled solutions to critical problems in K–14 STEM learning in the context of an open and inclusive national effort. CILT's goals were to centered outward, on empowering research advances in learning using technology, specifically, in visualization, assessment, community tools, and ubiquitous computing.

The contributions reflect the choices, on both format and content, by their authors. No attempt was made to adapt them to a single format, to highlight their multiple points of view, since different readers may be more interested in different lessons learned from the effort.

The intended readership of this report includes the many researchers, educators, and others in the world who have an interest in different models of increasing the capacity of the field to engage in the broad field of learning and intelligent systems.

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Introduction

Six Years of Knowledge Networking in Learning Sciences and Technologies

For learning and education to take full advantage of new and evolving information technologies and to contribute to the evolution of those same technologies, there is a fundamental need to explore research issues and potential synergies in cross-disciplinary studies of learning and technology.

For several decades, an objective of many NSF-wide programs has been to stimulate research on the integration of technology with different aspects of research on learning. Projects supported through these programs involved a significant research component in the information, computer, communications, and computational science and engineering aspects of learning technologies. From the learning and education point of view, these programs responded to the national need to improve the quality, accessibility, and efficiency of education, particularly in science, technology, engineering, and mathematics (STEM).

In October of 1995, an NSF multidisciplinary workshop on setting a Computer Science research agenda in educational technology (jointly sponsored by the CISE and EHR Directorates) proposed the following agenda for new research[1]:

> To conduct, in a collaborative fashion, interdisciplinary research and systems development that can lead to significant breakthroughs in our understanding of learning and cognitive functioning—from empirical research to theory development to classroom practices-as well as in the application of advanced technologies and new understanding of cognition and the learning process to intelligent systems to use in all facets of education, including informal and self-directed learning.

In response to this agenda, NSF solicited proposals to establish one or more centers for collaborative research on learning technologies, with the expectation that these centers would have the ability to undertake large, collaborative, cross-disciplinary projects; to act as technology transfer mechanisms by training new researchers; to support prototype or model projects; and to be impartial and comparative evaluation centers for learning technologies. Three 4-year centers were established with differing philosophies of how to leverage their activities and achieve broad impact:

- The Center for Innovative Learning Technologies. CILT was formed to *stimulate the development and implementation of important, technology-enabled solutions* to critical problems in K–14 STEM learning. CILT was an open and inclusive national effort led by five institutions: SRI International, Stanford University, the University of California at Berkeley, Vanderbilt University, and the Concord Consortium (http://cilt.org).
- The Center for Learning Technologies in Urban Schools. LeTUS was formed *to better serve urban science education needs* through innovative, hands-on, project-based curricula. The center's premise was that urban schools represent a challenging and important setting for shaping and assessing new organizational and teaching practices supported by technology. LeTUS was a partnership among the Chicago Public Schools, the Detroit

[1] NSF Educational Technology Workshop Report, available from the Computing Research Association and at http://www.cc.gatech.edu/gvu/edtech/nsfws/.

Public Schools, Northwestern University, and the University of Michigan (http://www.LeTUS.org).

- The Center for Interdisciplinary Research on Constructive Learning Environments. CIRCLE had three main goals: first, *to understand an extremely effective pedagogy*, human tutoring; second, *to build and test a new generation of computer tutoring systems* that encourage students to construct the target knowledge; third, *to help integrate this new technology into existing educational practices*. CIRCLE was a partnership between the University of Pittsburgh and Carnegie Mellon University (http://www.pitt.edu/~circle/).

Thus, the three NSF learning technology centers represent three distinct approaches to learning technology transfer:

- *Empower* research advances in learning using technology, specifically, in visualization, assessment, community tools, and ubiquitous computing (CILT).
- *Imbue educational systems* with technology supports for their own reform efforts, specifically, in science education and inquiry (LeTUS).
- *Advance a learning technology* (artificial intelligence tutoring systems) and disseminate its findings to the AI R&D communities (CIRCLE).

As these learning technology research centers come to an end, it is useful to reflect on how their goals were accomplished and what footprints they left. What has the field learned from the process? What is the knowledge on which future centers can build?

The World of Learning Technologies in 1997

In 1997, there was a general understanding that the time was ripe for information technologies to make major contributions to improved learning in STEM at all levels and for all learners. The continued exponential increase of performance in information technology, the huge interest in network technologies, the education community's increasing understanding of the benefits of learning and intelligent systems, and the widespread concern for educational quality, standards, and technology utilization combined to make what could be a decade of educational revolution led by technology.[2] The small and diverse learning technology research and development community was not in a position to seize this once-in-a-generation opportunity and imbue effective innovations into education. A coordinated, inclusive effort was needed because:

- *Work is increasingly complex*. Classroom-oriented tools have been the primary focus of R&D, and the field had to make a crucial transition to focus on ubiquitous access by all learners, in and out of school.
- *Broad collaboration is essential*. Few projects, funders, or institutions can encompass the range of expertise needed to use the combination of new technologies and new insights into learning to identify and solve real-world learning challenges.

[2] Office of Science and Technology Policy, 1997, http://www.ostp.gov/PCAST/k-12ed.html.

- *More interaction is needed*. The key to new and increasing utilization is to combine content and communication. There are surprisingly few opportunities for timely sharing of insights and prepublications among potential collaborators with similar goals but different professional affiliations.

- *Field-initiated R&D needs coordination*. Funders can rarely move quickly enough to explore emerging opportunities created by technologies that can go through two generations in the time it takes to conceive, submit, and fund a proposal. The usual strategy of relying on funded field-initiated projects to produce educational change needs to be supplemented with coordination provided by the profession.

In summary, mechanisms were needed to explore flexible, quick, but thoughtful innovations that solve important educational problems and draw from a wide range of expertise. These innovations needed to be winnowed and the best shepherded through several phases of development and dissemination, with input from a range of actors and institutions.

The centers were created in September 1997 and since then have been part and parcel of the evolution of the field. The world of technology and of technology in schools has changed significantly between 1997 and 2004. In addition to the lessons learned from each center's specific activities—both the ones that have led to significant new ideas and developments for the learning sciences and technologies community and others that did not work as we had hoped—NSF has developed an effective infrastructure and set of mechanisms for moving the field forward.[3] The goal of this publication is for the CILT team to share the major lessons learned from their work and to point out ways in which their work will continue.

Reflections of Eric Hamilton, NSF Division Director at the Time of CILT's Continuation Award

The LIS program explicitly acknowledged the interdisciplinary nature of the questions underlying research on learning and the limitations that inevitably arise when investigations originate in or are "cocooned" within single research traditions. The cross-cutting essence of LIS research and the cross-directorate nature of funding constituted an important intellectual experiment by the agency, an experiment whose impact continues to unfold in numerous communities.

While LIS produced important connections across disciplines, it was not structured to accommodate another multi-tier facet of NSF's funding organization. Congress appropriates resources to the agency in two broad investment categories: Research and Related Activities (R&RA) and Education and Training (ET). With some exceptions, most ET resources fall under the purview of the Education and Human Resources (EHR) Directorate, and the R&RA resources are primarily the responsibility of the disciplinary directorates. This division of fiscal resources corresponds to broad differences in mission, funding patterns, and expectations between EHR and the agency's disciplinary directorates. Broadly speaking, EHR supports the development of innovative approaches and tools to remedy both long-standing and newly

[3] The three CRLT/LIS centers have evolved as follows: (a) CIRCLE and CILT PIs have received two of three NSF Science of Learning Centers funded in 2004; (b) CILT PIs and the LeTUS team have become NSF Centers for Learning and Teaching. In addition the LeTUS group at the University of Michigan won the 2004 Urban Impact Award of the Council of the Great City Schools for their partnership with the Detroit Public Schools.

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arising challenges in STEM education; the disciplinary directorates support basic research in their respective areas.

The research base underlying educational improvement is the subject of extensive national debate and commentary. Germane here is the recognition within NSF that the interdisciplinary research base on learning that LIS was advancing was crucial to the agency's efforts to spur STEM education reform. Crossing disciplinary boundaries, however, can be less daunting than achieving genuine research to practice transfer. In fact, the research transfer model widely adopted in science and technology was already considered to be an inadequate paradigm for education research; publication of Stokes' Pasteur's Quadrant in 1997 just as LIS was reaching maturity gave new language and metaphors to this understanding.

To summarize important conditions, in the mid-1990s, NSF was engaged in full-throttle educational reform funding; on the research side it was undertaking a bold yet necessary experiment in interdisciplinary research on learning; this experiment promised critical knowledge to the reform effort; but the chasm between education and research appeared much more daunting to connect than the different research traditions that LIS supported.

It was in this context that the Collaborative Research in Learning Technologies (CRLT) Centers component of LIS was launched. It explicitly maintained the interdisciplinary focus of LIS research, but implemented an additional dimension of situating that research in educational settings and systems. The behavior and dynamics of those settings and systems played no less a role in the underlying research than did the research in cognition or learning technology. The three CRLT Centers each responded to the call for collaborative research in fundamentally different but complementary fashion.

The need to build a cumulative and high impact research base to the agency's education reform efforts were an important driver in the formulation of the CRLT program. That need gave rise to a "superset" effort—an experiment in its own right, actually—to test whether the agency's support for research centers might produce reliable and usable bodies of findings to guide reform. CRLT supported three of five centers that were supported in the mid to late 1990s as part of this experiment. The other two involved the National Institute for Science Education, or NISE, (FY95-FY00) and the Systemic Reform Center for Education, or SYRCE (FY98-FY02). NISE and SYRCE provided different visions and theoretical frameworks for large scale reform. NISE primarily supported and organized research efforts of national partners; SYRCE was primarily devoted to a novel model of what it coined implementation research in urban reform in Texas. While the CRLT Centers focused on learning technologies within reform, NISE and SYRCE more explicitly focused on the broad question of education research within reform—again, with strikingly different theoretical, methodological and intervention frameworks.

To call this portfolio of five centers an agency experiment is accurate but it should not be taken to mean that the agency purposed to develop such a portfolio (though the CRLT was explicitly planned). As is often the case with NSF, where peer review renders specific or preplanned portfolio experiments virtually impossible, it was not until after the portfolio was up and running—and the urgent needs to have a productive agenda for cumulative research findings in STEM education reform intensified—that a more deliberate reflection or systematic reflection on the nature of the research center approach was possible. In February, 2000, NSF

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convened the five centers to help provide more specification about their vision, structure and function, and to participate in a roundtable discussion of the nature and need for education research centers under NSF sponsorship. Dr. John Cherniavsky, Sr. Advisor for Research in EHR at the time of this workshop, summarized the following conclusions from this roundtable:

1. Centers are most properly started when a critical mass has formed and the topic of the center is timely.
2. Centers are better at becoming learning organizations than projects.
3. Centers provide permanency.
4. Centers are better at developing a community and becoming a community building resource nationally and internationally
5. Centers are effective as a convening area—there is time and safety and diverse community and cachet and opportunity to do work because the infrastructure is in place
6. Centers give linking functions through projects, structures, focus and mission, people, organizations, methodologies and technologies. Frequently aggregation of projects allows better results than single results
7. Centers build capacity through critical mass, interdisciplinary connections, shared resources, and disciplinary scientists in education.
8. Centers provide competition to excellence for one another.
9. Centers provide a communication ability through available infrastructure
10. Centers provide a mechanism for schools to enhance both general work and technical work.

Interestingly, these points, except for the last one, may apply to science and technology research centers more generally—the workshop confirmed (or relearned) much of the core logic that stood behind NSF's center funding for many years. And as is often the case, the funding model, once understood or specified, was soon set aside by newly emerging research programs. The legacy of the centers and their role in NSF's success or failure in stimulating large scale STEM education reform cannot be accurately assessed in the short-term. It is clear, however, that the CRLT component of the "centers experiment" has produced an enduring legacy. EHR's Research on Learning and Education (ROLE) program, for example, was explicitly formulated on the interdisciplinary research model that LIS and CRLT helped to pioneer for connecting multiple scientific and technological disciplines to in situ education research. Further, it was a vital part of the conceptual maturation process that gave rise to the current Science of Learning Center program that the agency now supports.

Center for Innovative Learning Technologies: Overview

CILT responded to several concerns shared by senior learning technology researchers: the nonleveraged and frequently noncumulative work in the learning technologies field; the increasing challenges of tackling the complexities of design-oriented and context-responsive learning technology development in partnership with universities, schools, and industries; and the critical need for human capacity building across sectors to create conditions for technological advances, scientific understanding of learning and teaching, and research-guided educational practices.

The approach taken was crafted to foster improvements in how the field addresses these problems and aimed to engage the collaborative efforts of a wide spectrum of people and institutions: educators, computer scientists and engineers, education researchers, cognitive scientists, and subject matter experts throughout the country. To accomplish this mission, CILT set the following objectives:

- Identify areas of high potential. Carefully evaluate educational needs and technology-enabled innovations and select broad "themes" with the greatest potential for breakthroughs that generate long-term learning gains.
- Support rapid innovation. Convene annual agenda-setting workshops for "theme teams" in these areas of breakthrough potential to identify prospects for important multidisciplinary prototype projects, and stimulate others to undertake similar R&D by drawing attention to promising targets.
- Stimulate collaborative development in selected areas. Convene meetings and online discussions around the "themes" designed to share ideas and build collaborations between diverse communities.
- Train new professionals. Recruit, train, and support postdoctoral fellows who will be an integral part of high-risk, high-potential multidisciplinary prototype projects.

CILT (1997–2001) brought together experts in the fields of cognitive science, educational technologies, computer science, subject matter learning, and engineering. It also engaged business through an Industry Alliance. CILT's founding organizations were SRI International's Center for Technology in Learning (Roy Pea and Barbara Means), University of California at Berkeley's School of Education and Department of Computer Science (Marcia Linn), Vanderbilt University's Learning Technology Center (John Bransford), and the Concord Consortium (Robert Tinker). CILT was extended until 2003 with an Accomplishment Based Renewal (ABR). Nora Sabelli, from SRI International's Center for Technology in Learning, joined as Principal Investigator for the ABR.

CILT was organized around "theme teams," shown in Figure 1, each contributing to the research, development, dissemination, training, and evaluation objectives of CILT. The final four themes were: Visualization and Modeling, Ubiquitous Computing, Assessments for Learning, and Community Tools. The fifth team, Design, was merged with Visualization and Modeling for both conceptual and funding reasons, as will become evident later in this document. Three initiatives—the Industry Alliance Program, the cross-theme Synergy project, and a Web infrastructure ("Knowledge Network," CILTKN)—supported CILT's work more broadly to unite related research projects in a collective effort to accumulate and disseminate knowledge more rapidly and widely. CILT saw its work as a combination of its own multidisciplinary projects and non-CILT work enabled by CILT's seed grants.

Figure 1. CILT Organization and Themes

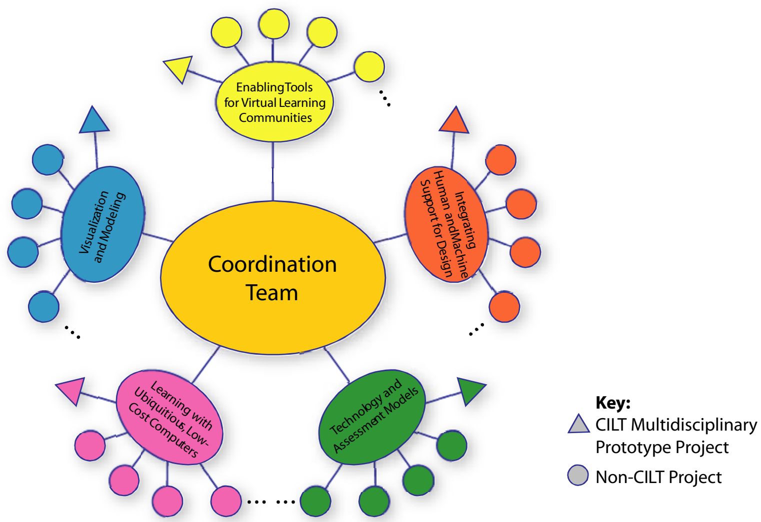
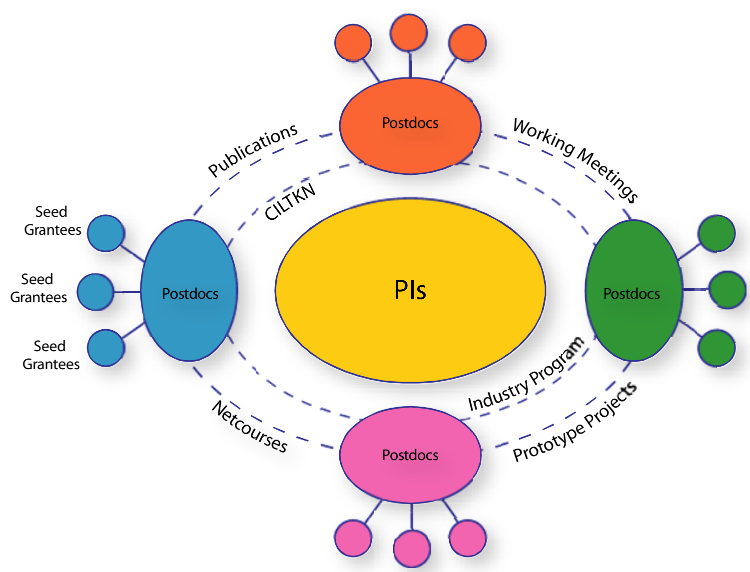


Figure 2. Graphical representation of the "CILT community"



Theme Team	Educational Challenge	Breakthrough Opportunity
Learning Communities *Leaders*: Pea, Roschelle, Schlager. *Postdocs*: Gray, Bos.	Leverage distributed expertise; connect disparate persons both within their local community and from other communities of practice, such as natural science and policy.	Increasing the effectiveness of network-based collaboration and community tools for learning can reshape the pace of learning along with the role of participants. Online tools can bridge gaps between distant research centers, academic developers, and researchers and practitioners.
Visualization and Modeling *Leaders*: Linn, Songer, diSessa.[4] [5] *Postdocs*: Baumgartner, Kali.	More students need to learn and apply STEM concepts in new and emerging fields, as these fields become increasingly complex. Fluency with information technology is a new part of literacy.	Dynamic, interactive images of complex phenomena combined with powerful modeling tools can potentially broaden access to science and technology literacy. Modeling provides a unifying conceptual vocabulary across major topics of modern science and mathematics.
Ubiquitous, Computing *Leaders*: Tinker, Horwitz. *Postdocs*: Hsi, Spitulnik.	Current technologies, developed primarily for business and research, have a suboptimal price, performance, and features for education and are the source of serious inequities.	The right combinations of software, inexpensive portable computers, wireless networking, probeware, and component software could enable much higher levels of student inquiry and support learning in a wide range of contexts.
Assessment *Leaders*: Bransford, Means, Quellmalz. *Postdocs*: Brophy, Ravitz.	Old testing practices undermine efforts to implement new, more powerful ways of learning and teaching. New testing practices that employ technology are needed.	Technology-enhanced assessments offer powerful and useful information for teachers and their students. Embedded and performance assessments can enable ongoing evaluation of teaching and learning and enrich educational programs.

The activities that embodied the four themes were workshops and meetings, CILT prototype projects, “seed grants,” the postdoctoral program, CILTKN, and netcourses. CILT reached beyond its members to create a web of organizations, individuals, industries, schools, foundations, government agencies and laboratories—devoted to producing, sharing, and using knowledge about how learning technologies can improve the processes and outcomes of learning and teaching. Each theme team was led by one of the PIs and one or two additional

[4] An earlier co-lead was Alice Agogino (UC Berkeley)
[5] Earlier co-leads at different periods were Earl Craighill (SRI) and Robert Broderson (UC Berkeley)

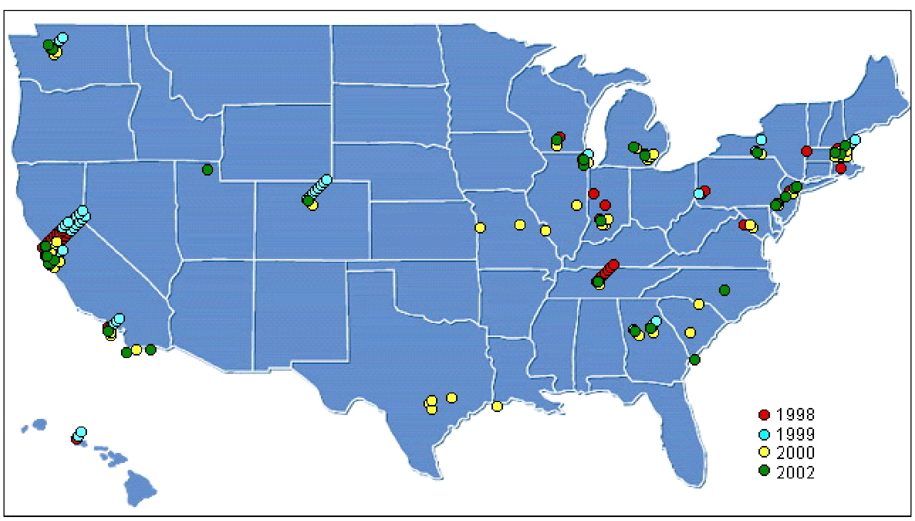
co-leaders and had a postdoctoral scholar working with both PIs and the community in a "leadership training" position (i.e., as a main participant in all field coordination activities of CILT). This arrangement reduced, but did not eliminate, the natural tension between a PI or postdoc seeking to promote their own research and the broader field work of CILT itself. This point will be explored in more depth in Marcia Linn's comments later in this document.

By linking each team through its postdocs to the project leadership, CILT was able to undertake flexible planning and a regular resetting of priorities. The theme team structure and the organizational activities of the postdoctoral scholars were crucial to the CILT goals of stimulating broad, national collaboration in a targeted, feasible, and nimble fashion.

CILT workshops and meetings were organized around the four themes. To stimulate collaboration and cross-project advances, CILT awarded small "seed grants" of $10,000 to $15,000 to proposals describing the collaborations developed during the meeting or workshop (Figure 3). Thus, the expectation of meeting participants was focused on sharing problems actually encountered in their work and finding complementary collaborators. Seed proposals were evaluated and monitored by the theme postdocs (supervised by theme leaders) according to criteria that included concept potential (e.g., innovative and generative); leveraging of other resources; involvement of multiple institutions; interdisciplinary teaming; rapid delivery plans; and plans for assessment, follow-up, and documentation of outcomes. The collaborative conference model, characterized by extremely short presentations by participants, focused on discussing problems and not results, and followed by ample unstructured time to develop ideas and proposals for seed grants, has proven very successful and has been adopted by groups outside the center, as mentioned in Roy Pea's comments earlier in this monograph.

CILT conducted four cycles of seed grants, awarding a total of 60 grants, for a combined support of $636,235 to researchers in approximately 169 institutions (see Figure 3).

Figure 3. Distribution of CILT Seed Grant Awards

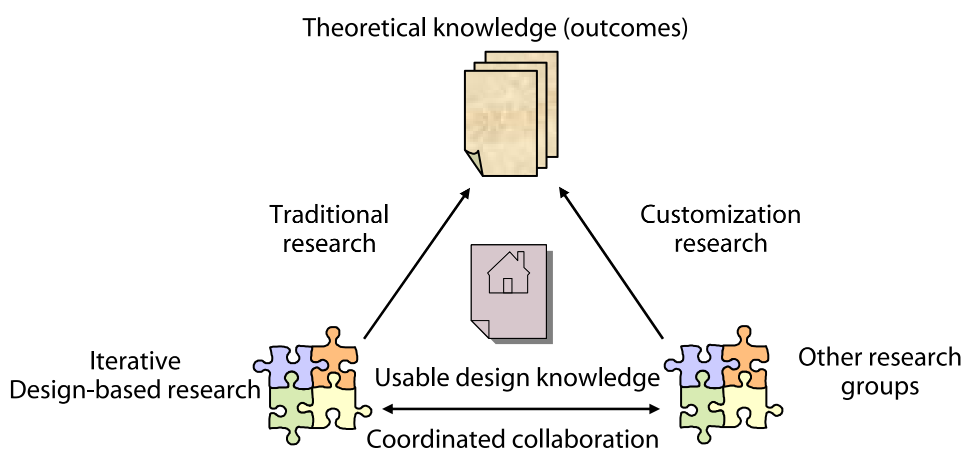


Two of the four themes (ubiquitous computing and assessment) conducted their work primarily through seed grants and, for ubiquitous computing in particular, via its input into the other themes. Before CILT's work began, little research had been done to show the value of handhelds, and few educational applications had been developed for them. As the ubiquitous theme has evolved, we broadened the theme to "Supporting Inquiry Using Ubiquitous Technologies." The new research included a focus on tools that support inquiry, including ubiquitous computing tools. The combination of technology development, software development stimulation, and pilot research has generated strong interest in educational applications of handheld computers, as discussed in Robert Tinker's contribution. The ubiquitous theme was an integral part of the Synergy and Design Principles work described below.

The postdoctoral student research included a prototype collaborative (across institutions, themes, and schools) Synergy project to study how to support diverse groups working on related technology-enhanced innovations in different environments. The close links among postdocs and theme leaders, and of each CILT group with the partner schools involved in Synergy, allowed CILT to explore issues of replication and accumulation of knowledge, which are so crucial to dissemination and implementation projects. The project developed methods for synthesizing like innovations where developers of an innovation attempt to create a similar educational activity using a novel learning environment and test it in the same classrooms where the initial research took place, as shown in Figure 4. Customization research explores the value of usable design knowledge in new contexts. Results of this research, along with coordinated collaboration across research groups, refine the outcomes of traditional education research.

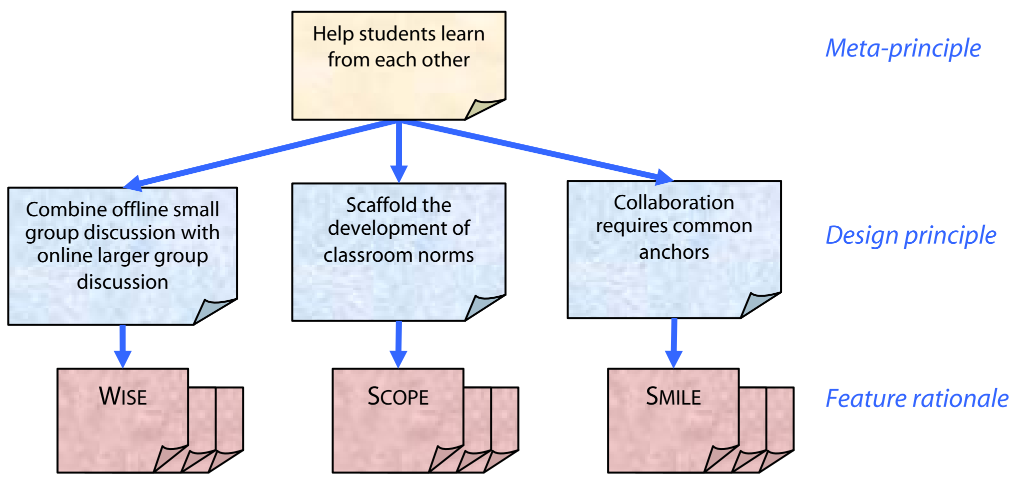
CILT postdocs also conducted important synthetic work in design principle for educational technology and developed a Design Principles Database as a synthesis for technology-based curriculum design based on the body of scientific knowledge that resides among designers and needs to be generated as principles to be publicly accessible. Such a synthesis needs large-scale collaborative efforts, in which teams of researchers share their design experiments to provide meaningful guidelines for design, and the CILT larger community provided an ideal forum for the collaboration. Reports of design efforts usually focus on successful artifacts rather than on lessons learned throughout the process, including the less successful iterations.

Figure 4. Toward a Model of Synergy Research



Several attempts have been made to abstract design processes and provide guidelines that can apply to other contexts, yet there is no common vocabulary or agreement regarding the relevant forms of evidence needed for designers to build on each other's experiences. CILT brought together designers from diverse projects and institutions to develop a common framework for communicating and synthesizing design practices. The framework has three levels of design principles (see Figure 5). Meta-principles offer abstract ideas about instruction and curriculum design. Next, design principles summarize lessons learned from diverse contexts into useful design guidelines. Examples of principles included in this level are a model of the inquiry process, and of multiple linked-representation for viewing data. Finally, specific principles called feature rationales, are the finest grain and capture the results from one study or the character of one technology feature. Examples of feature rationales include providing students with text boxes to define elements in a model, and enabling students to rotate geological structures and view various cross-sections of the structure.

Figure 5. Levels in the Design Principles Database



Digital video is an increasingly important medium for recording and analyzing interactions in educational contexts, but there is little community support for researchers and practitioners to make use of digital video as data. The barriers to entry for digital video are lower than ever, but guidance is sparse and scattered. Duplicative effort is being expended to produce a growing number of independent tool sets and approaches. A CILT-sponsored meeting of active practitioners was held at Stanford's Center for Innovations in Learning to identify areas in which collaboration and consolidation are possible. Noteworthy were concerns about the need for a framework for defining more clearly, for the benefit of IRB reviews, the ethical conduct of work in this field and the risks and benefits of repurposing research video records of learning and teaching for teacher education and for multi-investigator research studies after their collection. A significant development for the learning sciences field would involve following up on the tool recommendations of the workshop and convening a meeting for identifying and developing XML models for expressing coding schemes specifically for learning sciences and teacher education research communities, perhaps along the lines of the Design Principles work mentioned before.

Reflections By CILT Principal Investigators

Introduction to the Importance of Community Tools for Learning Technologies Research, Development, and Educational Practices

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This brief report is organized to illustrate how we conceived of community tools as an important theme for learning technologies research and development, and to highlight the major activities, publications, and impact from the work of CILT in relation to this theme.

Beginnings

When we developed the vision for the Center for Innovative Learning Technologies during 1996, we had a comprehensive and diverse rationale for why we wanted to focus on what we called "community tools" as one of our thematic areas for CILT workshops and research work. Community tools are technologies that support the social processes of learning. The challenges for education that we considered were: (1) leveraging distributed expertise—not only within and between K–12 classrooms, but for the learning sciences and technologies research community itself; (2) providing greater awareness and interactivity across disciplinary boundaries, which we knew to be required for developing higher-quality solutions to educational problems using learning technologies innovations that could work in educational practice (no one group has all the answers). We considered the breakthrough opportunities to be very significant, if not in the short term, certainly in the long haul. These opportunities for community tools we believed to include: (1) increasing the effectiveness of collaborative group learning, within and across classrooms; (2) enabling the re-shaping of content and curriculum to exploit the novel and linkable representational capabilities of computing (e.g., visualizations, video, and "active representations" that collaborators could develop together remotely via networking, e.g., Roschelle et al., 1999); (3) supporting distributed activities among communities of practice, including teachers and teacher educators, learning scientists and technology developers—making the "collaboratory" concept not only useful for the scientific community but to other Internet and computer users more closely allied to learning sciences and educational practices (e.g., Pea, 2002); and (4) bridging communications among researchers and practitioners to enable a more powerful coupling of the scientific inquiry and the wisdom developed through practice (e.g., Pea, 1999).

Three Areas of Emphasis

As we considered this theme in the original proposal, we were less enthused with distance education uses of ICT technologies that perpetuated teacher-centered knowledge transmission models of instruction, and we favored an emphasis on the ways in which project-based, active inquiries may allow learners to collaboratively construct meaning with local and distant peers, mentors, and guides (e.g., Edelson, Pea & Gomez, 1995; Gomez, Fishman & Pea, 1998; Linn, Bell & Hsi, 1998; Pea, 1993; synthesis in Bransford, Brown, & Cocking, 2000). Instead, we synthesized and foregrounded emerging innovative work in: (1) collaborative representations, (2) socio-cognitive scaffolding, and (3) network improvement tools for fostering self-improving communities (see Pea et al., 1999; Roschelle & Pea, 1999; Roschelle, Pea, Hoadley, Gordin & Means, 2001). We brought these themes together in one of our first CILT collaborative works for the 1997 CSCL (Computer-Supported Collaborative Learning) Keynote address I presented with a number of co-present and remote colleagues. Called "A Flying Circus on the

Collaborative Tailoring of Educational Objects," this vision "performance piece" combined existing multi-user virtual environments for learning (*Tapped In*), with feasible conceptions of an component architecture for mathematics learning objects that a teacher could be using in her classroom and plausibly seek and receive real-time component developer modifications to a program she is using, showing to the developer over the Internet some problems that she is encountering as her students work with the concepts of graphing acceleration and velocity using NSF-funded SimCalc math software simulations (http://www.cilt.org/resources/flying_circus/circus_concept.html). Select features of this vision were realized over the course of CILT's progress, in a related NSF project known as ESCOT (http://escot.org) co-directed by CILT Community Tools co-lead Jeremy Roschelle, myself, SRI computer scientist Chris DiGiano and Prof. Jim Kaput (U. Massachusetts, Dartmouth).

Collaborative Representations

Community tools for creating *Collaborative Representations* are those enabling remote interactions mediated by diverse visualizations, notations, and models that can be constructed together. We anticipated that such tools would provide critical enabling technology for successful learning conversations about complex subject matter in mathematics and science. Collaborative Representations may include text, graphs, digital forms of student work products, mathematical notations, simulations, gestural depictions, annotations, and video, and Dan Suthers' research work was influential for many CILT participants on this theme (e.g., Suthers, 1999; Suthers & Hundhausen, 2003). The core concept was that "seeing what we build together" when engaged in collaborative learning with technology (Pea, 1994), an issue of representational coordination, is crucial to establishing what psycholinguist Herbert Clark (1996) calls the "common ground" of communicative understanding.

Network Improvement Tools

We viewed *Network Improvement Tools* as having considerable potential for enhancing learning by linking individuals to teachers, mentors, like-minded peers, subject-matter experts, as well as new interactive knowledge sources. CILT workshops and projects examined multi-user virtual environments and diverse collaborative and groupware tools for network improvement. While we anticipated that industry-developed community-based information filtering technologies—pioneered in the early 1990's at Bellcore and in spinoffs from MIT and the University of Minnesota—such as user-profiling and recommendation engines (now familiar in Amazon.com and Netflix.com) would have great applicability for distributed learning environments and resources, our CILT-related proposals to NSF and bids of interest to industry and other researchers were not taken up. We also sought, unsuccessfully, to develop a collaboration with AT&T Labs on bringing social networking technologies to work in visualizing learning sciences and technologies researchers and labs. Today, "social networking" companies such as LinkedIn, Spoke, Friendster, and others are rapidly being adopted for business development and match-making connections. On the other hand, early CILT seed grants and conference discussions on the importance of using emerging "metadata" systems for fostering the efficient location and organization of learning materials by labeling them with categories that can be recognized with XML-compliant Web browsers have proved prescient (e.g., Instructional Management System, or IMS Global Learning Consortium, http://www.imsglobal.org/index.cfm; also Wiley, 2002).

Socio-Cognitive Scaffolding Systems

Finally, we hoped to catalyze integrative efforts in understanding the emerging variation and increasingly common socio-cognitive scaffolding systems such as CSILE, CoVis, KIE (later WISE), and Kids as Global Scientists that used pedagogical principles from the cognitive sciences to structure classroom network-based or distributed learning models which facilitated the conduct of more complex thinking, inquiry and knowledge building than would have been possible otherwise. Among other activities in this vein, CILT researchers developed a learning technologies vision paper for the 1999 National Governors' Association meeting (Means et al., 1999). The vitality and ongoing challenges of work in this vein of scaffolding systems, advanced significantly in the NSF LeTUS center (whose researchers including Louis Gomez, Joseph Krajcik and Barry Fishman were frequent CILT workshop contributors), is illustrated in a forthcoming 2004 special issue on "Scaffolding in Science Learning" of the *Journal of the Learning Sciences* (e.g., Pea, 2004), and by the highlighting of such issues in the CILT design principles database for computer-based learning environments that continues today (http://wise.berkeley.edu/design/, and see Kali et al., 2003).

Developments from Community Tools Emphasis

Within several years of launching the Center, we saw a trend toward researchers thinking more deeply about community tools, as they developed more advanced functionality and broader user communities, in terms of their social contexts of use, beyond their features and capabilities. Considering community tools as important to be designed, implemented and researched as socio-technical systems led to CILT postdoc Jim Gray working with frequent CILT workshop contributor, Sasha Barab to develop an edited Cambridge University Press book on theoretical and empirical developments on designing virtual communities in the service of learning (Barab, Kling, & Gray, 2004). We sadly lost our colleague Rob Kling from Indiana University during the preparation of this volume. During our CILT-2000 workshop, we highlighted issues of digital divide and equity in access to learning technologies, and I developed the opening address for CILT-2000 on these concerns into a policy paper that was broadly distributed in California through the California Council of Science and Technology (Pea, 2001), which advises legislative initiatives in the state.

CILT-2000 community tools theme team contributions surfaced considerable interest on the equity of student participation within and across classrooms (Gray, 2002). Examples included a design study of inclusiveness during problem-based learning activities, using online discussions to encourage equitable participation within a classroom, and a cross-cultural project designed to foster participation by US and Japanese students through the use of multiple representations, mentors, and personalized learning. CILT 2000 seed grants included a study of multicultural online playful learning environments (presaging the focus on "gaming to learn" that has erupted in the learning sciences in the 2003-2004 period), development of technological scaffolds for the study of race and other social issues through comparison of Shakespeare's Tempest and current issues; and creation of a rubric for assessing the equitable access to online learning environments.

One important development from the CILT community tools spirit and activities was a collective of early-career stage researchers assembled in a seed grant called the "Learning Sciences Research Group, "which grew to encompass a larger effort of young scholars which the Spencer Foundation funded as the Design-Based Research Collective (http://www.designbasedresearch.org/), and CILT PI Roy Pea served as a senior advisor to this effort. For some of the fruits of their efforts, see the *Educational Researcher* article by the Design-Based Research Collective (2003) and a special issue of Educational Psychologist.

Digital Video Inquiry and Community in Digital Video Collaboratories

A recurrent issue raised at many of the CILT community tools workshops and in some of the seed grants concerned the growing accessibility and uses of digital video in the field. These uses ranged from incorporation of digital video in interactive learning environments *as content for learning and teaching*, to digital videorecords *as a research medium* for studying learning and teaching practices, and to digital video *for teacher preparation and professional development*, affording a new platform for teachers and teacher educators to capture exemplary practices or their own practices and to develop use scenarios for fostering learning through reflections on practice. In November 2002, CILT sponsored its final workshop at the new Stanford Center for Innovations in Learning on the topic of “Digital Video Inquiry in the Learning Sciences” (http://cilt.stanford.edu), involving nearly 70 researchers to share their experiences and problems and ideas for building a more powerful learning community to advance the practices and the tools that their work requires. The momentum of the group assembled has led to the development of an edited volume of approximately 40 chapters to be published in 2005–06 by Erlbaum Associates, on Video Research in the Learning Sciences, edited by CILT workshop participants Ricki Goldman, Roy Pea, Brigid Barron and Sharon Derry. Building on the CILT workshop website, an affiliated community-oriented website for the forthcoming book enables authors and other researchers to register as members, contribute bibliographic resources, papers and URLs, conduct threaded discussions on issues for the field or any of these resources, and generally contribute to the emerging community of video research scientists.

A new project initiative building on these foundations was launched in late 2003 as a National Science Foundation Information Technology Research (ITR) project, by myself and CMU Professor Brian MacWhinney, to establish the socio-technical infrastructure necessary for “digital video collaboratories” in the human sciences. The Digital Video Collaboratory Project will enable research communities to collaborate in producing and annotating corpora of video data records in diverse disciplines studying learning and human interactions. We aim to create accessible, productive tools for video analysis, collaboration and sharing by focusing on core technical advances in human-computer interaction, video analysis and collaboration tools, web-based computing, video compression and streaming, and XML metadata/API standards to provide for broader impact across multiple disciplines and applications. We are: (1) developing a virtual video data repository and video analysis community portal; and (2) producing an open community toolkit to greatly expand generality and application interoperability for video analysis and output. Research communities will not make full use of video data so long as significant obstacles remain at any of the key points of video storage, retrieval, circulation and commentary. Enabling research communities to build knowledge through sharing video data and analyses constitutes an important enhancement to the national research and education infrastructure.

Learning Community Tools for Teachers and Teacher Educators

We also found tremendous appetite in the broad CILT community for learning community tools for teachers and teacher educators. A number of different CILT seed grants worked to synthesize knowledge about online professional development tools, methods, and research findings. Sun Microsystems, from whom we sought CILT industry partner support, was enamored of this area in particular, and donated $80K worth of computer server equipment to SRI International for advancing the community-building efforts of the NSF-funded *Tapped In* Project (http://ti2.sri.com/tappedin/, also see Schlager & Fusco, 2004, Schlager et al., 2002; Schlager & Schank, 1997). *Tapped In* PI Mark Schlager also served as Community Tools theme team co-leader in the final several years of CILT. *Tapped In* also served as a research site for the CILT ROC Project (Researching Online Community) conducted by CILT postdoc Jim Gray and Deborah Tatar (2004; also see Tatar, Gray & Fusco, 2002).

The Development of Teachscape

An additional CILT influence—at the intersection of teacher professional development and digital video—is worth highlighting in this vein of community tools. In April 1999, I was approached by former CBS news producer Mark Atkinson, initially as a consultant, to help develop a business venture code-named "Minerva" that would create CD's of expert K–12 teaching based on the best educational research knowledge. With my help and assistance from others at SRI, Mark became convinced that on-line professional development communities coupled with digital video libraries of exemplary teaching practice was a more appropriate and technically possible design. The ensuing large Minerva Project brought a significant commercial consulting and technology development venture to SRI under my direction. Subsequently, Mark Atkinson and I, with several others, co-founded the company now called Teachscape, based in New York City (http://www.teachscape.com), with funding from Sprout Capitol, Arcadia Ventures, Quad Ventures, New School Ventures, Intel, and other investors. CILT's close working relationship with Intel education leadership was instrumental to their funding relationship with this enterprise. Teachscape today serves tens of thousands of teachers, primarily in urban districts throughout the country, as a professional development and educational reform service that combines on-line and on-site services for fostering research-informed teacher preparation and in-service learning, especially in literacy and mathematics. In addition, Teachscape has collaborated as a design and distribution partner with CILT organization Concord Consortium in developing the "Seeing Math" video case studies of exemplary upper elementary and middle school mathematics teaching (Lu & Rose, 2003; http://seeingmath.concord.org), with US Department of Education support.

CILT Knowledge Networking (CILT-KN) and LT-Seek

One of the earliest activities planned by CILT's Community Tools theme team leaders was to use best practices in knowledge networking to support the community-wide activities of the Center. Given the aims of CILT, an internal planning document from early February 1998 sketched a vision of a knowledge network to be developed concerning learning technologies (LT) that would be: "a coordinated web of organizations, individuals, industries, schools, foundations, government agencies and labs, that is devoted to the production, sharing and use of new knowledge about how learning technologies can dramatically improve the processes and outcomes of learning and teaching." We felt that it could provide: "a broad and deep set of community-generated resources on the latest in: (1) LT researchers, their projects and results, and LT research syntheses; (2) LT research labs and graduate programs; (3) LT project funding sources; (4) LT information exchanges and services; (5) Free and commercial software, activities and assessment items (and other products) for use in demonstration, lab, and school design experiments; (6) LT-relevant journals, magazines, publications and conferences, professional societies and SIGs to participate in; (7) Annotated LT bibliographies and course syllabuses; (8) LT in the news."

We conducted early experimentation during 1998 using a Chicago-based company's knowledge management system for CILT knowledge networking (i.e., Digital Knowledge Assets' SceneServer; out of business in 1999) that had the broad functions of today's WIKI (e.g., http://wiki.org/) and blogging (e.g., http://www.blogger.com/) groupware technologies, but costs and sustainability issues were clearly going to be a problem. I oversaw the operationalization of the CILT knowledge networking agenda in co-planning what came to be called "CILT-KN" with CILT research scientist Chris Hoadley at SRI International, who developed and then operated this valuable service for the CILT community (Hoadley & Pea, 2002). CILTKN provides an information infrastructure to support collaborating researchers, teachers, and industry partners in the area of learning technology. CILTKN is a means for collecting and disseminating information about learning technology research and its stakeholders. This information about the community resides in several structured databases, allowing dynamic access to the information. The network allows users to share information about people in the field, research or development projects, and opportunities for collaborating. In addition, a library of course syllabi and reading lists from premier graduate schools in the learning technology field allows users to access information about foundational research. By making information like this easy to find and share, CILTKN helps people learn about the field and locate collaborators.

As CILT-KN is reported on separately in our CILT final report, I will not further describe it here, other than to note that as of May 29, 2004, it had 9038 members from 97 countries. Given their complementary knowledge networking aims for the learning sciences and technologies community, as of late May 2004, LESTER (Learning Science and Technology Repository: http://lester.rice.edu) has now integrated tools and services formerly offered by CILTKN. Through its partnership with CILTKN, LESTER now offers information about researchers, research institutions, research projects, and funding organizations in educational technology, course syllabi, and a bulletin board for collaborations to share and identify research collaborators, with a bibliography of learning science and technology resources coming soon. The LESTER team will continue to actively maintain its database of research projects and other resources for the LT community. Dr. Christopher Hoadley, CILTKN director emeritus and now Assistant professor of Education at Penn State University, has joined the LESTER advisory board. CILT is making the CILTKN code and supporting documentation available to benefit the learning technology research and development community. If you are interested in using the CILTKN code or just learning from its architecture, visit http://www.cilt.org/resources/kn.html.

Another CILT community tools activity took place for several years as a network news service. During CILT's operation (August 1998-January 2002), John Rakestraw at CILT partner Vanderbilt's Learning and Technology Center (LTC) was responsible for developing a new daily electronic news service called LTSeek (archived at http://ltseek.ltc.vanderbilt.edu/). He would find on-line resources relevant to learning technology issues in the New York Times and other on-line resources, provide a quick summary of an article's content and a link to that specific story. CILT postdocs and researchers also made contributions.

CILT Community Tools and the National Academy of Sciences

US Department of Education Director of Learning Technologies Linda Roberts was a regular participant at CILT workshops in the late 1990's and decided to sponsor a two-year project at the National Academy of Sciences. I was asked in August 2000 to co-chair what came to be called the "Committee on Improving Learning with Information Technology, or ILIT, with National Academy of Engineering President William Wulf. As approved by the Board on Behavioral, Cognitive, and Sensory Sciences (BBCSS), Center for Education (CFE), and Computer Science and Telecommunications Board (CSTB), the mission of the committee was: "Collaborating on a project to catalyze the creation of a community of experts in technology, cognition and learning, and education who are devoted to improving education through creative applications of information technology." Our work in convening interdisciplinary and intersector organizations at the CILT workshops—universities, think-tanks, industry, K–12 educators and leaders, government—was a foundational influence in the motivation for and the conduct of the ILIT committee work over the two year period. As the NAS committee rationale observed: "It is time to forge a working alliance of technology wizards, learning experts, and educators to take on the challenge of exploiting the promise of computer-based technologies for promoting learning." The statement of task for the ILIT committee noted that its aim was to: "lead to the creation of a National Academies Standing Committee on the Roles and Uses of Technology in Education that would monitor developments in technology, research on cognition and learning, and advances in curriculum and classroom practice that would help school officials and faculty make more informed and strategic decisions about the acquisition and use of education technology. The periodic publications by this standing committee would make this information widely available to decision-makers in education and educational policy and help guide the Federal research agenda."

Two monographs were developed through the ILIT committee's work activities (Pritchard, 2002; Pea, Wulf, Elliot, & Darling, 2003), which included a series of broadly attended technology demonstration and project review workshops on the East Coast and West Coast. In significant part due to the unprecedented nature of the coalition and community development aims of the ILIT committee when compared to the policies guiding the standard mode of work at the National Academies of producing vetted reports that summarize and synthesize research findings, the committee was not able to develop a community-oriented website to serve on an ongoing basis as a mechanism of bringing together these disparate groups to achieve a vision for strategically improving learning with information technologies. And the National Academices did not develop a standing committee on the roles and uses of technology in education following the ILIT activities. The primary contributions of these activities and the ensuing reports were in documenting the challenges and in examining lessons learned in successful partnerships that have productively engaged educators, researchers in the learning sciences, and industry in powerful models of using IT to improve learning and teaching, in developing an initial roadmap for improving learning with information technologies through the collaborative engagement of these different groups, and in developing new personal and organizational connections among these diverse communities.

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CILT Postdoctoral Scholar Program

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The Center for Innovative Learning Technologies (CILT) postdoctoral program addressed the goal of building capacity in the field of science and technology education. This section summarizes how the CILT themes benefited from the contributions of the postdoctoral scholars. It also describes specific activities, including the Synergy project and the Design Principles Database, and the net courses. Finally, the section comments on the career opportunities provided by the program.

The postdoctoral program emerged over the four years of the CILT grant and was further developed during the ABR period. Initially, the grant called for both postdoctoral scholars and graduate students to be affiliated with CILT but budget reductions led to a staffing model that included the principal investigators, the administrative support staff, and the postdoctoral scholars. Due, in part, to the shortfall in industry contributions, limited funding was available to support the research of the postdoctoral scholars. These factors were important in shaping the ultimate outcomes of the postdoctoral program because the postdoctoral scholars were the main staff to each of the themes. The postdoctoral scholars had numerous responsibilities associated with meetings, CILT conferences, seed grants, and community building. As a result they had limited time and resources for traditional postdoctoral activities such as carrying out independent investigations, learning new research skills, and learning new research methods.

Three tensions characterize the postdoctoral program in CILT. First, CILT fundamentally had the obligation of building a community of individuals concerned about technology and science learning, which clashed with values in the field for new researchers. This goal ensured that the postdoctoral scholars would be collaborating to identify goals for conferences, invite participants to activities, and carry out a process for developing research questions and seed grant topics. This goal clashed with the postdoctoral scholars need to embark on their careers. They needed to develop individual, identifiable, research programs in order to pursue career opportunities. The field of educational research strongly values investigator-initiated activities and rewards individual over group collaboration. Thus, the postdoctoral scholars faced an important tension between their desire to work collaboratively and achieve the goals of CILT and their desire to develop an independent research program that would ensure their career success.

A second tension in CILT concerned competing desires to carry out research either individually or collaboratively and responsibilities within CILT to plan conferences, develop net courses, encourage the formation and success of seed grants, and to initiate additional community activities based on the needs and desires of the field. The postdoctoral scholars wished to carry out research, but often they found that the responsibilities of monitoring seed grants, writing reports, planning AERA sessions, planning CILT conferences, designing net courses, delivering net courses and coordinating across CILT filled their time. The postdoctoral scholars felt responsible for research involving the four CILT themes. To carry out a coordinated research program, they interacted with the leaders of each of the themes as well as individuals participating in the themes and individuals conducting seed grants funded by the themes. Developing this skill in research management and coordination was an unintended consequence for many of the postdoctoral scholars of their participation in CILT.

A third tension inherent in all research projects and equally central to CILT concerns the tension between expectations and resources. CILT established itself as a leader in building community in the field of mathematics, science and technology education. Allocation of resources to this primary goal meant that very few remained for research initiatives. To remedy this problem the postdoctoral scholars sought to affiliate with projects at their local institution that could augment their efforts with resources and personnel. Each postdoctoral scholar found a solution to this challenge, typically by affiliating with a research project at one of the participating CILT institutions. However, unlike typical postdoctoral situations, these collaborations did not include graduate students who could take responsibility for any of the community building or coordinating efforts in CILT. The CILT postdoctoral scholars could not delegate activities such as communicating with seed grantees, developing agendas for conferences, contacting presenters. or scheduling phone meetings to other collaborators. The tension between expectations and resources also meant that the leadership of CILT came to depend extensively on the postdoctoral scholars to carry out the collaborative and community building activities.

A main consequence of these tensions is that the value that postdoctoral scholars contributed to CILT made it difficult to encourage them to seek jobs. In addition, because the postdoctoral scholars research agendas were slowed by the numerous research management activities that they undertook, they were less prepared to go on the job market than they might have been in a more traditional setting. As a result, the initial postdoctoral scholars remained beyond the two years initially targeted and new postdoctoral scholars came into the Center for Innovative Learning Technologies later than initially anticipated. As discussed in the conclusions, these experiences also influenced the career paths the postdoctoral scholars ended up following.

Chronological Activities

It is useful to look at the series of activities for the postdoctoral scholars in CILT. These activities are roughly organized by year, but of course, there was spill over from year to year and the fourth year was extended due to the ABR funding.

Year 1

During the first CILT year postdoctoral scholars for all four of the themes were recruited. The postdoctoral scholars joined CILT at various points during the year. The initial postdoctoral scholars were at Berkeley, SRI and Vanderbilt, and the postdoctoral scholar collaborating with the Concord Consortium remained at Berkeley during the entire CILT grant. This decision was compatible with the source of funding which was the University of California, Berkeley. This situation made travel to the Concord Consortium an important component of CILT's postdoctoral program. To ensure that the postdoctoral scholars could collaborate effectively, during the first year we organized visits to each site at CILT for all the postdoctoral scholars . These visits turned out to be a significant bonding opportunity. Postdoctoral scholars invited visitors from other sites to stay at their homes, meet their families, bring their children, play quartets and in other ways become well acquainted and cohesive. The postdoctoral scholars visited the Concord Consortium, Vanderbilt University, SRI and University of California at Berkeley. They attended the AERA meeting and collaborated at the CILT conferences. During the first year, CILT ambitiously one conference for each theme and quickly reached a state of exhaustion. After the first year, CILT held one conference to address all four themes. CILT chose the single conference focus in addition to ensure synergy across the themes.

During the first year, the postdoctoral scholars and I met on numerous occasions to talk about how we might initiate a research program within the available resources that would contribute to individual postdoctoral scholars 's interests as well as the overall CILT goal of understanding the process of community building. Initial interactions with members of the CILT community established that many groups were working on very similar topics with little knowledge of each other's efforts. A clear goal for community building was to leverage these individual efforts into more collaborative undertakings. Many factors, most importantly, the *not-invented-here* phenomena, stood in the way of this effort. Undaunted, the postdoctoral scholars began to plan and analyze interactions among members of the community. The postdoctoral scholars noted that water quality activities were a focus of research groups at all of the CILT sites, as well as many other sites, where postdoctoral scholars had previously done their work, or individuals in other centers funded by the same initiative were working. In particular, the LeTUS and CILT groups both had work in the area of water quality currently under way.

The initial description of the CILT Synergy project was to enable individuals who were developing projects in a similar domain to "walk in each other's shoes"[6]. By this we meant that individuals would learn about the goals, commitments, decision-making processes, assessments and activities of each other's projects in the same area. Furthermore, we envisioned the possibility that by exchanging assessments and looking at outcomes from different projects, we could start to identify strengths and limitations of the projects. This exchange of assessments proved extremely informative. Assessments developed by four different groups were compared and it quickly became apparent that there was almost no overlap between the goals of the projects, in spite of the fact that many of the activities looked very similar. For example, in all the activities students did some measurement or interpretation of water quality data.

Discussions of the interesting similarities and differences among these projects, led to the decision to hold a Synergy summit where each project would present their approach in depth and all the participants in the projects could discuss the overlaps and unique aspects of each project. The goal of the summit was to synthesize the various findings and determine whether economies of scale were feasible.

The water quality summit described in the Baumgartner and Hsi contribution revealed fascinating conundrums. Individuals from the University of Michigan argued that they would not even speak to individuals whose water quality projects lasted less than eight weeks. Individuals from the University of California wanted to know how to complete a water quality project in under a week, since teachers in California had so many standards to address they had only a week for the topic. Whereas, individuals from Vanderbilt raised the issue of doing water quality projects without visiting a body of water, since many of their students in urban settings couldn't afford field trips to lakes, streams or other areas where water quality might be studied. These discussions led the group to characterize what came to be called *customization*. The group began to identify the dimensions along which individuals take one project and adjust it for their own needs. Each school participating in a water quality project, implemented a slightly

[6] A model of cross-research group collaboration that had been pioneered in the Schools for Thought project (Lamon, M., Secules, T., Petrosino, A. J., Hackett, R., Bransford, J. D., and Goldman, S. R. (1996). Schools for thought: Overview of the international project and lessons learned from one of the sites. In L. Schauble & R. Glaser (Eds.), *Contributions of instructional innovation to understanding learning*. Hillsdale, NJ: Lawrence Erlbaum.

different version of the activities based on the time, commitments, knowledge, prior experience and other characteristics of the region. In addition, the Web-Based Inquiry Science Environment group had created their materials in an on-line learning environment and were encouraging teachers to take the design pattern in and completely customize it to a new water environment. Teachers were encouraged to add new maps, points for data collection, connections to local ecology etc.

At the time of the first advisory board meeting, the Synergy project was underway and the postdoctoral scholars attempted to communicate to the advisory board the importance of this activity. One goal of this communication was to secure resources from the CILT budget for Synergy activities. The advisory board was definitely underwhelmed by these ideas. Members of the advisory board complained that this direction of research lacked a sound research focus. Others pointed out the extreme difficulties the project had faced— groups for example, couldn't even agree on a definition of water quality. The postdoctoral scholar group responded by arguing that customization was indeed an extremely important research topic since it afforded the economies of scale so essential to success in the field. In addition, the postdoctoral group pointed out that questions such as; what are the goals of water quality projects, were central to the research agenda in the field and to determining what is meant by standards in different states or even in the same state. Although limited resources were made available to the Synergy project the group continued its efforts in the second year.

Year 2

During year two, the Synergy project initiated a series of research investigations in collaboration with the LeTUS project and individually at each site. There were comparisons between different versions of activities, efforts to reconcile assessments or to build assessments that cut across projects as well as efforts to analyze how individuals carrying out Synergy projects connected to the individuals designing the project.

Two important activities emerged in these efforts; first the group began to define customization. They also began to determine the important questions concerning customization. This effort led to a proposal to the National Science Foundation to gain funds to study customization.

A second major outcome of the efforts to explore customization concerned the development of new research outlets. Individuals studying the Synergy activities began to recognize that they were using research methods that systematically described the trial and refinement process, and enabled comparisons between groups following different trial and refinement trajectories. These methods ranged from ways to analyze embedded assessments to ways to design activities, so that outcomes could inform future designs. During the second year, the postdoctoral group synthesized these Synergy activities into a successful presentation at AERA summarizing the various directions the Synergy project was taking. These ideas lay the groundwork for further exploration of methodologies and for efforts to find new ways to synthesize research finding.

Year 3

During the third year of CILT, the value and definition of the Synergy project was well established. In addition, the Synergy project had spawned and institutionalized a set of group processes that led to successful small conferences focused on synergizing research. These processes were refinements of the initial processes developed by CILT as a group for carrying out CILT conferences. They involved mechanisms to support the knowledge integration of an entire group, methods for eliciting the ideas of all the group members, encouraging sub-groups to form, refining the agendas of the sub-groups and capturing those agendas in seed grant proposals. These were perfected with the Synergy focus in mind. These processes enabled the postdoctoral scholars to carry out small and medium sized conferences about aspects of Synergy.

The success of these processes led the Concord Consortium leadership to wonder whether we might capture some of this expertise and process in net courses that could be offered more widely. The postdoctoral scholars undertook the process of first learning how to manage and run net courses and then designing their own net courses within the themes of CILT. The net courses enjoyed varied success. The most successful ones furthered the Synergy agenda, bringing together individuals with alternative approaches for solving a given problem such as; creating a visualization for thermodynamics and enabling them to understand how their different projects arrived at solutions, as well as to learn how they could customize their approach based on successful elements from other research programs. More information about the net course process is found in another section of the report.

During this year it was also a central goal of the Synergy and postdoctoral program to more systematically capture understandings concerning assessment, especially as it applied to the customization of alternative approaches to teaching a similar topic. The assessment net course synthesized some of these ideas and brought together a community to think more systematically about assessment and alignment with instruction.

The emphasis on methods and how they contribute to research in technology and education also gained momentum during the third year and became a major focus of the fourth year.

Year 4

During the fourth CILT year, most of the participants in CILT became certain that CILT years and dog years bore important resemblances, each lasting seven normal years. The Synergy group during the fourth year convened a series of workshops following the model described above to encourage the comparison of different research approaches as well as the synthesizing of research questions. These activities focused largely on methodologies in research. These activities were funded by CILT and by the NSF funds that resulted from the proposal produced in year two. At these meetings, which are described in the contribution to this section on design principles, considerable progress was made in understanding how research methods in the field contribute to the kind of research that gets undertaken and therefore, to the kinds of problems that can be addressed. Describing this effort as design research, the CILT postdoctoral scholars along with other participants, developed a perspective on research that informs both design and understanding of learning and instruction. This series of activities, funded by the Spencer foundation, culminated in a paper published in the *Educational Researcher*.

During the fourth year, the group saw numerous ways to represent findings from customization projects. One important approach concerned creating a database of features from various approaches to teaching in science education and synthesizing the characteristics of these features in design principles. This effort built on the work of one of the CILT postdoctoral scholars Sherry His, co-author of a book called, *Computers, Teachers, Peers*, [Linn & Hsi 2000] that included a preliminary set of design principles. In collaboration with Yael Kali and others in CILT, this group began to define the nature of a design principle and build a design principles database. The design principles database work continues today extending beyond the CILT funding[7]. Details about current design principles activities are found in the design principles paper in this report.

During the fourth year the postdoctoral scholars also became more meta-cognitive about the processes of collaboration they had been using and studying and began to think more abstractly about this process. As described in one of the contributions to this section, the postdoctoral scholars identified characteristics of collaborations that were successful as well as those that interfered with long-term progress.

During the fourth years as the postdoctoral scholars all moved to identify new job opportunities, the Synergy project foci continued to inform their activities. Each of the postdoctoral scholars took a piece of this work and continued to extend it in their current activities. The extensions of these activities are reflected in all the papers in this section.

Discussion

The Synergy project brings together the goal of building a community of researchers, each of whom has important commitments and detailed experiences. It reflects the complexities of designing and building technological innovations and the importance of achieving economies of scale. It stems from the realization that the field has matured to the point where innovations can be productively compared and where individuals can learn from the innovation failures and successes of others.

The Synergy project initiates an important direction in educational research, one that both celebrates the importance of ground-breaking new solutions to educational problems and the crucial contribution that the customizations made in each classroom and by each teacher, contribute to student learning. Designers, when they build up on each other’s work come up with much more effective ways to support visualization and modeling, collaboration, ubiquitous computing and embedded assessment. At the same time, these more powerful and effective solutions always require customization to be successful in individual contexts. When innovations are too complex to customize, they often are neglected instead. Innovations that are too easy to customize often break rather than succeed in new settings. Finding the balance between too much and too little customization, and designing innovations that bend but do not break is an important debate that was supported by CILT. The Synergy project captures this debate and offers guidance to others concerned about this question.

The Synergy project proved a perfect vehicle for training and developing the skills of the postdoctoral participants in CILT. At the same time the Synergy project enabled the postdoctoral scholars to develop a set of capabilities and skills not always found in individuals who complete postdoctoral training. For example, the CILT postdoctoral scholars had extensive

[7] For example, with the work of the NSF Center for Learning and Teaching called “Technology Enhanced Learning of Science” (TELS, co-directed by former CILT co-PIs Marcia Linn and Robert Tinker)

experience in managing research, planning conferences, encouraging collaboration, building community, communicating across disciplines and carrying out large-scale complex undertakings.

Synergy produced new understanding of research and new knowledge for the field. Understanding of the process and dimensions of customization was fundamentally advanced by the Synergy project. When the Synergy project first proposed an emphasis on customization to the advisory committee and to the NSF, they were met with skepticism and only Herculean efforts produced a modicum of respect for these ideas. Today customization is discussed from numerous vantage points.

The Synergy project produced new research methodologies building on early descriptions of design experiments and design research and also on a seminar held at Berkeley that many of the individuals involved in CILT had participated in which was part of the science and design graduate training program funded by the National Science Foundation. The CILT postdoctoral scholars and other collaborators brought into the many workshops on design ended up building what became known as the "Design Underground", and producing effective and influentially scholarly work in this area.

The Synergy project led to the development of a generative way to think about design principles and a project to produce and synthesize the features of a large number of technological innovations and to begin to identify principles that might describe the characteristics of successful features of these innovations. Considerable debate exists in the field concerning the value, importance and impact of design principles. This work continues with many of the postdoctoral scholars from CILT now incorporating this commitment into their own work. In addition many new researchers in the field are joining in this endeavor and reflecting on how design principles might be effectively incorporated into the work of the field.

Conclusions

In conclusion, the tensions that motivated the Synergy project and contributed to its development continue to play a role in the lives of postdoctoral scholars who participated in CILT. Many of the postdoctoral scholars complained that their collaborative efforts aren't properly responded to or respected in the field and have shaped their career paths away from traditional research activities at universities and towards more collaborative undertakings in varied research and development centers.

The tension between carrying out a research program and building a community concerned about innovative learning technologies meant that the postdoctoral scholars developed a set of community building skills that has served them well in the careers they've chosen. These skills are compatible with almost all career paths in the field and have typically propelled the postdoctoral scholars into positions of greater leadership than would be typical at these stages in their careers.

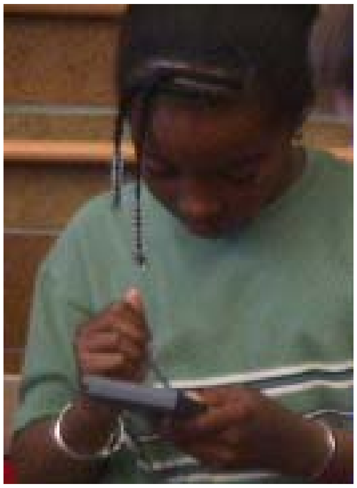
The tension between expectations and resources in CILT is the source of the greatest frustration expressed by the postdoctoral scholars . This frustration is understandable; the postdoctoral scholars spent, in their minds and probably realistically, more time on tasks that could have been delegated had resources been more plentiful. In addition the postdoctoral scholars choice for research agendas was constrained because they needed to affiliate with projects that were underway in order to get any funds for their own research. This difficulty combined with the reluctance on the part of CILT to encourage turnover in postdoctoral scholars due to the improbable demands of CILT and the difficulty of bringing in newcomers certainly shaped the career paths shaped by the postdoctoral scholars .

Looking at the careers of the postdoctoral scholars in CILT, the picture is extremely bright. One of the postdoctoral scholars has followed a traditional path taking an assistant professorship position at the Technion in Israel and developing a research program focused on design principles. Two of the postdoctoral scholars have chosen careers in research management at non-profit organizations. One of the postdoctoral scholars is working in research management in informal learning. The other is engaged in running a grant program at a small foundation. In both cases, skills developed at CILT are extremely useful for these careers. Two of the postdoctoral scholars are currently working in research management at universities and deploying their skills in developing innovations as well as in conducting research. These postdoctoral scholars may well enter into university career paths at some point and will be very competitive if they make that decision. Finally, two of the postdoctoral scholars have gone into software development work, one at a for profit organization and the other in a consulting firm. These individuals are deploying their understanding of innovative learning technologies as well as their management skills in advancing the field of technology and education.

The Synergy project and the CILT postdoctoral scholar program were developed and re-conceptualized over the life of the CILT program. These programs impacted the individuals concerned with learning technologies and the research directions and research methodologies in the field.

Ubiquitous Computing In CILT

ROBERT TINKER, Concord Consortium

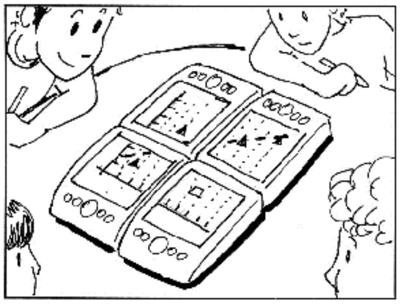


The Ubiquitous Computing Strand of CILT made a major contribution to educational technology by launching a series of initiatives that demonstrated the educational value of handheld computers.

It is hard to realize that when CILT started, handheld computers were rare and almost no one had even thought that they might have any educational value. In June 1997, a CILT team met with 3Com, the owners at that time of Palm, to discuss the educational applications. This happened to be the day that Palm Computing Donna Dubinsky and Jeff Hawkins founded Handspring, the consumer-oriented handheld computing company (later acquired by Palm), although this was not public until November 1998. The top brass we met with had no interest in education, but as we left, we recognized many friends from the Newton effort at Apple and so we returned to meet with them. They pointed out that the modem case could be purchased and that it would be ideal for a lab interface. This led directly to the founding of the company imagiworks (now a division of PASCO), which builds and markets educational probe accessories for the Palm. This meeting at 3Com also began a long-term association between CILT and Palm that benefited both. Palm became a CILT supporter, helped sponsor several events. Palm also enabled research via a donation of 20 Palm Pilot units to the Concord Consortium/CILT which were tested in K12 classrooms in the Boston area, San Francisco Bay Area, and Nashville schools. Building on a series of CILT initiated events and proof-of-concept design research, Palm then contracted with SRI International's Center for Technology and Learning (CILT's home base) directly to run a major research program called PEP: the Palm Education Pioneers grants, see http://www.palmgrants.sri.com/findings.html

The major CILT activities in support of Ubiquitous Computing included four workshops, a software contest, ten seed grants, graduate student/post-doc "synergy" research, and dissemination. Each of these made a contribution, but in their totality they actually transformed the discussion about educational computing. CILT's Ubiquitous strand team were the first to identify handheld computers as important, the first to sponsor research in their use, and the first to identify their importance in low-wealth schools. CILT did not try to dominate the area, but instead served the role of convener and catalyst, bringing researchers, students, teachers, developers, and vendors together, providing small amounts of seed funding and travel money as required, and standing out of the way. Almost everyone currently contributing to educational applications of handhelds was involved with these early events and were touched by the dissemination efforts.

CILT held stand-alone workshops on this topic in 1998 and then twice merged them into large conferences: CILT99 and CILT2000. The U-strand held one of these stand-alone workshops and was one of five strands making up "workshops within a conference" in the two conferences. Eight paper abstracts for the U-strand at the 1999 conference can be found at http://cilt.concord.org/events/1999/cilt99-uc-presentations.html and three posters are at http://cilt.concord.org/events/1999/cilt99-uc-poster.html. Brief reports of U-strand working groups, several of which became seed grants, can be found at



http://cilt.concord.org/events/1999/cilt99_breakout_uc.html. Twenty paper abstracts and posters on projects and seed grants reported at CILT 2000 can be found at http://cilt.concord.org/events/2000/body_cilt2000_submissions.html (search for Ubiquitous on that page.)

Several current innovations can be traced to seed grants enabled by CILT U-strand. As part of a seed grant enabled by CILT, a design session led by Jeremy Roschelle and Mike Mills at IDEO resulted in a description of an ideal educational handheld. This paper, which included scenario-based design sketches has influenced the thinking of many people in the field. http://cilt.concord.org/themes/DataGotchi.pdf. The seed grant given to the Exploratorium to test the concept of a mobile information resource led by Noel Wanner and Rob Semper for science museums has led to two further grant initiatives (http://www.exploratorium.edu/guidebook/) that has influenced the informal science institution (ISI) community and museums.

In the Fall of 1999, the U-strand organized a competition to stimulate the field in developing educational applications using the Palm Operating System. This competition enabled a set of criteria to develop for evaluating handheld educationally-sound software. Judges included a local elementary school teacher, a high school physics teacher, the former director of the Apple Multimedia Lab (Kristina Woolsey), the President of Handspring (Jeff Hawkins), New York Times technology writer (David Pogue) and Professor Elliott Soloway, director of the Hi-C group at the University of Michigan. The judging took place at the Exploratorium in a public event and was webcast live over the Internet. The first prize went to an application called “Geney” which a player could build a pond of fish, see how they developed, then breed pond fish with other Palm players via beaming to see the outcomes of genetic diversity (or lack thereof). The competition caught the attention of the technology industry representatives, who had donated prizes and co-sponsored the event (HandSpring, Palm, DataViz, LandWare, HandDango, and LearnLots.com).

Second grade students tested the temperature inside their shoes using a probe attached to a Palm handheld computer. At left is a closeup of how the boys inserted a probe and recorded the data.

Concurrently, in 1998–00, as part of the CILT post-doc program, Sherry Hsi and other CILT post-docs (Eric Baumgartner, Sean Brophy) formed a “synergy project” intended to cross-fertilize the efforts across theme teams. The CILT synergy project developed a web-based water quality unit using a new curricular customization design approach and tested this in middle and high school classrooms, leveraging the Web-based Inquiry science environment, ImagiWorks probeware interfaces, TERC Global Lab approaches, concept mapping software, and Vernier probes (see Baumgartner & Hsi, 2002).

This early work tied learning in urban and suburban formal settings with informal learning activities including an after school ecology club and field trips to creeks. Several design prototypes with handhelds were also developed during the synergy project. These included a Palm-based field guide for macroinverterbate identification using AvantGo, developed by a high school volunteer who learned how to program for the Palm, and was later hired by HandSpring as a summer intern during college. Other applications included the first handheld

student/teacher assessment tool (Sean Brophy and Justin Manus) using Jtutor for students to assess their understanding water quality and ecology (e.g., watershed, turbidity, dissolved oxygen, nitrates, eutrophication, etc.). As part of the synergy efforts, a water quality meeting was held at University of Michigan to share CILT projects. After that gathering, several educational applications emerged including PicoMap and Cooties which are currently disseminated at GoKnow.com.

In Feb 2001, the U-strand held a final conference at the Intel Research campus in Portland, Oregon attended by approximately 80 participants. Intel generously contributed the facility, on-site conference costs, and area transportation. The agenda gives a feeling for the content of the workshops; abstracts of 22 talks, posters, and demos is at http://cilt.concord.org/events/2002/ubiquitous/abstracts_list.php?query=.

The brief descriptions of the ten seed grants can be viewed at http://cilt.concord.org/seedgrants/ubiquitous/ Reports of eight of these are attached.

One of the areas we concentrated on involved linking handhelds with probes. This required advances in probeware, because no equipment then available was battery powered and so could not, match the portability of handhelds. Handhelds seemed particularly appropriate for younger students, who (along with their teachers) demanded plug-and-play simplicity. We build several prototypes that exemplified these designs and coined the word "SmartProbe" to define these. A "SmartProbe Concept Paper" helped stimulate thinking in this area. [8]see

Footprints at the Concord Consortium (CC)

It is possible to see several important spin-off projects at CC that can be traced directly to the CILT Ubiquitous strand.

- Palm funded the Concord Consortium to establish an online directory of educational software for handhelds, see http://usight.concord.org/
- CC was funded to pursue probeware for handhelds in a project called Technology Enhanced Elementary and Secondary Science (TEEMSS), see http://www.concord.org/teemss/. This project established the educational value of probes and developed innovative hardware and software.
- CC used TEEMSS funding to establish an online directory of probeware, see http://probesight.concord.org/
- A second round of funding for TEEMSS is currently funded to develop substitution units that use any available hardware, including handhelds in grade 3-8 science.

[8] http://www.concord.org/research/probeware_history.pdf

People

Bob Tinker, co-PI and director of the Ubiquitous Computing Strand
Earl Craighill, co-director of Ubiquitous Computing Strand, 1996-97
Robert Broderson, co-director of the Ubiquitous Computing Strand 1997–98
Philip Vahey, co-director of the Ubiquitous Computing Strand 2000–02
Sherry Hsi, CILT post-doctoral scholar 1997–00
Justin Manus, high school summer intern, 1999
Michelle Spitulnik, CILT post-doctoral scholar 2000–01
Stephen Bannasch, co-director of the Ubiquitous Computing Strand 2000-2002
Carolyn Staudt, Mobile Inquiry Technology Project Leader, Concord Consortium
Dan Bega, Science teacher, Kennedy High School, Fremont, California
Aaron Glimme, Science teacher, Berkeley High School, Berkeley, California
Ariel Owens, Science teacher, Foothill Middle School, Walnut Creek, California
Jeff Parish, Science Teacher, Foothill Middle School, Walnut Creek, California

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Reflections on CILT's Influence: Contributions from the Assessment Strand

BARBARA MEANS, SRI International

The CILT Technology and Assessment Theme, as originally proposed, was intended to support innovation in "technology-based mechanisms for supporting both formative (diagnostic) assessment and summative assessment to help students, teachers, school systems, and communities see qualities of student achievement that are invisible on traditional, standardized tests." This dual focus on both classroom assessments to support teaching and learning and summative assessments to serve research and accountability needs remained characteristic of the theme throughout CILT's existence.

At the first CILT Assessment Workshop, held at Vanderbilt University in February 1998, brief presentations highlighted the participants' work on technology-supported assessments embedded in prototype learning technologies. This emphasis led one attendee to characterize the meeting as being "about learning and not about assessment." Others countered that education needs more assessment tools that support learning and fewer assessments for accountability purposes. Differences of opinion concerning the uses and value of standardized tests created some sparks. There was general agreement, though, that standardized tests do not reveal many of the aspects of students' thinking that both teachers and researchers should know, and, at the same time, that standardized test scores drive many decisions and are unlikely to go away. For the most part, participants embraced the goal of developing technology-supported alternatives to conventional assessment approaches that would tap deep conceptual understanding and "preparation for future learning."

During this time frame, as members of the emerging CILT community were working on how to incorporate assessment into their learning environments in ways that would support student learning, the education policy community was looking for guidance on how to provide research evidence with respect to the impact of educational technologies on student learning. This topic dominated presentations and discussions at the second Brazil-U.S. Education Dialogue with key governmental officials in attendance, held at SRI's conference facilities in Menlo Park, in December of 1998. In preparing a panel presentation for that meeting, I contrasted a description of technology-supported mathematics and science learning (in the GLOBE environmental education program) with the kinds of factual knowledge and table-reading skills tapped most commonly by large-scale science assessments. While meeting participants could perceive the mismatch between the learning goals of many technology-supported innovations and the skills and knowledge assessed by standardized tests, they wanted advice on how educational technology *could* be rigorously evaluated. *"If end-of-year standardized test scores won't tell us whether our technology investments are worthwhile, what will tell us?"*

A few years earlier, the educational technology community itself, when tapped to advise the President's Committee of Advisors on Science and Technology (PCAST) on the use of technology to strengthen K–12 education had made much the same plea. The Panel on Educational Technology noted the lack of adequate education research funding in general, and the paucity of rigorous studies in the learning technology arena in particular. The Panel's 1997 PCAST report on educational technology called for "rigorous, well-controlled, peer-reviewed, large-scale empirical studies designed to determine which educational approaches are in fact most effective in practice" (p. 10).

In conversations at the Brazil-U.S. meeting, Linda Roberts, then Director of the Office of Educational Technology within the U.S. Department of Education, spoke of the increasing pressure from Congress to provide research evidence justifying expenditures on technology. Roy Pea and I urged Linda to think about convening leading methodology experts and giving them the challenge of coming up with appropriate, rigorous designs for studying technology's impact.

In combination, the Brazil-U.S. Education Dialogue discussions, the PCAST report, and the CILT Assessment Workshop, inspired me to develop an unsolicited proposal for the U.S. Department of Education with the perhaps overly ambitious title "Building a Foundation for a Decade of Rigorous, Systematic Educational Technology Research." (For reasons that are probably obvious, the project subsequently went by a shorter nickname—"the Foundations Project.") In the proposal I set forth two basic strands of activity. With my SRI colleague Geneva Haertel, I proposed to identify and invite nationally recognized research methodology experts and educational technology researchers to take on the research design challenge posed by PCAST and the Brazil-U.S. meeting participants. Concurrently, I proposed working with Edys Quellmalz and Bill Penuel to develop some prototype technology-supported assessments of important learning outcomes that are not easily captured by standardized, multiple-choice tests. These two endeavors were tied together in our minds because of our conviction that the kind of research that would shed light on educational technology's effects would need to incorporate outcome measures other than standardized tests.

This logic apparently made sense as well to the U.S. Department of Education, which funded a grant for this work in August 1999. In consultation with the department, we developed a slate of experts whom we invited to write commissioned papers describing research designs addressing the effectiveness of educational technology in supporting student learning. We were careful to seek a balance between individuals who had studied educational technology before and those who did not work in the technology field, and, among the research methodologists, a diversity of methodological specializations and perspectives. Most of the individuals whose participation we sought agreed to work with us, and we achieved the desired methodological diversity, as shown by the slate of authors and topics for the ten papers, shown in Table 1. Each researcher drafted a paper (usually with several colleagues) on their design perspective, and the group came together at SRI in February 2000 to present their draft designs and give each other feedback prior to preparation of final papers.

Table 1. Papers Commissioned on Methods for Studying Technology's Effects

Theme I: Evaluating the Effects of Learning Technologies: Alternative Approaches
The Case for Using Randomized Experiments in Research on Newer Educational Technologies: A Critique of the Objections Raised and Alternatives Proposed Thomas D. Cook, Northwestern University and Barbara Means, Geneva Haertel, and Vera Michalchik, SRI International
A Larger Role for Randomized Experiments in Educational Policy Research Lincoln E. Moses, Stanford University
Determining the Effects of Technology in Complex School Environments Alan Lesgold, LRDC, University of Pittsburgh
Local Relevance and Generalizability: Linking Evaluation to School Improvement Katie McMillan Culp, Margaret Honey, and Robert Spielvogel, Education Development Center/Center for Children and Technology
Technology and Evaluation Eva L. Baker and Joan L. Herman, CRESST
Theme 2: Assessing Important Student Learning Outcomes
A Project-Based Assessment Model for Judging the Effects of Technology Use in a Quasi-Experimental Design Henry Jay Becker, University of California, Irvine and Barbara E. Lovitts, American Institutes of Research
Leverage Points for Improving Educational Assessment Robert J. Mislevy, Linda S. Steinberg, Russell G. Almond, Educational Testing Service, and Geneva D. Haertel and William R. Penuel, SRI International
Theme 3: Studying Long-term Effects within a Complex, Multi-Level System
Designing Studies to Measure the Implementation and Impact of Technology in American Schools Larry V. Hedges, Spyros Konstantopoulos, and Amy Thoreson, University of Chicago
A Multi-level, Longitudinal Approach to Evaluating the Effectiveness of Educational Technology Russell W. Rumberger, University of California, Santa Barbara
Investigating the Cumulative Impacts of Educational Technology Barbara Means, Mary Wagner, Geneva D. Haertel, and Harold Javitz, SRI International

The proposed designs ran the gamut from "true" experiments with random assignment of classes to treatment and control conditions to "contextualized evaluations" in which research organizations would work closely with school and district personnel to tailor research and data collections to the issues of greatest local concern. Those proposing the latter approach argued also for mechanisms to coordinate and link multiple local evaluations in order to provide for an accumulation of more general knowledge for the field (see Baker & Herman, 2003; Culp et al., 2003).

Two of the papers focused on issues of assessment design. Hank Becker and Barbara Lovitts (2003) came to the issue of assessment design out of concern for how to create a test that would be "fair" both for students in technology-using classrooms and those in classrooms not using technology. They point out that standardized tests by design administer "tasks" on which computer experience is unlikely to make a difference. They argue that the limited range of tasks incorporated into standardized tests and the minimum-resource standardized testing environment deny technology-capable students the opportunity to demonstrate what they can do *with* technology—an important competency in the so-called Information Age. On the other hand, Becker and Lovitts view the assessments incorporated into many innovative technology-based curricula as idiosyncratic and dependent on specific technology competencies (e.g., spreadsheet proficiency) that make comparisons with non-computer-using students illogical. As an alternative, they propose developing assessments around culminating tasks for extended projects—tasks that could be accomplished with or without technology supports. The outcomes and skills to be assessed would be defined at a level of generality that permits but does not require technology use (e.g., use of relevant information to support an argument).

Bob Mislevy (along with Linda S. Steinberg, Russell G. Almond, Geneva D. Haertel, and Bill Penuel, 2003) wrote a paper describing use of an evidence-centered design process for developing assessments of performance in intellectually complex tasks in ways that draw on advances in cognitive psychology and adhere to rigorous standards of psychometric quality. They illustrate use of this design approach with a range of assessments and argue that technology can be used to support the assessment development, delivery, and scoring processes in ways that make the use of well-designed assessments of complex performances much more feasible than they have been in the past. This work is currently being advanced in the Principled Assessment Designs for Inquiry (PADI) project, led by Geneva Haertel and Bob Mislevy (http://padi.sri.com/).

As the revised commissioned papers were coming into SRI, I was also involved with the CILT leadership team in developing plans for CILT 2000, to be held in October of 2000. We felt that it would be useful for the CILT participants, many of whom had connections to projects funded by the National Science Foundation, to have exposure to the kinds of advice with respect to learning technology research that the Department of Education was getting. Arrangements were made for a subset of the Foundations Project commissioned paper authors to present a CILT 2000 panel. One of the themes that emerged across the conference presentations was the potential for doing a better job of having cumulative research if we could increase coordination across projects and the use of common measures of aspects of educational context and of important educational outcomes. The CILT community was very receptive to this message.

At the same CILT conference, the Assessment Theme Team was gratified to hear Allan Collins, in his capstone presentation, argue that assessment was the critical issue that would determine whether or not innovative instruction finds its way into significant numbers of K–12 classrooms.

One of the CILT 2000 attendees was Brian Ellerbeck, senior editor for Teachers College Press. Brian and I met to discuss prospects for turning the ten commissioned papers into a book. Brian was eager to build a critical mass of publications focused on educational technology at TC Press. I was eager for the design papers to have a wider distribution and longer shelf life than we could achieve with a Department of Education technical report. Geneva Haertel and I began the process of organizing and editing the papers. We sent a prospectus and several sample chapters off to TC Press for review. After getting a strong endorsement from external reviewers based on the sample chapters, Brian was eager to strike a deal. As he began talking to the business office at the press, however, they questioned whether a volume of methodological papers would have sufficient appeal beyond an academic audience to produce an economic return for the press. Brian dealt with this concern by offering to publish the commissioned papers as a hardcover book targeted to an academic audience if Geneva Haertel and I would agree to write a shorter book distilling the main points of the commissioned papers for a policy and practitioner audience. Although we realized the challenge of trying to produce the "lite" version of hierarchical linear modeling or evidence-centered assessment design, we appreciated the opportunity to reach out to a broader policy-oriented audience that would include individuals making decisions about research funding. We agreed to take on the challenge of producing the less technical, policy-oriented summary and asked several additional individuals, including Nora Sabelli and Jim Pellegrino from the CILT community, to write commentaries on subsets of the commissioned papers that would round out the second volume.

After extensive processes of contract negotiation and editing, the two volumes were published: *Evaluating Educational Technology: Effective Research Designs for Improving Learning* (Haertel & Means, 2003) with the commissioned papers and *Using Technology to Enhance Student Learning* (Means & Haertel, 2004) with our synthesis of issues raised by the papers and a discussion of policy implications.

During this time period, neither the education technology field not education policy was standing still, of course. The passage of the No Child Left Behind (NCLB) Act of 2001 placed an unprecedented emphasis on standardized test scores as the measure of adequacy of the education provided to students in schools receiving federal funds. [9] The requirement to demonstrate "adequate yearly progress" in reading and mathematics not only for students in each grade as a whole but also for each ethnic subgroup has brought about unprecedented emphasis on teaching to the content in standardized tests. This emphasis has made it more risky for teachers in classrooms with students who have historically scored lower on achievement tests (generally students from low-income families) to devote significant class time to the kind of innovative, inquiry-oriented learning activities that CILT researchers design and study. States and districts are reporting a declining budget for technology (Park & Staresina, 2004), and where funds are being spent, anecdotal reports and the advertising appearing in publications aimed at district and school administrators suggest a renewed emphasis on software that helps prepare students for standardized test or helps administrators keep track of their students' likely upcoming test performance relative to "adequate yearly progress" goals.

In addition to its influence on educational technology as a byproduct of its accountability provisions, NCLB Act contains a mandate for a national study of the effectiveness of educational technology. Section 2421a, Part D of Title II of the act calls for the Secretary of Education to "conduct a rigorous, independent, long-term evaluation of the impact of educational technology on student achievement using scientifically based research methods and control conditions." Although not quite explicit, the language in the legislation reflects the

[9] Technically, the law allows for the use of other types of assessments if national norms are available and adequate reliability and validity can be demonstrated. In practice, given the costs and technical difficulty of this demonstration, almost no state has submitted scores on anything other than standardized tests.

emphasis on experimental designs (also called "randomized field trials") as the "gold standard" for education research as promoted by Grover (Russ) Whitehurst in his position first as director of the Office of Educational Research and Improvement and then of its successor agency, the Institute for Education Sciences.

The contracts for designing and implementing the mandated national educational technology study made it clear that it had to be a randomized field trial in which schools, teachers, or students were assigned at random to technology treatment and control conditions. In contrast, the "long-term" provision (originally a call for a longitudinal design) ended up as just assessing student achievement twice, in the fall and the spring of the same school year. The Institute for Education Sciences stipulated also that nationally normed standardized tests would be used to assess student outcomes. The design contract was awarded to Mathematica, a research organization known for conducting large-scale evaluations using random assignment. The decision was made that the educational technology experiment would concentrate on those areas emphasized by NCLB (i.e., reading and mathematics) and that educational software vendors would be invited to nominate their products for inclusion in the study with selection based on the quality of prior evidence of effectiveness. Given the choice of outcome measures and subject emphasis, the types of innovative technology-supported products of interest to the CILT community had little to gain from involvement. Moreover, selection of products from those that companies had nominated was based on the presence and quality of prior evidence of effects on standardized test scores—a requirement that tended to favor older, well-established products over newer pieces of software. In the end, the decision was made to run four concurrent randomized field trials—one each on a set of products aimed at supporting early reading, fourth-grade reading comprehension, sixth-grade mathematics, and algebra.

In a somewhat ironic twist, SRI's CILT-inspired involvement with research methodology experts representing a whole range of stances with respect to the priority that should be given to randomized field trials was, at least indirectly, one of the factors that led Mathematica to seek SRI's support for execution of the national experimental study. SRI's Center for Technology in Learning is collaborating on the national educational technology experiment, with specific responsibility for conceptualizing and implementing the measurement of context and implementation quality. SRI decided to participate not because the products included in the study are the most interesting educational applications of technology available today, but because the products are important from the standpoint of practice and policy. Cash-strapped school districts are investing millions of dollars in these products in the belief that they will help the district boost test scores. We believe that districts would be well-served by objective evidence with respect to the products' effects. From a research standpoint, we are excited to learn much more about the ways that educational technology products generally do get implemented (when the product developer is not a partner in implementation as so many CILT researchers are) and see the four concurrent technology experiments as an opportunity to develop the kind of linked studies with consistent measures of context and implementation that the methodology experts speaking at CILT 2000 advocated.

As the experiments proceed, it's important to emphasize the fact that whether the products in this study do or do not get implemented appropriately and do or do not have a positive impact on students' test scores will not tell us anything about the effectiveness of "CILT-like" science and mathematics applications. The experimental results—whether positive or negative—should not be over-generalized.

As suggested by the preceding discussion, CILT-like assessments are not at the forefront of policy discussions today. In some ways, this is discouraging for those of us who believe that better assessment practices supported by technology could leverage significant improvements in teaching and learning. There is, however, a silver lining. Technology-supported, performance-oriented assessments of complex reasoning and inquiry skills were not yet ready for mass implementation in 2002. Reliability and development cost issues persisted and remain troublesome today. I would suggest that the research community use this time—a time when policymakers are looking to conventional standardized tests as the silver bullet—to continue the CILT assessment agenda and address reliability and cost effectiveness issues so that when the policy pendulum swings once again, we'll be ready.

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The CILT Experience: A Personal Perspective

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My goal is to discuss some key lessons that I learned from the opportunity to participate in CILT (Center for Innovative Learning Technologies), lessons that I hope are relevant to others who are interested in establishing collaborative Centers. I focus especially on lessons from CILT that helped a group of us shape a proposal for the recent NSF "Sciences of Learning Centers" competition. The Center proposal we submitted is called LIFE (Learning in Informal and Formal Environments)—a Center that involves SRI, Stanford, and the University of Washington as the prime partners. In each of the sections below, I discuss CILT lessons and then show how they affected our plans for LIFE. But ultimately this reflection piece is neither about CILT nor LIFE. Instead it is about some principles for the design of collaborative centers that, hopefully, can be helpful to the field as a whole

Face-based versus Distributed Collaborations

One of nature's ways of revealing her secrets is by presenting us with contrasting cases. If we live in another culture, for example, we are better able to articulate the features of our own culture—especially those that previously were tacit and taken for granted. When Vanderbilt was invited to join the group that wrote the CILT grant, creating a collaborative center seemed like a natural extension of our ongoing work in the Learning Technology Center (LTC) at Vanderbilt. As it turned out, CILT provided some powerful contrasts regarding collaboration that many of us in the LTC had not explicitly thought about before.

Collaboration within the LTC

LTC at was highly collaborative. It began around 1984 with about seven people. Even when we grew to around 70 people there was a very strong level of collaborative work across the center.

We knew that collaboration was not ideal for many things—especially for the individual recognition needed for tenure. Many people in the LTC were outstanding scientists who were not interested in tenure track positions—so that made it easier for them to collaborate. But many others did indeed want to pursue the tenure route. For them especially, we tried to balance the needs of the individual and the larger LTC—not always successfully. When we erred it was frequently on the side of collaboration. There were many benefits to working collaboratively—including insights from multiple perspectives on projects, and finding ways as a group to turn hard work into fun.

CILT as a Contrasting Case

In retrospect, the CILT experience helped us understand, as a contrasting case with LTC, some of the nuances of successful collaborations in much more detail. For example, LTC's collaborative activities were primarily "face-based" and took place in a single setting—Peabody College at Vanderbilt with additional connections across the rest of Vanderbilt (e.g., Arts and Science, Vanderbilt's Center for Teaching; Engineering and Computer Science; the Medical School). We had also developed long term collaborative relationships with teachers, principals and superintendents in the school system.

In each of these situations, we tended to know each other well and were frequently able to talk face to face—not only in formal meetings but "around the water cooler" where new ideas often arose. The importance of these face-to-face relationships did not "jump out at us" until we began to work in the context of CILT's *distributed* collaboration. With CILT we did not have a shared water cooler. Our face to face meetings were, of necessity, few and far between. We relied much more on phone conferences, e-mail, videoconferences. But as discussed below, there were other, more fundamental differences as well.

Example of an Initial Disconnect

As CILT began its work as a Center, we at the LTC experienced some communication disconnects that at first were surprising to us. For example, we agreed to take the lead in what we were used to calling a "sacrificial draft"—in this case a draft at crafting a CILT logo. Creating sacrificial drafts was an honored tradition in the LTC. Everyone expected their initial ideas to be 'sacrificed" (criticized), and we entered into these kinds of situations in a fun-like "don't take this too seriously" manner. All of us had had many ideas that were "sacrificed" by the larger group and felt at home taking a chance.

We sent a sacrificial design for a CILT logo to the rest of the CILT groups and were taken aback by the feedback. Some treated our ideas as sacrificial and included thanks for taking the first stab as well as friendly comments about changes and improvements. This fit the culture of our LTC. In contrast, a number of responses to the sacrificial logo (via e-mail) seemed highly critical and went on and on about the stupidity of the idea and—if one read between the lines—even about the stupidity of the people behind the original design.

We in the LTC probably overreacted to the feedback. One reason is that, in many cases, none of us had actually met the people writing the e-mails, so it was very hard to interpret their true intent. But to us the feedback seemed extremely negative, and it had a strong effect on our feelings about sharing ideas. We felt we already had one strike against us with many in CILT and didn't want another. We became much more cautious and much less willing to take risks in floating sacrificial ideas. The sense of fun was replaced with a "don't look stupid" attitude. Luckily, this was only a momentary glitch.

Solving the Problem

The problem became solved as CILT members engaged in Cultural Exchanges across partner institutions. A several day CILT workshop for PI's, post docs and others was one way that personal information was shared. We got to meet one another, exchange stories, see different work styles and senses of humor, etc. I note this because at one level mentioning the potential value of these kinds of meetings seems trivial. But our experiences with CILT, and with several other groups since then, have helped us see that things like trust and people knowledge are fundamental for successful collaboration—especially when innovation (which often involves lots of false starts) is a major goal.

Relationships and People Knowledge

Researchers in the leadership literature talk about the importance of relationships and trust. Comprehension theorists like Karl Buhler discussed the importance of "shared semantic fields". Reports such as How People Learn (NRC, 2000) and How Students Learn (Donovan & Bransford, in press) have used Lionni's Fish is Fish story to illustrate the constructive nature of knowing and how new interpretations are built on existing knowledge. Changes in assumptions about other people have been shown to strongly affect strategies for solving problems that one may have with them (Lin & Bransford, under review). In all these cases, we can begin to see some of the fundamental challenges for distributed organizations—especially where the people involved did not all know one another ahead of time. The contrast between early CILT and the LTC, and early CILT and later CILT, brought home to us the extreme importance of creating the kinds of culture and personal relationships that allow innovation to thrive.

LIFE Lessons

There are several ways that the experiences noted above have enhanced our work on the LIFE Center. One is that may CILT members are part of the LIFE Center—either directly or as partnering centers. Examples of people connections established through CILT include those that came from research collaborations that began as CILT seed grants; a set of outstanding CILT postdocs who remain closely connected as colleagues as they pursue exciting careers in academia, museums and other informal learning settings, and the private sector (e.g., startup software companies); a set of cross-institutional connections that continue to foster partnerships and training (e.g., several Vanderbilt PhD's are currently (non-CILT) postdocs at Berkeley, one of CILT's founding partners); New Centers that have built on the experiences of CILT and taken some new (giant) steps beyond. One is the NSF Technology Enhanced Learning in Science (TELS) Center headed by Bob Tinker (Concord Consortium) and Marcia Linn (Berkeley)—two of CILT's founding partners, and with Roy Pea (Stanford) and Nora Sabelli (SRI) in the TELS Advisory Board (the others were at SRI as lead institution and Vanderbilt).

Additional collaborations formed in the context of CILT have played an important role in LIFE's genesis. Roy Pea (director of CILT when he was at SRI) is now at Stanford, which is a major LIFE partner. Nora Sabelli (who came to SRI and directed CILT during its latter years) heads the SRI part of the LIFE partnership. I was at Vanderbilt while CILT was in operation and I'm now at the University of Washington –another one of LIFE's major partners. LIFE also has maintained a connection to Vanderbilt's Center for Bioengineering Education Technologies. In fact, Sean Brophy, CILT's first post doc, is co-leader (along with Bransford) of the learning sciences group that is working with the NSF Bioengineering Center at Vanderbilt, Norhwestern, University of Texas and Harvard/MIT.

Forging New Relationships The LIFE center also includes a number of outstanding new collaborators why were not originally part of CILT. One lesson from CILT involved the realization that different kinds of expertise are needed to solve different kinds of problems. The purpose and mission of LIFE is different from CILT, and LIFE is a much larger center than CILT. So we needed different kinds of expertise for LIFE. But this made it even more important to establish personal relationships that forged a culture of openness and trust.

In part, the NSF application process for Science of Learning Centers forced much more personal, face-to-face interactions among all LIFE members than had been necessary for CILT. The competition for LIFE took more than a year (and was still ongoing as of this writing). LIFE as a whole held two face-to-face meetings, a major NSF site visit, preparation for a reverse site visit, and a strategic planning meeting last July. Numerous sub groups also met face-to-face and virtually as we prepared. The fact that LIFE's major partners are all on the West Coast made face-to-face meetings much easier to arrange—and our decisions to be geographically close were not accidental. By the same token, we didn't want to be so close all the time that we lost the advantages of intellectual and cultural diversity. Overall, the important point is that –from the beginning of the Center—LIFE members will know one another as individuals and groups at a level that was not true for CILT when it first began.

Strategies for Openness LIFE has also developed some explicit strategies that are designed to promote an appreciation for "sacrificial ideas" and "conceptual collisions". Our goal is to celebrate disagreements across research strands (implicit learning and brain, informal learning, formal learning and beyond) with the hopes of advancing understanding by discovering ways to overcome them. These strategies probably would not have a powerful effect without a basis for personal trust. But the strategies also probably add to the openness of LIFE because they explicitly mark features of the LIFE culture that are learning oriented rather than performance oriented. We have already heard from graduate students and post docs that it was very revealing to them to sit in on practice sessions where the PI's critiqued and learned from one another. Just as a reminder—we eventually reached this point of trust in CILT, but it took longer because we had fewer opportunities to establish personal trust prior to launching the Center.

New Foci for Research Our experiences with CILT, as well as with other attempts to collaborate at a distance, have also promoted us to begin to study the important role of "people knowledge" in learning and communication. This topic is relevant to all three of LIFE's research strands and is an important topic of study in LIFE's first year.

Open versus Closed Centers

The preceding discussing focused on issues among CILT's and LIFE's primary members. Issues of building a culture of trust and innovation were also relevant to one of CILT's primary (and I think most important) goals—to be an "open" rather than a "closed" Center. Many national centers do great work and "disseminate" it to the field, but they do not actively attempt to get others directly involved in the Center's work.

CILT Strategies

CILTs strategies for carrying out its open center mission included workshops, conferences and competitive "seed grants" [10] that allowed groups of researchers (who probably would not have otherwise) to team up and write cross-institutional proposals. CILT workshops and conferences typically were organized around seed grant opportunities—-and participants had time to write them on site. CILT received and funded a number of very strong proposals that created not only new research but new pathways for collaboration in the future.

Issues of Trust

A major question that was often voiced to me in private (and to others in CILT) was of the form: "Why should I go to CILT meetings and give my best ideas to CILT?" A statement like "You might get a (less-than-10 thousand-dollar) seed grant" was not a sufficient answer to this question—nor was it meant to be.

[10] See later sections on conferences and on seed grants.

CILT conferences were different from many others because they were "let's-roll-up-our-sleeves and work together to identify, define and explore new problems" conferences. This is very different from "presentation" conferences where people explain their current work and what they have found. But the CILT conference design did indeed mean that people were being asked to suggest new ideas as they worked with groups on new problems. Couldn't CILT members merely harvest these new ideas and run with them on their own?

Our assumption was that, ultimately science runs on trust—trust in others' data, honesty in citing others, etc. Hopefully the actions of CILT over time helped relieve anxieties among some that their best ideas would be "borrowed". The fact that a large community of scholars attended CILT meetings and wrote proposals also helped codify ideas of ownership. CILT meetings represented a change in ways of doing things and, as noted before, this raised concerns by some. My impression was that worries about losing one' ownership of ideas became less of a problem over time. One of our strategies was to trumpet seed grantees work. For example, at several AERA meetings our explicit goal was to provide a forum for seed grants researchers to present their work.

Two Different Audiences

Was CILT totally successful in addressing all concerns about "idea rustling"? I honestly don't know. Evaluations from attendees at CILT meetings tended to be highly positive and people who received seed grants were free from any CILT influence except for accountability (e.g., some report of the work that had been accomplished). However, I learned some time ago (e.g., CTGV, 2000) that it is useful to pay attention to two different audiences: Those who chose to participate in some endeavor (e.g., CILT meetings) and those who did not. What did people who choose not to participate in CILT think about CILT?

I know some people who did not participate in CILT events because they had grave concerns about "idea ownership" and were not certain that CILT could handle the challenge. I can't remember if they had formed this opinion without ever giving CILT a try or after attending a CILT meeting—I hope the former. But the point I want to make is this: People who attempt to create open centers might want to understand not only how people who participate feel, but also why some people choose not to participate. By systematically exploring this information, we might be able to move toward open center mechanisms that exceed what I consider to be CILT's great start.

LIFE Lessons

The new LIFE Center is explicitly designed to be an open center, and much of that focus is a direct result of CILT. CILT helped us see the need to help build a field, not just a Center, and we hope to continue that tradition with LIFE.

LIFE's Education, Collaboration and Outreach activities (ECO) includes money for seed grants, and we have also established a number of partnerships with other institutions—including minority serving institutions.(MSI's) LIFE's assumption, consistent with lessons learned from CILT, is that win/win partnerships provide a powerful way to create positive change.

Win/win partnerships are different from one-way partnerships. For example, it has become clear to us that many MSI's have insights into learning that are not currently captured in the mainstream literature. LIFE wants to learn from them and hopefully can contribute something as well. Especially important is a model of collaboration where LIFE and partner institutions identify research and education issues that are of mutual interest to both groups. This is a more focused model for creating partnerships than the open CILT meetings where groups who attended wrote seed grants. So LIFE has learned from CILT and, we think, gone beyond it as well.

Thinking about the kinds of relationships established in CILT has also helped us see the importance of new kinds of analyses for the impact of centers—in particular, social network analyses. The evaluation team chosen to work with LIFE pioneered these methods and we are grateful for the opportunity to work with them.

Planning for Organizational Change

CILT's title, "Center for Innovative Learning Technologies", reflects the fact that "innovation" was a major part of its mission. Included were innovations in collaborative learning, community tools, visualization tools, assessment practices, and the ubiquitous use of hand held devices. In the early years of CILT, these were its major organizational units. Each had a major leader or co-leader, each held workshops, etc. In my opinion, these were extremely fruitful themes to explore and they helped create an efficient organizing structure for CILT.

As time went on, CILT also engaged in innovation (or reinvention) at the level of a Center. For the most part we kept the four major thematic areas. But increasingly, attention turned to synergy projects where all four themes were brought together to focus on a particular educational topic—helping students learn about rivers as ecosystems, for example. [11] This made great sense. None of CILT's initial themes had the answer to more effective instruction when used only by themselves—they created synergies when insights from all four themes were applied to a common educational challenge. So the emphasis on synergy projects emerged and became strengthened as CILT developed over time.

Focusing CILT's theme groups on real problems in real schools also helped us see the need for different approaches even to the same educational issue. For example, researchers at Berkeley, University of Michigan, and Vanderbilt were all working on issues of designing and using technology to help students learn about issues of water quality and about rivers as ecosystems. But the tools we emphasized were quite different. For example, at Vanderbilt we concentrated on *simulations* that students could explore in their classrooms. In contrast, the group at Berkeley focused a great deal on hand-held devices that allowed students to measure water temperature, amount of dissolved oxygen and so forth. Was this merely a difference in opinions about 'best technologies", or was something else involved?

We eventually discovered that the group at Berkeley was working with a school that had a creek that ran right through the school yard. They could visit it daily if they wished, so measurement tools were a great thing to emphasize. In contrast, the Vanderbilt group was working in inner city schools where the nearest river was over 30 minutes away by bus—and field trips were expensive. So they concentrated on using simulations in order to prepare students for a river trip where they used what they had learned to analyze the river and write

[11] See the long Synergy paper later in this monograph.

reports to the state. Clearly, Vanderbilt would have preferred more trips to the river, but costs made that prohibitive.

The point I want to make here is how CILT's movement toward synergy helped us understand issues that otherwise could easily have escaped our attention. If each of our theme areas had focused on different educational problems, for example, we would not have seen the need for very different sets of technology tools depending on the situated nature of the instruction in different settings. (e.g., the need for simulations in river-less environments vs. "measuring tools" in environments where water quality assessments were only a few steps away). These insights seem obvious in retrospect but are relevant in many settings—irrespective of extensive uses of technology. For example, if district or state standards mandate certain kinds of curricular activities (e.g., studying water quality), they may be specified in a way that makes it difficult for some people to implement but easy for others. So flexibility needs to be the name of the game.

LIFE Lessons

Designing an organization to be adaptive to change is a challenge that is very important. CILT helped us see the importance of adapting our work over time, and these lessons have been extended to LIFE. For example, LIFE has three basic strands of research (implicit learning and brain; informal learning; designs for formal learning and beyond), but the explicit goal of LIFE is to continually increase the amount of cross strand collaboration in terms of theorizing and research. Specific strategies (e.g., conceptual collisions that result in "signature projects for testing ideas) have been put in place to specifically drive these changes. Additional strategies include specific mechanisms for input by LIFE's advisory board and review boards, plus specific plans for forging new relationships with research and educational partners. And of course, there is the ever-present issue of budgets. LIFE has tried to keep some flexible reserves so that we can take advantage of research and partnership opportunities that emerge in the course of our work.

Leadership and Capacity Building

I learned a great deal about leadership and capacity building by participating in CILT. The most important lesson was that the function of good leaders is to help develop new leaders. I had read that many times in the leadership literature, but CILT brought these ideas to life (and later to LIFE).

CILT's Post Doctoral program is an excellent example of leadership development. We were lucky to find outstanding candidates for these positions. But each post doc also had well-defined professional roles within CILT and stepped up to those roles. They designed and directed research, oversaw seed grants, learned to work collaboratively, made professional presentations on behalf of CILT, etc. All of them have grown into positions of responsibility (working in academia, informal settings like museums, educational software companies). This is an outcome from CILT that has been extremely positive.

LIFE Lessons

The LIFE Center has similar goals for developing the capacity of a new set of leaders. LIFE is larger than CILT, and we have graduate students, post docs, junior, mid-level and senior faculty.

We have already seen people step up to the plate as we worked last year to compete for LIFE. For example, the graduate students and post docs across Stanford, SRI and UW organized themselves and have done incredible work already. LIFE has established an 11-member leadership council that is considerably larger than the 5 CO-PI's OF LIFE (the NSF wanted no more than 5) and everyone on this council has made major contributions to LIFE. Specific researchers are also taking responsibility for particular studies in LIFE. And opportunities are being provided to help LIFE's partner institutions gain access to research knowledge and tools that they can take back to their home institutions in order to help others there.

In all these cases, the focus is on developing new leaders for the future. For me at least, CILT made that process come alive. Hopefully it will also live in LIFE.

In the spirit of sharing professional responsibilities, my turn has come and I am the PI for the LIFE Center. Defining my role (has been very important to me personally, and I learned a great deal from watching CILT's PI (Roy Pea) and my other Co-PI's (Marcia Lin, Bob Tinker, Barbara Means)

My CILT colleagues did not think of themselves as "cat herders", and neither do I. I also don't think they thought of themselves as "leaders *of* leaders". Instead, I think their attitude was one of being "leaders *among* leaders". I am comfortable with this latter role in LIFE, and I appreciate the opportunities that CILT provided to show what that kind of role entails.

As PI, I am ultimately *responsible* for ensuring that LIFE lives up to its promises, and so was Roy Pea for CILT. But this is different from being a cat herder or a leader of leaders. Without the opportunity to be a leader among leaders, I would not want to accept the PI responsibility for LIFE.

Summary

To summarize, my goal has been to discuss four key lessons that I learned from the opportunity to participate in CILT (Center for Innovative Learning Technologies). There are many others lessons, but these were my top four. I focused especially on lessons from CILT that helped shape a proposal for the recent NSF Science of Learning Center competition. Without CILT, I doubt that there would have been LIFE—at least not in its current form.

Lessons Learned

NORA SABELLI, Center for Technology in Learning

The original proposal to establish CILT put forward evaluation questions as markers for what should be its impact in the field. The criteria evolved from considering the meaning of "success" for a center whose objective was to *empower research advances in learning using technology*, where the word "empower" implies the field as a whole, not only the CILT researchers. The specific questions were:

- What lessons have been learned from CILT's experience in creating a "distributed center?" What are the strengths, weaknesses, and impacts of the CILT distributed center model?
- What lessons have been learned from CILT's experience in fostering collaboration across traditional boundaries (research, industry, practice, policy)? In what ways has CILT supported the creation of a new learning technology community?
- What lessons have been learned from CILT's experience in recruiting, mentoring, and supporting students and young professionals in its structures and activities? How has CILT functioned as an incubator for the next generation of learning technology leaders?
- What lessons have been learned from CILT's experience in pursuing its overall mission "to serve as a national resource for stimulating research on innovative, technology-enabled solutions to critical problems in K–14 learning in science, mathematics, engineering and technology?" In what ways have the CILT structure, activities, and impacts been innovative?

The report on CILT's evaluation at the end of its fourth year states:

> The fourth and final evaluation question—how the CILT experience has itself been innovative or has created the conditions for innovation—can be seen as an amalgam of the first three questions. Innovative ideas and practices can be discerned in the CILT experience in functioning as distributed center, in CILT's effort to create a new learning technology community that bridges the research, practice, commercial, and policy worlds, and in the role that CILT has played in the mentoring and support of young scholars. As the findings from the seed grant interviews, survey of the CILT community, and postdoctoral scholar interviews make clear, the innovative aspects of CILT are seen most clearly in the interplay of activities and structures identified in the evaluation questions—distributed leadership, community-building, and incubation of learning technology leaders. Other aspects of CILT's structure and functions (including the Industry Alliance, Netcourses, and the School Partners Program, among others) were not directly involved in our evaluation data collection and analysis. Although absent from our analysis, these aspects of CILT are nonetheless integral to an understanding of the innovative aspects innovating potential of the CILT experience.

Here we use the evaluation findings to reflect on how CILT activities contributed, or failed to contribute, to achieving the stated goals, i.e., how can the CILT experience help in the creation of other capacity-building learning sciences collaboratories, projects, and programs? What worked and what didn't?

Major Lessons

Audiences Served

CILT was conceptualized as a "knowledge network" among researchers, industry, and schools *to stimulate the development and implementation of important technology-enabled solutions to critical problems in K–14 science, math, and technology learning*. CILT could be seen as a three-legged stool, with legs consisting of (1) the nation's researchers in education and technology (2) active and invested industry participants and (3) a reasonably large testbed of innovating teachers and schools. CILT was expected to act as a matchmaker for new partnerships and provide seed funding for pilot projects resulting from those partnerships. As CILT progressed, the level of participation by each of these three legs evolved and succeeded in different ways. The most successful leg was undoubtedly the community of researchers, and the patterns of interaction will be discussed at length in this monograph. The other legs, industry and practice, had a mix of successes and failures, with most successes being derivative of activities aimed at researchers as an audience.

One postdoc described the school partners project as never taking off because it did not offer teachers a clear way to participate; "they didn't see a role for themselves and needed support." Though a successful effort was made the first year to bring teachers to the CILT conference, the human and monetary resources to keep a dual focus on *empowering a community of researchers*, and *bringing a community of teachers to work with researchers*, dictated otherwise. Though not absent, teachers were not independent and significant contributors to the research activities orchestrated by CILT. On the other hand, teachers constituted the main—by a large margin—users of the CILT Knowledge Network, using it as a resource. CILTKN was seen as a tool to help build on the strengths of the field and to bring people together, especially teachers, to share expertise. CILTKN itself was viewed by postdocs as a potentially wonderful but undervalued activity.

CILT was interested in working with industry to help ensure that learning science research innovations meet the requirements of most teachers, while also meeting the timetable of the early adopters. Thus, CILT set out to address this situation through collaboration between educational research and innovation leaders in industry.

The relationship proposed was a *reciprocal* relationship between industry and research: through deep collaboration that could be able to influence the technology that is introduced in the classroom, and keep the research community abreast of the most recent and relevant evolving technologies.

Prior evaluations of productive partnerships between research and industry found that the most effective partnerships were based on a true collaboration model: the more effort that an industry partner puts into the partnership, the more benefits that partner will receive. CILT steered away from models that provided surface contact between industry and educational research, but without significant collaboration. Specifically, CILT stayed away from industry's philanthropic institutions that do not influence corporate strategy. CILT hoped to build a self-sustaining organization that could have a positive impact on educational research and practice. Though this vision was not achieved, CILT workshops drew a significant number of industry attendees. We were also surprised to find that a significant number of industry participants chose to collaborate with academic researchers in follow-on research projects after the CILT workshops, including seed grants.[12] A model based on industry sponsorship of CILT activities, industry participation in CILT activities such as workshops and conferences, and opportunistic joint projects were successful in the long run.[13]

Distributed Center or Collaboratory?

In considering the strengths, weaknesses, and impacts of CILT's distributed center model the seed grantees, the CILT community at large, and the CILT post docs all agreed that the model's mission to bring together learning technology professionals from universities and private research centers, industry, schools, and government for collaborative research and networking is both a great strength and a great challenge.

Key challenges related to CILT's model as a "distributed center" revolve around balancing the demands of the center and participants' home institutions, and an ongoing tension between activities that have been successful for CILT, and specific research projects of interest to the PIs and postdocs. There is a significant difference, in terms of resources required, between field activities undertaken sporadically, and field activities undertaken as an *ongoing goal*.

The advantage of having four strong affiliated institutions with a weak center is that each PI brings a wealth of resources to CILT, making activities such as the conferences possible, and provides the flexibility needed for responding to the field. The same comment can be made about the presence of four distinct themes. The disadvantage is the lack of a central message from CILT, which could have a greater impact on the field; such focus should be contrasted with the ability to build bridges among themes, and to appeal to a wider segment of the research community. In this sense, CILT should be seen more as a successful "collaboratory"[14] rather than a successful distributed center. CILT was, in the eyes of a staff member, as "more distributed than center."

CILT's potential to defragment the learning technology field and build a community of innovative, diverse collaborations was seen as its great promise, as was CILT's attempt to look across multiple perspectives and communities simultaneously. Many of the seed grantees commented on the value of the collaborations, assistance, and opportunities that the seed grant program made possible, as will be discussed later.

An unavoidable challenge identified with a distributed center model concerns inter-institutional contracting issues. These issues manifested in the form of funding delays to seed grantees when their institution's intellectual property policies conflicted with that of CILT's. The question of who owns work produced through CILT seed grants is an important one. For CILT postdocs, intellectual property issues were one aspect of what they perceived as conflicts of allegiance between CILT and their home institution. A challenge faced by seed grantees, the CILT community at large, and postdocs was identifying outcomes attributable to CILT alone;

[12] For example, over 50 companies were represented at CILT conferences, with 18 sponsors, and over 20 companies participated in seed grants.
[13] The Industry Alliance program is discussed at length later in the monograph.
[14] See the reflections by Nathan Bos, a CILT postdoc.

since the model of seed grants implies a collaboration built from needs identified by ongoing researchers. Post docs and some of the seed grantees faced an additional challenge—the tension between CILT's emphasis on collaborative research, with the opportunity to create innovative and diverse partnerships and build upon each other's work, and the conflicting need for those seeking tenured positions to create a body of individual work.

One clear case of the CILT "distributed center" structure serving as a model for other initiatives has been the "Improving Learning with Technology" project[15] (organized jointly by the National Academy of Sciences and the National Academy of Engineering). This project, running from 2000 to 2002, had goals that are similar to those of CILT and built on the CILT experience. Like CILT, a central goal of the project was to build bridges among diverse communities (including in this case, "curriculum developers and school practitioners, developers of hardware and software to be used for enhancing education practice, researchers in cognition and learning, and experts engaging children with the use of information technology"). This attempt to shift the focus from empowering researchers to empowering transfer may tell us much about structuring field-oriented, transformative activities.[16,17]

Community and Capacity Building

The evaluation activities revealed a considerable amount of data regarding CILT's role in fostering collaboration across traditional boundaries (research, industry, practice, policy) and in supporting a learning technology community. The evaluation provided a look at the people who consider themselves to be a part of the community, how they experience the CILT community, what benefits they experience as part of the community, and how they view CILT's role in building the community.

Identification of self as part of the CILT community seems to be strongly related to one's perceived role in CILT activities. When asked how they experienced the CILT community, both seed grantees and online survey respondents named conference participation, support from CILT leadership, and networking to form partnerships based on common research interests. Online survey respondents also named reading CILT publications as a means of maintaining a link with the CILT community. Interaction in the CILT community took place through theme team work, collaboration on grants and conferences, sharing expertise with postdocs, networking through CILTKN, and sharing work with CILT's diverse audience. Some seed grantees named being involved with CILT from its inception or having relationships with colleagues who are CILT members before CILT existed were important to their sense of CILT community. Being in touch with CILT, knowing what is going on within CILT, were important for some seed grantees to their sense of community. A number of seed grantees, nevertheless, did not think of CILT beyond their seed grant work.

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[15] See comments of Roy Pea

[16] The clearest mark of CILT's influence on the design of the project is the intention "to begin a conversation among three sets of people who do not naturally interact but whose collaboration is essential, a conversation that by the end of the two years will have evolved into ongoing partnership, institutionalized through an NRC Roundtable that provides education planners and decision makers timely, continually updated, and integrated information about developments in and uses of information technology" (Project Summary sent by Kevin Aylesworth, August 15, 2000).

[17] Another collaborative meeting that adopted the "seed grant" process and is behind LIFE's Center collaboration strategies is the Gordon Research Conference on Scientific Visualization in Education.

Much of what we learned about CILT's success in incubating the next generation of learning technology leaders came from our interviews with the postdocs, supplemented by some data from the online survey and seed grantees. The majority of the seed grantees (84%) said that yes, participation in the CILT seed grant program had benefited one or more participants in their projects; 27% of those interviewed specifically mentioned that graduate students had benefited. The seed grantees reported other funded proposals and work as a result of the seed grants. *It was also an opportunity for early career researchers to build relationships with established researchers, and to increase their visibility.* Some named the opportunity to develop new skills and experience in important new areas as being tangible benefits; for some it was their first experience as a PI on a project. Other grantees named less tangible benefits, such as being part of a larger community, developing a broader understanding of the field, and reducing isolation.

The CILT postdocs felt their experience had helped them through increased visibility and learning. They also valued their expanded professional networks ("knowing and being known in the LT community"). They also learned how to write and manage grants, explore new research interests, come to understand more about the R&D world, and forge important connections with others in the LT community. While CILT brought early career researchers together with established researchers in meaningful ways, some postdocs questioned if CILT provided adequate opportunities for professional development of new scholars.

Innovation Findings

As we consider CILT's role in fostering innovation within the learning technology field, looking back at the evolution in CILT's mission statement provides some perspective. CILT's mission statement has changed slightly over the years to reflect a changing vision of CILT's structure and its role as a source of innovation. The current statement is as follows:

> To serve as a national resource for stimulating research on innovative, technology-enabled solutions to critical problems in K–14 learning in science, mathematics, engineering and technology

In a 1998 presentation to the CILT advisory board, the CILT mission was as follows:

> To catalyze the development and implementation of important, technology-enabled solutions to critical problems in K–14 learning in science, mathematics, engineering and technology.

The change in language, from "to catalyze development and implementation" to "to serve as a national resource for stimulating research" can be traced to the advice provided by members of the CILT advisory board during the 1998 meeting and to subsequent internal changes in CILT's plans and activities. CILT advisory board expressed reservations about CILT's potential role as a direct source of change and innovation in educational practice. They felt that CILT could not be oriented to the cutting edge of research and development on innovative learning technologies and at that same time be directly involved in developing approaches and solving problems in the implementation of learning technologies in schools. They also felt that CILT's strengths and its potential contributions would be greater in the research and development areas than in implementation.

There is evidence that CILT has indeed fostered innovations for the field, both through its process for generating collaboration and through specific research outcomes. Seed grantees and online survey respondents commented on the unique structure of the CILT conference and how, in combination with the seed grant program it fostered important collaborations. CILT's introduction of five-minute "firehose" presentations and theme team breakouts were ways of quickly disseminating learning in the field and determining critical areas of research focus. The opportunity to form working groups and rough out seed grant proposals at the conference spawned many collaborations. These collaborations in turn have led to a variety of innovations, some CILT-related—such as Playspace and the Datagotchi approach—others not.

The seed grants themselves were an innovation. Their size allowed for work on specific topics in a short period of time, focused on collaboration from the beginning. Seed grants brought together diverse groups of people, which in turn led to uncommon syntheses of ideas. The seed grants were also flexible in their ability to fund ideas with no short term payoff that may be difficult to fund otherwise. The CILT project manager compared this to the strength of the business model, which allows project development to go where it needs to, rather than be tied to an initial grant plan that may prove to be less workable.

When asked which CILT components were most valuable in envisioning new directions for research, respondents named the conference, the seed grants, the theme teams, the CILT publications. Other components mentioned included the synergy project, the postdocs program, and the website. The collaborative research across institutional lines and CILT's role in raising awareness for the use of technology in education were named as important to innovation in the field. An important comment pointed to CILT's support for research in specific areas, such as the use of handhelds.

While there is evidence that CILT has produced some innovative processes and has supported the development of some innovative directions in research, its true value may be the infrastructure of human capital and collaborations that will yield further innovations down the road, reflected in the new Centers formed by CILT principal investigators.[18]

[18] The three CRLT/LIS centers have evolved as follows: (a) CIRCLE and CILT PIs have received two of three NSF Science of Learning Centers funded in 2004; (b) CILT PIs and the LeTUS team have become NSF Centers for Learning and Teaching. In addition the LeTUS group at the University of Michigan won the 2004 Urban Impact Award of the Council of the Great City Schools for their partnership with the Detroit Public Schools.

Reflections by CILT Postdoctoral Scholars

Synergy: Design Strategies and Practices for Accelerated Research and Development in Education

ERIC BAUMGARTNER, Inquirium and SHERRY HSI, The Exploratorium

Introduction

Education reform is often inspired by the promise of improved learning and teaching with innovative curricula, content-rich disciplinary activities, and designed resources mediated by learning technologies. However, the process of designing these innovative materials in educational settings has not benefited as much as it could from the collective expertise and accumulation of knowledge from research in the learning sciences, cognitive sciences, and information technologies. How can we facilitate the transition of research into practice? That is, how can we take advantage of research on learning, cognition, and development to implement effective curricular, technological, and pedagogical change in real classrooms in real schools?

We argue for a new approach called "synergy," to conducting education research and designing educational interventions. Synergy research addresses the challenge of developing usable knowledge that contributes to educational practice, pedagogy, and theory and encourages customization research. In this paper, we will discuss the progress the Center for Innovative Learning Technologies (CILT) has made toward defining the nature of synergy research and discuss how synergy research may provide the means to capture and refine usable knowledge in education.

Challenges in Pasteur's Quadrant

One of the important trends in the learning sciences over the past decade has been a continuing move away from conducting laboratory-based studies toward designing and studying more complex interventions that take place in naturalistic classroom settings (Edelson et al., 1999; Krajcik, Blumenfeld, Marx, & Soloway, 1999; Linn & Hsi, 2000; Reiser et al., 2001; Songer, 1996; Vye et al., 1998).

Conducting research in authentic classroom contexts addresses a need for a more applied approach to educational research, in which researchers take responsibility to apply their own research, and that of others, to educational practice, while continuing to investigate fundamental scientific questions. This trend reflects a broad move within education toward research in Pasteur's quadrant: fundamental research on learning conducted in an applied setting (Stokes, 1997).

However, such research efforts are very complex. Whereas in lab settings, researchers can design and examine brief, tightly focused interactions that inform a very specific research goal, the classroom setting demands that researchers develop a broad range of expertise, spanning curriculum development, assessment and evaluation, teacher professional development, classroom management, school policy, and learning technologies, among others. Researchers that work in these naturalistic settings have to take into account multiple levels of agency in learning, ranging from higher-level organizational influences down to microgenetic interactions among learners. The complexity of designing for classroom settings places greater demands on research groups, who now take on the responsibility to partner with practitioners to write curriculum, design assessments, develop technology, and support teacher professional development.

A natural response to the demands of designing for the classroom is to look to the educational research community. Researchers should be able to create partnerships and draw on the work of others to inform aspects of educational design in which they have no expertise. The principal investigators from CILT emphasized the importance of collaboration as a means to address these demands.

> Given this increasing complexity, few projects, institutions, disciplines, or funders can encompass the range of expertise needed to mobilize the combination of new technologies and new insights into learning to identify and solve real-world learning challenges. Achieving major impact requires aggregating ideas and integrating innovations. Innovation must start with an understanding of both educational needs and technological possibilities and be based on technical trends, learning theory, changing school realities, possible marketing arrangements, and dissemination strategies. Close collaboration among a broad range of researchers, industries and schools is the only strategy that can marshal these resources in a timely, effective manner. (Pea et al., 1999)

Usable Knowledge in Education

As researchers look to the accumulated knowledge of the field to inform and leverage their efforts to inform educational practice, creating what Lagemann (2002) terms "usable knowledge in education" becomes an important goal. Lagemann defines usable knowledge in education as knowledge that can inform the design of educational innovations and concurrently improve educational practice. It may be theory driven, but its pragmatic, applied focus grounds it firmly within Pasteur's quadrant.

The need for usable knowledge is clear. Without such knowledge, educational researchers and developers are forced to expend precious resources creating content, tools, and technologies that probably already exist. Industry groups produce and market learning solutions that are weakly informed by current educational research. And educational practitioners are left in the role of consumers of research and commercial products that are designed for specific uses and do not lend themselves to customization in both formal and informal learning environments.

What is less clear is the nature of usable knowledge itself. What form does such knowledge take? How is it applied by educational designers, researchers, and practitioners? Researchers have begun to explore representations for usable knowledge, focusing on ways to make their research findings accessible to practitioners and other researchers.

For example, Ball and Cohen (1996) have advanced the idea of "educative curriculum," curricular materials that explicitly represent key theoretical and pedagogical ideas that drove the design of the materials. This approach helps practitioners understand the basis for innovative curriculum so that they can effectively adapt the materials to their own practice and perhaps apply the underlying principles to other aspects of their practice.

In a similar vein, Schwartz et al. use the term "flexibly adaptive design" to capture the notion that curricular innovations need to be able to adapt to local context, and innovators need to address adaptability explicitly in the representation of the innovation (Schwartz, Lin, Brophy, & Bransford, 1999).

The focus of educative curriculum and flexibly adaptive design lies in providing explicit information about the underlying design and goals of a given innovation. A slightly more abstract approach that also explores the nature of usable knowledge focuses on the principles, or patterns, that drive effective learning.

Researchers often seek to define “design principles” that explain why effective curricular innovations are successful (Linn & Hsi, 2000). Although these principles are typically derived post hoc and used to explain past successes, educational practitioners and designers have begun to explore the use of such principles in more generative way, applying them to inform the design of new curricula.

In theory, design principles are promising because their generality allows them to be applied to a variety of settings. However, principles that are too abstract can be difficult to apply. Researchers in other fields, notably architecture and computer engineering, have focused on a related idea called “design patterns” (Alexander, Ishikawa, & Silverstein, 1977; Gamma, Helm, Johnson, & Vlissides, 1995). Design patterns are more focused than design principles and attempt to capture robust solutions to common challenges. Design patterns are intended to be generative by nature and help designers to identify cases where they can be applied. Researchers in education have recently begun to explore the nature of design patterns and ways to represent patterns for education.

These examples—educative curricula, flexibly adaptive design, design principles, and design patterns—all reflect efforts to represent usable knowledge. But how will we know if these new representations of educational innovation are actually usable?

Our view is that the study of the nature of usable knowledge is not complete without a close examination of the process of applying such knowledge to design new educational innovations (or adapt existing innovations to new settings). The efforts described here are useful for shaping initial descriptions of candidate knowledge representations, but they do not go far enough. We need research paradigms for testing the utility of such knowledge in practice. Is the knowledge robust enough to inform educational design in settings that differ from that of the original research? Can educators and researchers make sense of such knowledge and apply it appropriately to new settings? How do we test and refine usable knowledge so that, as a field, we build a knowledge base that truly informs educational design?

Synergy Research

Synergy research began as an effort to address these questions. It focuses not only on the forms of usable knowledge but on the collaborative research practices that might lead to the generation, testing, and refining of usable knowledge in education. Synergy research makes an explicit effort to address the challenges and benefits of leveraging existing learning technologies research and designing new materials that lend themselves to future use by others in other settings. We believe that understanding the specific obstacles to effective reuse of learning technologies research is an important first step toward describing and creating usable design knowledge.

The topic of synergy research is particularly relevant and timely given the focus at the national level on cross-institutional, multidisciplinary research being implemented and planned for the future to improve learning and teaching. We will argue that these synergy research and design practices are an important collaborative step towards building a robust, usable knowledge base within learning technologies.

There are two key components to synergy research, which can take many forms. The first is that synergy research is focused on usable knowledge—defining it, applying it, and assessing its utility. Typically, this means that synergy research is tied to the design of learning environments, teaching practices, and curriculum, since the purpose of usable knowledge is to inform educational practice.

The second is that synergy research connects *producers* of usable knowledge with *consumers* of usable knowledge. This is an important factor that goes beyond simple research-to-practice paradigms (Pea, 1999). It is important, particularly in early stages of synergy research, to actively connect those who claim to be producing usable knowledge with those who seek to apply it. First, creating this connection provides a way for the consumers to ensure that their understanding of the innovation is accurate. This ability provides a check against the "lethal mutation" problem that can arise when innovations are misinterpreted by practitioners who lack the experience and background knowledge of the original researchers (Brown & Campione, 1996). Second, this connection provides a way for consumers to provide feedback to the producer of the knowledge, which enables the iterative refinement of the knowledge as it is applied in more and more diverse settings.

Put another way, synergy research is, fundamentally, the study of *customization*—that is, the study of how research-based educational innovation can be applied to new learning contexts. Synergy research addresses both (1) the issue of customizing new innovations (which might be brittle in nature), as well as (2) studying how to *design for customization* to allow next-generation learning environments and educational interventions to be more easily adaptable, sharable, and usable by others. Knowledge of "what works where" is the result of customization research, and this knowledgecontributes to a growing base of usable knowledge of how to design for learning.

CILT and Synergy Research

The Center for Innovative Learning Technologies (CILT) was an NSF-funded, cross-institutional, distributed research center created to stimulate the development and study of important, technology-enabled solutions to critical problems in K–14 science, mathematics, engineering, and technology learning (Pea et al., 1999).

CILT began its investigation of synergy research and the nature of design knowledge in 1998. CILT researchers had a strong interest in aggregating "best practices" in the field while continuing to support ongoing research and development within four themed areas: Ubiquitous Computing, Visualization and Modeling, Tools for Assessment, and Community Tools (see Gray, 2002; Kali, 2002; Ravitz, 2002; Tinker & Vahey, 2002).

The concept of synergy was refined over a series of discussions of how CILT might fulfill its mandate to aggregate best practices in learning technologies. The center was in a unique position of having the resources to host conventions that would bring together researchers and practitioners with learning technologies. We wanted the center to serve as something more than a glorified information broker. Although serving as a knowledge network and information broker would be a valuable resource and service for the field, this knowledge networking model does not actively engage practitioners in the application of usable knowledge.

The name "synergy" arose initially to reflect an effort to engage in research that cut across the four themes within CILT. Although it made sense to differentiate among the themes for the purpose of summarizing research findings and convening like-minded researchers, we realized that when engaged in classroom-based research, all of these themes would come into play. One cannot develop a visualization tool for the classroom, for example, without addressing questions of how we will assess what students learn by using the tool. Thus, the "Synergy project" was viewed as work that could explore how to unify the four theme-based research efforts.

Much of what was viewed as "synergy" at CILT began with a specific water quality curriculum project. This project provided a context in which CILT researchers, chiefly postdoctoral scholars, could compare and contrast theoretical and pedagogical traditions of the different educational institutions that made up the center. This activity, initially dubbed "walking in each other's shoes," leveraged the act of designing a curricular intervention as a means to force us to develop a deeper understanding of these traditions. In effect, we needed to understand each other's intellectual and curricular frameworks well enough to actually use them to productively inform curriculum design. We were trying to develop usable knowledge.

Over time, however, the idea of synergy research grew to be represented in its own right at CILT conferences and workshops (e.g., Baumgartner & Hsi, 2002). CILT began to explore ways to foster synergy research more broadly through its role as "convener" of theme-based meetings within learning technologies and funder of modest "seed grant" projects.

Taken together, CILT's efforts to engage in synergy research fall into three broad categories: enabling synergy among researchers by hosting theme-driven meetings, pursuing synergy through hands-on curriculum design in a new setting, and exploring forms of usable knowledge that result from synergy research efforts. We will describe each of these efforts in detail.

Enabling Synergy Research

One activity that CILT has used repeatedly, in a variety of settings, is the small workshop model. The small workshop model is a precursor to synergy collaboration and serves as a forum for identifying potential partners and negotiating shared goals.

Small workshops typically consist of up to 40 participants and focus on a very specific topic. Past CILT-sponsored workshops have focused on a comparison of inquiry-based water quality curricula, the potential role of "datagotchis" in mathematics education, the nature of educational design principles, and the use of digital video in educational research.

These workshops usually last two days and consist of two parts. In the first part, participants give rapid "firehose" overviews of their research interests and current projects. Participants are encouraged to highlight what they can bring to a partnership, as well as what they seek in a partnership. These talks are an effective means to introduce the participants to each other's work. Demo sessions late on the first day provide an opportunity to learn more about each other's work and, significantly, provide opportunity for much deeper, hands-on engagement with the work than is typically possible in more formal conference settings.

In the second part, participants self-select themselves into emergent interest groups that capture areas of common interest and greatest need. These groups then have time to begin to negotiate a common focus for a shared research agenda and explore ways to pool resources and research to achieve their goals. Although an agenda by itself is not sufficient to define synergy research, small workshops do a good job in establishing working collaborations that cut across traditional research groups, collaborations that contain the prerequisites for future synergy research. In the case of CILT workshops, CILT was often able to offer seed funding to such collaborations that, in effect, launched small synergy collaborations. In other cases, these groups took the initiative to pursue funding to support further collaboration.

Synergy Research through Curriculum Design

The CILT water quality project was an effort to use a curriculum design project as a means to explore ways to "work smarter" and leverage usable knowledge in the field. The project focused primarily on classroom-based studies in California, but it included a working meeting, organized in typical CILT fashion, to promote greater collaboration between CILT and another NSF-funded center, LeTUS.

The water quality project initially developed an Internet-based curriculum called Strawberry Creek. The 2-week-long curriculum was targeted at high school students in biology, chemistry, and physics classes. The curriculum was delivered by using the Web-based Inquiry Science Environment (WISE), which provided significant technological support for structuring student investigations. WISE is based on a pedagogical model called scaffolded knowledge integration, which emphasizes providing students with multiple opportunities to integrate new evidence and ideas with their prior knowledge and experience (Linn & Hsi, 2000).

To explore the customization process, we twice adapted Strawberry Creek to new classroom contexts. Alameda Creek was targeted at high school biology students and adapted the water quality data to a different watershed and expanded the curriculum to include a series of staging activities that familiarized students with data collection procedures using Palm PDA-based probes. Pine Creek brought the water quality curriculum down to the sixth grade and again refocused the activity on a different local watershed.

Our curriculum design efforts were based on the Partnership Inquiry Process (Linn, Shear, Bell, & Slotta, 1999). This approach invites experts from a variety of fields, including educators, designers, researchers, and scientists, to contribute their expertise to the design of curricular goals, instruction, technology, and assessment measures. A strength of the Partnership Inquiry Process is its explicit framing of the collaborative process. Rather than having responsibility (and authority) based solely on initial areas of expertise, all partners in the process are encouraged to contribute throughout the iterative design process. Participants are expected to engage in respectful debate around design dilemmas and to articulate the implicit assumptions and expertise that underlie their claims. In this way, the overall design capacity of the team grows over time, as knowledge gradually becomes distributed among the group.

Although synergy research is predicated on bringing together diverse forms of expertise, it is important that synergy projects move forward on the strength of a shared set of learning goals. Shared goals ensure that collaborating researchers are ultimately working toward the same end and that some common ground is established. Establishing shared goals is not always easy, particularly when trying to negotiate the tensions among goals and values from different research traditions. However, the process of reaching consensus and operationalizing these goals can be highly productive in itself, as such discussions, which often continue over the course of a research project, provide opportunities to articulate the specific issues that fuel these tensions (McCandliss, Kalchman, & Bryant, 2003).

The design team included researchers whose graduate training encompassed distinct views of what constitutes inquiry-based science education. The project and the process provided an opportunity to put the "walking in each other's shoes" approach into practice. This term sought to capture the idea that, in spite of what one might learn by reading or talking about someone else's theoretical perspective or curricular design framework, the best way to *really* understand the other view is to actually design a curricular activity using this perspective or framework.

Engaging in this kind of design exposes a range of intellectual, curricular, and technological barriers to successful reuse of innovation (see Baumgartner, Seethaler, Cheng, Lo, & Slotta, 2000; Hsi, Collison, & Staudt, 2000). There is something fundamentally different about reviewing curricular materials when the goal is reuse. Sound theoretical frameworks continue to be important, but the simple fact that we may use the materials in the classroom changes what we attend to and how we assess innovation. Pragmatic concerns like technology requirements, curricular fit, and demands on available class time become much more important.

In addition, the focus on curriculum design allows us to explore how different intellectual and theoretical transitions may lead to fundamentally different curriculum designs. In the case of the CILT water quality project, the design of a WISE-based water quality unit provided an opportunity to explore the degree to which three distinct approaches to scaffolding student learning—scaffolding knowledge integration, project-based science, and anchored instruction—really led to radically different curriculum designs.

Walking in each other's shoes is a specific instance of a more general approach of engaging in synergy research by extending the context of innovation. This approach studies the application of educational innovation in new learning contexts that differ from the original research context to various degrees. Such customization efforts provide feedback for the original researchers about the robustness of their innovation in new settings. A key challenge to such studies lies in documenting how context varies from one setting to another. As a field, we do not yet have a shared language for speaking about the nature of context in design research.

Customization research efforts may provide an important intermediate step in the transition from small, highly focused studies to broad-based reform efforts. Because broad curricular reform efforts must address differences in context, customization research that occurs prior to extensive reform can yield insights into specific aspects of context that impact a particular reform.

From Synergy Research to Usable Knowledge

Thus far, most of the strategies we have outlined focus on initiating and sustaining synergy research and the challenges to adapting external research. There are also strategies that researchers and designers can adopt that seek to anticipate future customization and the use of innovation in various contexts.

The idea of flexibly adaptive design captures the goal of these strategies: to find ways to allow designed innovations—curriculum, technology, and other practices—to flexibly adapt to local needs, while preserving the core pedagogical elements that are embodied in the innovation (Schwartz et al., 1999). Recent efforts to enable educators to modify innovative technology-based curricula like WISE and WorldWatcher (Edelson et al., 1999) point to the appeal of this approach, while underscoring the difficulty of ensuring that core innovations stay intact.

Issues of flexibly adaptive design arose in the WISE creek projects, particular in discussions within the design team about how to support future customization of creek projects by teachers. In the case of water quality, we expected teachers to adapt these projects to align—at a minimum—with the conservation issues facing their local watershed, their grade level, and the amount of available time for the curriculum. Given these changes, and their attendant impact on the cohesiveness of the original unit, how could we frame the curriculum in a way that preserved the key idea of scaffolded knowledge integration? Ultimately, we produced a two-tier curricular model that segmented the curriculum into a series of structured, inquiry-specific activities and encouraged customization around content and time within each step (Baumgartner, 2003).

An alternative approach to designing for adoption is to attempt to provide future adopters of innovation with what amounts to "informed consent," by explicitly articulating design decisions and rationales and making these articulations accessible. This approach presumes that the curricular materials alone cannot ensure a particular pedagogical practice, and instead builds on Ball and Cohen's (1996) model of "educative curriculum" to help curriculum authors and educators understand the original design intent and then make their own customization choices.

Another form of articulating and sharing design knowledge is to package research findings and experience in the form of design principles that are accessible to developers, education practitioners, and researchers. These design principles aim to capture not just the principles that lead to successful designed artifacts, but also the lessons learned throughout the process, including the less successful iterations and design rationales.

Design principles (and a related idea, design patterns) have provided a representation for knowledge in other fields and have been used in education as explanatory devices (e.g. Roschelle et al., 1999). Their value as a form of usable knowledge in education is not yet known, but CILT's initial efforts are allowing others to explore these kinds of knowledge representations.

To permit abstract design processes and provide guidelines that can apply to other contexts, a design principles database hosted by CILT was created to enable multiple participants to form a common vocabulary or agreement regarding the relevant forms of evidence necessary for designers to build on each other's experiences. Moreover, the online database could provide a collaboration infrastructure for a broad community of educational designers to browse, publish, connect, and discuss their design principles with peer designers. The design principles project is online (http://wise.berkeley.edu/design/).

An Agenda for Future Synergy Research

We have presented synergy research as a means for developing, testing, and sharing usable design knowledge. We do not expect that a single model for synergy research exists. Supporting productive synergy is challenging. The process of identifying potentially usable knowledge and adapting it to the demands of specific learning contexts is also difficult. The activities we have described here reflect activities and processes that contributed to productive synergy within the context of CILT.

It is important to view synergy research as a set of practices that shape the research enterprise in several ways. In this section, we offer a series of recommendations for improving and advancing synergy research. The purpose of these recommendations is to suggest productive directions for future research efforts that share our goal of generating and refining usable design knowledge for education.

It is particularly instructive to consider how to advance synergy research by assessing its potential impact across the trajectory of educational research. By trajectory, we mean the natural arc of work that commences with identification of a research question and ends with the communication of findings to the field and/or a newly enacted practice informed by design research. Our recommendations speak to different points along this trajectory of research to practice, and are presented in the following section.

Recommendations for Furthering Synergy Research

Develop human capacity for collaboration across institutions. Designing and assessing educational practices for authentic settings is an extremely complex task that demands multiple forms of expertise. Rather than attempt to develop diverse expertise internally, many research groups have adopted a partnership model, in which a diverse group of educators, researchers, and scientists work together to design effective learning environments (Linn et al., 1999; Reiser et al., 2000). Although such diverse partnerships offer clear value to ongoing design efforts, a major challenge facing synergy collaborations is how to manage the tensions inherent among participants who may have varying views of what constitutes successful learning.

Synergy research requires forming initial collaborations to bring together the expertise needed to successfully design and implement interventions that work in naturalistic settings (whether classrooms, museums, after-school programs, professional development centers, etc.). Established researchers are often entrenched in their particular ways of working in the field, with preferences for particular research methods, theoretical perspectives, and learning theories. More opportunities for cross-institutional research create near-customization opportunities and opportunities for junior researchers to be immersed in a variety of learning and design approaches, while formulating their own models of collaborative research and next-generation theories of context, theories of action, and theories of practice. The CILT postdoctoral scholar program serves as one model for this approach to human capacity development.

Support active, reciprocal collaboration. Ultimately, we hope that synergy research will result in the development of usable design knowledge that can be applied to new contexts without relying on the expertise of the original designer. First, however, synergy must explore the nature of such design knowledge, and this kind of research requires collaboration not only by the core research team but also by researchers and designers whose work is adapted for new contexts. Researchers seeking to apply prior work to new settings quickly become aware of the extensive implicit expertise that is usually needed to properly interpret and apply such work. Access to this expertise, in the form of collaborations with the original designers, is a key resource that affords synergy. Conversely, original designers should recognize the importance of uncovering such implicit knowledge. Synergy research can expose key assumptions and identify or test the contextual limits of the original design. Such research has clear value, and designers who are interested in contributing to usable design knowledge should welcome opportunities to participate in such reciprocal collaborations, since the knowledge gained from such instances can inform future reuse. The resulting dynamic between "producers" and "consumers" of usable knowledge drives synergy collaborations.

Develop theories of context that can explain and predict classroom variation. To understand how research may be usable in the classroom, we need to understand the contextual variations among classroom settings well enough to inform the customization process. If we cannot anticipate the ways in which one classroom will differ from another, we cannot know how to customize an educational innovation to account for those differences.

The notion of a theory of context attempts to capture the need for this kind of understanding of the space of variation among classroom settings. Obvious contributors to this variation include factors such as grade level, curricular learning goals, and available time. Certainly many other aspects of classroom practice also affect the ways in which materials are customized for use. Research toward a theory of context would attempt to articulate as many of these factors as possible and draw causal relations among these dimensions. Such a theory would be a rich taxonomy of classroom practice, as well as a theoretical argument for why certain aspects of practice may be more important than others.

The value of a theory of context is that it informs both the design of flexibly adaptive materials and the customization of such materials to new settings. If critically important dimensions of variation can be identified in advance, designers can explicitly address customization within those dimensions. Researchers also benefit from the development of a theory of context, since it may inform the experimental design of customization research trials.

Develop and scaffold frameworks for customization research. Synergy research needs to be packaged in a way that makes it easy for consumers to understand when it can be used and what results can be expected. Further, this process of customization by other researchers or education practitioners in the field needs to be viewed as a legitimate form of research because new practices are developed. Customization is a reflective practice to inform both researcher and practitioner what works in context.

Producers of synergy "content" need a mechanism to receive feedback from consumers of that content. We all view production of knowledge (and resources) to be an activity that the field rewards. At present, research that uses synergy "content" is viewed as derivative and therefore not worth pursuing within academic circles; we need to make research as a synergy consumer into a legitimate activity. But if we constantly put things out there and never get any feedback about how they do when they hit constraints we never thought about, the field will not grow in a cumulative way.

Also, consider whether the process of taking synergy content from the community "store" and customizing it occurs in the presence of a knowledgeable guide. Typically, it doesn't—you're on your own to figure out what I meant. But the CILT postdocs were able to serve—to a point—as guides for one another. This has the potential to radically change the model and is, to some extent, what happens at CILT workshops and conferences. We need to explore ways to institutionalize this kind of reciprocal teaching among junior researchers.

Develop representations and venues for usable design knowledge. If synergy research is viewed as a stepping-stone toward developing usable design knowledge, what can it tell us about the ultimate forms that such knowledge would take? The practices described in the prior section offer some insight into specific representational forms, but much work remains to be done to document specific forms of usable design knowledge.

Ultimately, synergy research is intended to generate usable design knowledge. However, as a field we are still struggling to find adequate ways to document and disseminate design knowledge among our colleagues. An important lesson from the CILT Synergy project was how surprisingly difficult it was to round up and make sense of the curricular artifacts from prior research efforts within the domain of water quality.

There are two central elements of this challenge. The first is that the field lacks consensus on exactly what form design knowledge takes. Candidate representations range from high-level design principles to annotated curricular materials. Researchers have not identified an appropriate grain size for design knowledge—are we describing curricular materials themselves, the principles and constraints that informed the design of the materials, or something else entirely? Nor have we identified a methodology to rigorously assess the utility and broad applicability of such knowledge.

Potential representations for design knowledge include educational versions of the design patterns found in computer science (Gamma et al., 1995), as well as illustrated design principles such as those that populate the CILT design principles database. We need to explore additional models for creating an infrastructure that enables ongoing discussions and captures the design rationales that lie behind specific educational innovations. Other efforts also demonstrate effective synergy practices, such as the National Education Database including National Certification of Teachers video collection of effective teaching practices, as well as shared assessment practices and item banks for science achievement.

The second element of this challenge is identifying appropriate venues for publishing design knowledge. Because such knowledge is intimately tied to specific curricular artifacts, traditional publication venues may not offer enough bandwidth to adequately communicate design intent. Many researchers have begun to experiment with publishing materials (e.g., curricular materials, software, classroom video) on the Web as a way to share complete design implementations. Future work along these lines would explore formal representations for such information and offer suggestions or templates for articulating and publishing design knowledge.

Summary

We have described synergy research as a process of exploring how usable knowledge in education can be generated and refined in collaborative settings. Specific examples of synergy research were drawn from past work of the Center for Innovative Learning Technologies and are meant to illustrate ways in which the learning technologies field, and education more broadly, can advance our understanding of how research on learning can be productively applied to educational practice.

Synergy research treats the study of curricular customization and the idea of replicability studies as critically important but currently underemphasized aspects of education research. It is important that the field find room to support such studies as a complement to original research. In our view, usable knowledge within the field will grow only to the extent that there are both original producers of knowledge and scholarly, reflective consumers who are constantly applying theoretical and practical knowledge in ways that afford comparison and replication of original work.

Our own synergy research within CILT is a small start in this direction. Our hope is that researchers and practitioners in the field, together, can accomplish more such collaborative work in the future.

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The Evolution of CILTs Design Principles Database

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Introduction

One mission of the Center for Innovative Learning Technologies was to define and build effective learning technologies. A project sponsored by CILT, the Synergy project, focused on one curricular domain, water quality, as a way to explore the salient features of different implementations of technology-based learning environments. The Synergy project researched several water quality learning environments, including University of Michigan's Model-It project, Vanderbilt Learning Technologies' Scientists in Action series, and University of California's WISE Pine Creek project. During this investigation, several similar features were identified across the environments, even though the instantiations of the features were different within each environment. Some of these common features include contextualization of a problem, posing a question, and providing data or evidence to analyze the problem. The commonalities identified within these learning environments motivated CILT's Visualization and Modeling (VisMod) theme team to continue defining the key components within learning technologies. We moved beyond the one domain of water quality to expand the research to all types and contexts of learning technologies. The goal of this initiative has been to identify the rationale or critical components of learning environments, which we call *design principles*, and to build a community of researchers and designers to articulate and refine a set of design principles for effective learning tools.

Why a Design Principles Database?

Just as successful curricular materials depend on a process of iterative refinement to respond to needs identified in the classroom, so do successful technology-based learning environments require iterative design and refinement. Emergent design-based research methods suggest ways to capture this process (Barab & Squire, 2003; Brown, 1992, Collins, 1992; Edelson at al., 1999; Linn & Hsi 2000; The Design-Based Research Collective, 2003). These methods describe how research teams gather evidence and make decisions about refinements (Bell, Hoadley, & Linn, in press; Linn, Davis, & Bell, in press).

CILT's Design Principles project sought a mechanism to capture the learning that happens within the design-based, learning technologies research community. The *Design Principles Database* was developed as a concrete artifact to capture and support the evolutionary process of building and documenting innovative software features. Many researchers share the lessons learned from their studies and make their innovations available on the Web, yet other designers rarely make use of these findings to enhance their own innovations. Learning by simply interacting with the available software is difficult because the rationale behind the design of the features is not always clear. Also, the iterative process of the design is invisible to the software users. Publications usually report success stories in technology-enhanced learning and instruction, rather than the lessons learned from the design process. The Design Principles Database not only describes innovative technologies but also includes design rationales, contexts of use, histories of refinement, and reports of effectiveness.

We describe the evolution of the Design Principles Database as a mechanism to support designers in sharing and building design knowledge. The Design Principles Database was developed as an infrastructure for designers to publish, connect, discuss, and review design ideas. The database is designed to bridge research and design in a communicable and systematic manner. It also has the potential of enabling designers to build on the successes and failures of others rather than reinventing solutions that others have struggled to develop. The database is intended to be built by and serve the community of educational software designers. Although we expect our main audience to be educational researchers who are involved in software design, we believe other audiences could also benefit. Ultimately, we envision the database being useful to communities harvesting their design knowledge, designers creating new applications, teachers and curriculum developers customizing and tailoring existing instructional materials, and graduate students in the learning sciences learning about, and contributing to, the design field. The database synthesizes findings from multiple research groups and also validates these findings by supporting the process of communitywide peer review of innovations.

In this report we describe: (1) a new vocabulary that was developed to discuss design, (2) the events that led to the development of the Design Principles Database, and (3) research that is converging around the use of the Design Principles Database as a community tool. We highlight one approach that uses the database to build communitywide design knowledge.

Design Vocabulary

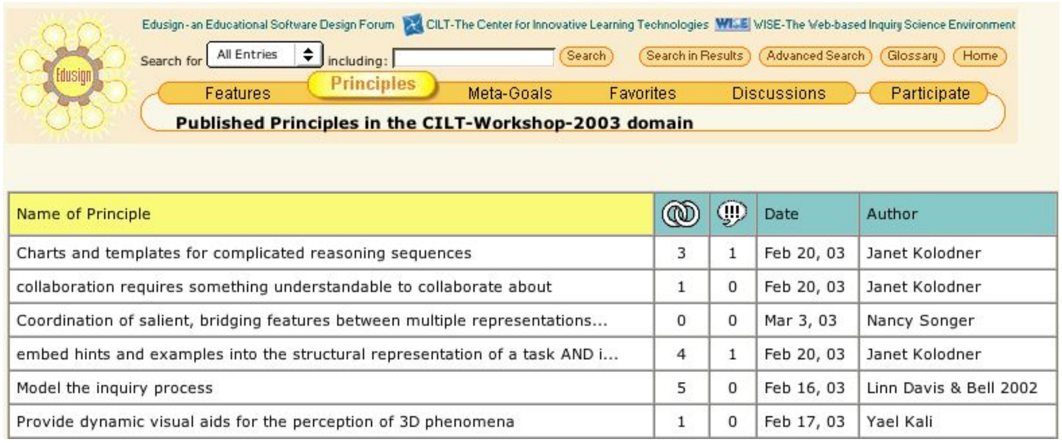
The Design Principles project has stimulated the development of an emergent vocabulary to communicate design ideas. We use *feature* to refer to any effort to use technology to advance learning. In particular, we use "feature" to describe designed artifacts, or parts of artifacts, such as modeling tools, simulations, microworlds, visualizations, collaboration tools, games, and assessment tools. A *rationale* describes the thought and research substantiating a feature.

Building upon substantiated features, a *learning environment* is a system that incorporates a set of features along with a navigation system and curriculum materials. We use *design principle* to refer to an abstraction that connects a feature to some form of rationale. Design principles can be at several levels of specificity, articulated below. Principles can link to one feature or to several features, and can link several principles together. Design principles emanate from and connect to theories of learning and instruction.

The Design Principles Database

The Design Principles Database (http://wise.berkeley.edu/design) is a set of interconnected features and principles. Each feature is linked with a principle, and principles are linked between themselves in a hierarchical manner. Principles in the database are described in three levels of generalization: *Specific Principles* are those that connect directly to a single feature or single research investigation and provide the specific rationale behind the design of that feature. *Pragmatic Principles* connect several Specific Principles, and *Meta-Principles* capture abstract ideas represented in a cluster of Pragmatic Principles. Figure 6 lists these multiple connections and provides examples of software features and principles in the three hierarchical levels.

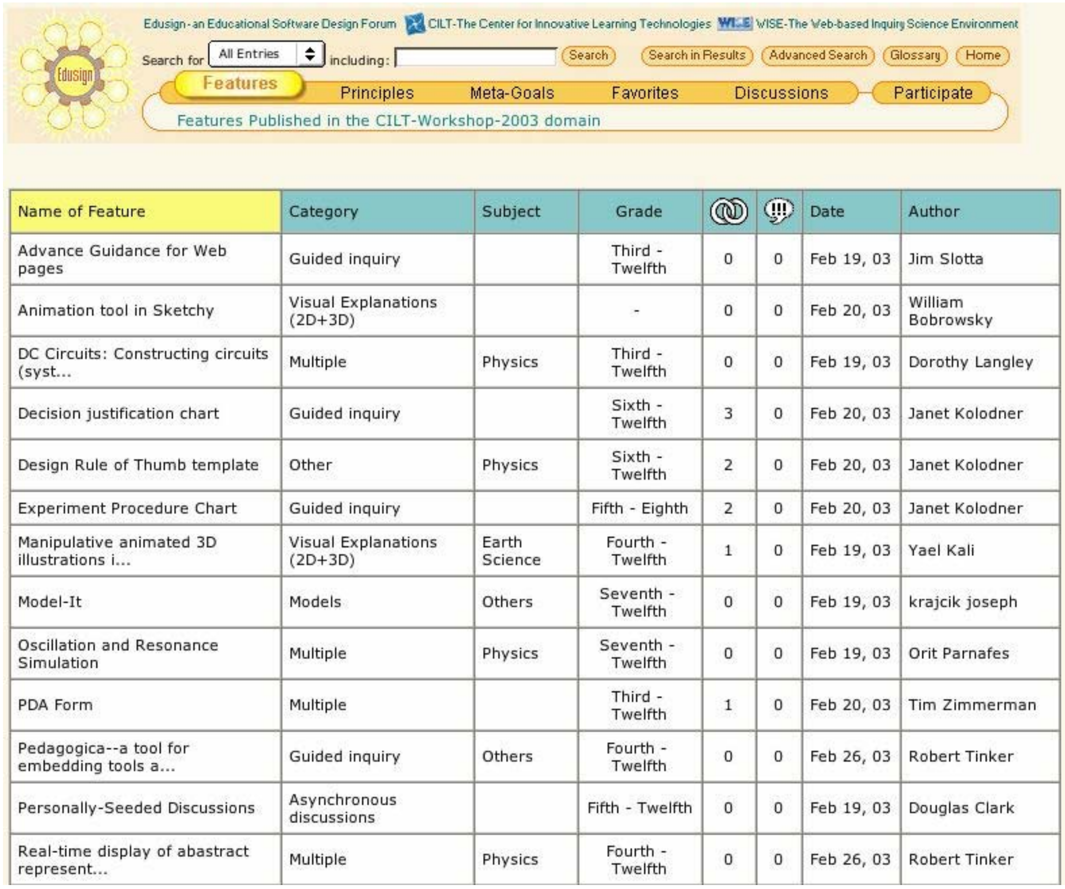
Figure 6. Design Principles in the Design Principles Database



Name of Principle			Date	Author
Charts and templates for complicated reasoning sequences	3	1	Feb 20, 03	Janet Kolodner
collaboration requires something understandable to collaborate about	1	0	Feb 20, 03	Janet Kolodner
Coordination of salient, bridging features between multiple representations...	0	0	Mar 3, 03	Nancy Songer
embed hints and examples into the structural representation of a task AND i...	4	1	Feb 20, 03	Janet Kolodner
Model the inquiry process	5	0	Feb 16, 03	Linn Davis & Bell 2002
Provide dynamic visual aids for the perception of 3D phenomena	1	0	Feb 17, 03	Yael Kali

The database includes two main modes of interaction: a *Contribute* mode and a *Search/Browse* mode. The Contribute mode enables designers to describe features of their software with the theoretical framework and evidence of their success. **Error! Reference source not found.** provides a screen capture of the New Features form in the Design Principles Database. To contribute a feature to the database, a designer is required to provide several pieces of information: a detailed description of the feature, a rationale (i.e., the specific design principle that led to the design of the feature), the context in which the feature is used, evidence of success or lack of success, reference, and an image illustrating the feature. A designer is also required to choose a category or several categories to describe the feature (e.g., visualization tools, inquiry tools, communication tools, ubiquitous computing, etc.), provide URLs for downloads, and connect the feature with a pragmatic design principle. To contribute a pragmatic design principle, designers are required to provide a detailed description of the principle, its goals, limitations, trade-offs, and pitfalls. They are also required to connect their pragmatic principles with meta-principles. In this way, the database can grow while keeping connectedness between features and principles and between principles in the different levels.

Figure 7. Entering a New Feature into the Design Principles Database



Name of Feature	Category	Subject	Grade			Date	Author
Advance Guidance for Web pages	Guided inquiry		Third - Twelfth	0	0	Feb 19, 03	Jim Slotta
Animation tool in Sketchy	Visual Explanations (2D+3D)		-	0	0	Feb 20, 03	William Bobrowsky
DC Circuits: Constructing circuits (syst...	Multiple	Physics	Third - Twelfth	0	0	Feb 19, 03	Dorothy Langley
Decision justification chart	Guided inquiry		Sixth - Twelfth	3	0	Feb 20, 03	Janet Kolodner
Design Rule of Thumb template	Other	Physics	Sixth - Twelfth	2	0	Feb 20, 03	Janet Kolodner
Experiment Procedure Chart	Guided inquiry		Fifth - Eighth	2	0	Feb 20, 03	Janet Kolodner
Manipulative animated 3D illustrations i...	Visual Explanations (2D+3D)	Earth Science	Fourth - Twelfth	1	0	Feb 19, 03	Yael Kali
Model-It	Models	Others	Seventh - Twelfth	0	0	Feb 19, 03	krajcik joseph
Oscillation and Resonance Simulation	Multiple	Physics	Seventh - Twelfth	0	0	Feb 19, 03	Orit Parnafes
PDA Form	Multiple		Third - Twelfth	1	0	Feb 20, 03	Tim Zimmerman
Pedagogica--a tool for embedding tools a...	Guided inquiry	Others	Fourth - Twelfth	0	0	Feb 26, 03	Robert Tinker
Personally-Seeded Discussions	Asynchronous discussions		Fifth - Twelfth	0	0	Feb 19, 03	Douglas Clark
Real-time display of abastract represent...	Multiple	Physics	Fourth - Twelfth	0	0	Feb 26, 03	Robert Tinker

The Search/Browse mode enables users to search for features and principles by using filters that include any of the pieces of information described above. Figure 8 provides a screen capture of the Features window in the Design Principles Database. For instance, a hypothetical browsing path could include a search for all the features in chemistry that are based on inquiry learning for 10th grade. The user of the database could review the features with these characteristics, review the related design principles connected to features, and, finally, review other features from other contexts that are also connected to these same design principles.

Figure 8. The Features Window in the Design Principles Database

Name of Feature	Category	Subject	Grade			Date	Author
Advance Guidance for Web pages	Guided inquiry		Third - Twelfth	0	0	Feb 19, 03	Jim Slotta
Animation tool in Sketchy	Visual Explanations (2D+3D)		-	0	0	Feb 20, 03	William Bobrowsky
DC Circuits: Constructing circuits (syst...	Multiple	Physics	Third - Twelfth	0	0	Feb 19, 03	Dorothy Langley
Decision justification chart	Guided inquiry		Sixth - Twelfth	3	0	Feb 20, 03	Janet Kolodner
Design Rule of Thumb template	Other	Physics	Sixth - Twelfth	2	0	Feb 20, 03	Janet Kolodner
Experiment Procedure Chart	Guided inquiry		Fifth - Eighth	2	0	Feb 20, 03	Janet Kolodner
Manipulative animated 3D illustrations i...	Visual Explanations (2D+3D)	Earth Science	Fourth - Twelfth	1	0	Feb 19, 03	Yael Kali
Model-It	Models	Others	Seventh - Twelfth	0	0	Feb 19, 03	krajcik joseph
Oscillation and Resonance Simulation	Multiple	Physics	Seventh - Twelfth	0	0	Feb 19, 03	Orit Parnafes
PDA Form	Multiple		Third - Twelfth	1	0	Feb 20, 03	Tim Zimmerman
Pedagogica--a tool for embedding tools a...	Guided inquiry	Others	Fourth - Twelfth	0	0	Feb 26, 03	Robert Tinker
Personally-Seeded Discussions	Asynchronous discussions		Fifth - Twelfth	0	0	Feb 19, 03	Douglas Clark
Real-time display of abastract represent...	Multiple	Physics	Fourth - Twelfth	0	0	Feb 26, 03	Robert Tinker

Evolution of the Project

The Design Principles Database emerged from meetings, conversations, collaborative activities, and conferences that occurred between 2001 and 2004. The Design Principles project started as a grassroots movement and gradually grew to involve a substantial number of educational software designers who contributed to the development of the current form of the database. Below is a description of the activities and events that were part of the project and brought the development of the database to its current state. Table 1 summarizes these activities.

Table 2. Summary of Activities in the Design Principles Project

Activity	Participants	Issues	Outcomes/Action
CILT2000	Public	▪ How to synthesize community design knowledge	▪ CILT seed grant to NCSA ▪ Design becomes focus of the VisMod theme
Chicago 2001 workshop	Invited	▪ Grain size ▪ Trade-offs and pitfalls	▪ CSCL workshop ▪ AERA symposium
Leadership seminars 2001–02	Bay Area community + speakers	▪ Validity (what counts as evidence ▪ Design methods	▪ Design for a prototype database
CSCL 2002 workshop	Public/CSCL participants	▪ Embededness (clustering)/ Easy to author—hard to link	▪ Three CILT Seed grants ▪ Clusters of principles
AERA 2002 symposium	Public/AERA participants	▪ Connections to principles in instructional design	▪ Revise the prototype database
Leadership seminars 2002–03	Bay Area community + speakers	▪ Purpose, usefulness, function of the database ▪ Validity/methods	▪ Design Principles Database 1.0 ▪ Seed principles added to the database ▪ Internal review process (as model for peer review)
CILT Online Workshop (2003)	Invited mentors and mentees International teams	▪ Database catalyzes and focuses community synthesis ▪ Need for community criteria and review	▪ Online workshop model for using the database ▪ Features and principles connected in the database
AERA 2003	Public/AERA participants	▪ Contingency and design narratives ▪ Connections to assessment	▪ Institutionalize the online workshops ▪ Establish review board

CILT 2000

The project was initiated at the CILT 2000 conference, at the Visualization and Modeling workshop, led by Marcia Linn (PI), Nancy Songer (Co-director) and Yael Kali (Postdoc). The workshop included about 50 international representatives of schools, industry, university, research organizations (e.g., SRI), and policy-makers. Throughout the workshop, participants raised the issue that design knowledge is distributed among the community and too sequestered. They suggested that a set of guidelines should synthesize knowledge in the field and enable designers to create innovative technology-based learning environments that are founded on principled design knowledge (Kali, 2002). This call resulted in a CILT seed-grant project, "Principles and Guidelines for Design of Technology Based Learning Environments: Construction of an Online Guide," led by two CILT postdocs, Yael Kali and Nathan Bos, and Lisa Bievenue, (NCSA; University of Illinois) (http://cilt.org/seedgrants/visualization/2000.html). This seed-grant project subsequently organized a series of invited face-to-face and online workshops (described below).

As a result of the active role of the VisMod theme team members in this seed-grant project, the Design Principles project became the main focus of CILT's VisMod theme (including Marcia Linn, Yael Kali, Michele Spitulnik, Nathan Bos, Eric Baumgartner, and Co-directors Nancy Songer and Andy diSessa) from CILT 2000 until the culminating CILT poster session at AERA 2003 (http://cilt.org/events/2003/aera_2003_reflections.html). The rationale for this shift was explained in the 2001 annual report to NSF, in which we wrote:

> The focus of the theme team on design, and design principles this year rather than on visualization and modeling, represents a shift of interests in the VisMod field, which was also seen at CILT2000….If in previous years the focus was on different types of usage of technology for VisMod tools, then this year the focus was on synthesis and generalization of the existing knowledge in the field. The impetus for this project was the belief that knowledge about effective design was fragmented between many different development groups. Too often, educational technology projects have duplicated, or failed to learn from each other's work. Partly because our field grew from social sciences, we lack a design orientation and well-established ways to communicate design ideas. This project is laying groundwork for a better functioning design science of educational technology by exploring methods that are appropriate for communicating design ideas, and by beginning the process of collecting and synthesizing the best design ideas currently available. On a larger scale the shift from VisMod to Design principles represents a certain maturation of the field, which we at CILT want to promote, and a real need to create a common vocabulary, and common knowledge, about successful (and unsuccessful designs) in different learning contexts, for further development of the field.

Chicago 2001—Establishing an Initial Framework

The first workshop organized by the Design Principles project was hosted by Brian Reiser at the School of Education at Northwestern University. The workshop included about 30 invited participants from 10 academic and industry institutions (Northwestern University; University of California, Berkeley; University of California, Santa Cruz; University of Michigan; University of Texas; University of Toronto; Intel; NCSA; Riverdeep Interactive Learning; SG Systems). The main issues in online discussions before and during the workshop were the types of building blocks necessary to compare and communicate design ideas. In particular, issues of grain size, discipline focus, trade-offs, and pitfalls of design principles were discussed. Groups compared features and identified common design characteristics. The main outcomes of the sessions were a preliminary framework for communicating design ideas, a poster session at AERA and a public workshop at CSCL (described below), in which these ideas would be elaborated.

Leadership Seminars 2001–02

Between 2001 and 2002, the Design Principles project leaders organized several seminars at UC Berkeley and at the Center for Advanced Study in the Behavioral Sciences, led by Marcia Linn, Andy diSessa, and Yael Kali (e.g., http://kie.berkeley.edu/transitions/history.html). Guest speakers included Alan Collins, Naomi Miyake, Nancy Songer, Cynthia Hoyes, Richard Noss. Other guest contributors included Barbara White, Joe Campione, Kathy Metz, Bob Bjork, Rosemary Joyce, John Bargh, Roy Pea, Chris Hoadley, Alan Baddeley, and Elizabeth Bjork. Discussions between guests, graduate students, and postdoctoral scholars from Berkeley, Stanford, and SRI who attended the seminars focused on articulation of the main issues in creating a design principles database. What counts as evidence and other issues of validity were discussed in detail. The main outcome was the development of a prototype design principles database, which was based on a framework that emerged from these discussions.

Computer Supported Collaborative Learning (CSCL) 2002

At the CSCL 2002 annual conference, we organized a public workshop that hosted approximately 50 international participants from the CSCL community (Kali et al., 2002). At the workshop, interest groups formed around common software features, and the groups were requested to author design principles for these features. Although the structured activity we used for eliciting these principles failed, discussions were extremely fruitful. An iterative process of presenting these ideas was established via three seed-grant projects that committed to author design principles in the following areas:

- Identifying Emergent Design Principles through Analysis of Learning Technology in Action (PI: Jody Underwood, Educational Testing Service. Other collaborating institutions: SRI International; North Carolina State University; University of Colorado, Boulder).
- Building Blocks for Virtual Worlds: Design Principles for a Starter Kit for Educational Virtual Worlds (PI: Katy Borner, Indiana University. Other collaborating institutions: Cornell University; University of California, Santa Cruz).
- Towards Design Principles for Designing a Project-Based Inquiry Learning Environment for Middle School Science (PI: Janet Kolodner, Georgia Tech. Other collaborating institutions: Northwestern University; University of Michigan).

(See abstracts of above at http://cilt.org/seedgrants/visualization).

These seed-grant projects represent the initiation of organizing design principles into clusters, which serve as organizing schemes in the database. Another important outcome from this workshop was our realization that designers find it fairly easy to author new design principles but difficult to create mutual principles that link to others' software features and principles.

AERA 2002

The groups that were formed at the Chicago meeting presented their work at a structured poster session, "Design Principles for Educational Software" that we organized for AERA 2002 (Bos et al., 2002) (proposal at: http://yaelkali.org/design/AERADesignPoster(6).htm).

The session included 10 posters with the following topics:

1. Enable students to make their perspective on knowledge explicit and inspectable (Marcia Linn, UC Berkeley; Brian Reiser, Northwestern University; Nancy Songer, University of Michigan).
2. Provide graphical displays of students' work history (Nicole Pinkard, University of Michigan).
3. Provide multiple linked representations (Hollylynne Drier Stohl, North Carolina State University; Jody Underwood, The Math Forum/Educational Testing Service).
4. Improve asynchronous discussion with multiple-author discussion notes (Jim Hewitt, University of Toronto).
5. Use persistent (server-side) storage as a search aid (Nathan Bos and Joseph Krajcik, University of Michigan).
6. Enable groups to form and disband naturally in an online environment (Melissa Koch, SRI International).
7. Use process maps to describe the space of possible activities for learners (Chris Quintana, University of Michigan).
8. Using the Design Principles Database to inform software design: The construction of the "Rock Cycle" Web-based learning environment (Michele Spitulnik and Yael Kali, UC Berkeley).
9. Design Studies: Enabling rapid cycles of trial and refinement using the WISE design principles (Alex Cuthbert and James D. Slotta, UC Berkeley).
10. What will we do with design principles? Design principles and principled design practice (Eric Baumgartner, UC Berkeley; Philip Bell, University of Washington).

The session, chaired by Marcia Linn and with Yasmin Kafai (UCLA) as discussant, had a standing-room-only audience of at least 100 participants. The main issue discussed among participants was the interconnections between the notion of design principles and the theory of instructional design. These discussions led to further development and revisions in the prototype database and eventually to the development of Design Principles Database version 1.0.

Leadership Seminars 2002–03

During 2002 and 2003, we organized additional seminars for the project leaders to present the ongoing project and elicit feedback from guest speakers and participants of the San Francisco Bay Area community. Speakers included Don Norman, Sherry Hsi, Bill Sandoval, Chris Hoadley, Phillip Bell, Jim Slotta, and Eric Baumgartner. Using Design Principles Database version 1.0, participants contributed their features and ideas as seed principles and reviewed each other's entries. These reviews served as models for the peer review process for quality control of the database. The main issues discussed were the purpose, usefulness, and function of the database, and methods to improve the database.

Online Workshop (2003)

In February 2003, we hosted a 2-week online workshop to support educational technology designers in contributing features and design principles to the Design Principles Database. See Figure 4 for the introductory page to the online workshop. The workshop was hosted and supported through *Blackboard*. Using this online environment, we provided all the directions participants needed to enter information into the Design Principles Database, and it also supported participants' online threaded discussions (for more details, see http://cilt.org/events/2003/design_db_workshop.html).

The participants included 24 educational technology researchers in 10 teams. Each team consisted of a mentor—a leading figure in the field of design—and a mentee—a postdoctoral researcher or graduate student working with the mentor. The teams came from various universities and institutions, mostly in the United States (including UC Berkeley, University of Michigan, Northwestern University, Georgia Tech, Penn State University, Arizona State University, and the Israeli Weizmann Institute of Science). The first week focused on presenting a feature and entering it into the Design Principles Database. Each mentor-mentee team was required to contribute a feature from the software they had developed and present it in a teleconference at the end of the week. Following the presentations of the features, multi-institutional groups of two or three teams were formed to synthesize pragmatic design principles that connected their teams' features. These groups entered their principles into the Design Principles Database.

The second week focused on building cross-linking design principles, principles that cut across the 2-3 features. In the second teleconference at the end of the second week, each group presented the design principles that they had synthesized.

The workshop resulted in the addition of 21 new features and 6 new design principles to the database. More important, however, was the learning that happened with respect to how to support contributions to the database and how to support a community of designers. An analysis of this workshop comes later in this report.

AERA 2003

At AERA 2003, we organized another structured poster session that included presentations of the three seed-grant projects established after the CSCL workshop and design principles generated during the online workshop. The session was named "The CILT Design Principles Database: A New Form of Synthesis for Technology-based Curriculum Design" (http://cilt.org/events/2003/aera_2003_designdb.html). The main purpose of the session was to share, critique, and find connections between the sets of design principles discussed by each of the projects. We also sought to discuss the framework and the general infrastructure with the audience as means for synthesizing knowledge in the field of educational design. The session, which brought together 70 curriculum designers, researchers, and other participants looking for innovative forms of synthesis in the educational design field, was chaired by Marcia Linn and Yael Kali, with Nora Sabelli as discussant.

Figure 9. Welcome page of Design Principles Online Workshop

Five posters were presented:

1. Design Principles of the ESCOT Math Environments (Jody S. Underwood, Educational Testing Service; Christopher Hoadley, SRI International; Chris DiGiano, SRI International; Hollylynne Drier Stohl, North Carolina State University).

2. Design Principles for Educational Virtual Environments (Katy Börner, Indiana University; Margaret Corbit, Cornell University; Bonnie DeVarco, VLearn 3D SIG of the Contact Consortium).

3. Design Principles for Project-Based Inquiry (Janet L. Kolodner, Georgia Tech; Brian Reiser, Northwestern University; Danny Edelson, Northwestern University; Joseph Krajcik, University of Michigan; Ron Marx, University of Michigan)

4. Design Principles for Ubiquitous Computing in Educational Settings (Michele Spitulnik, CILT/University of California, Berkeley).

5. Community Tools for Learning and Development (Jim Gray, CILT/SRI International; Melissa Koch, SRI International).

The main issues that were raised in the discussion with the audience were the relationships between design principles and design narratives and the connections between design principles and standardized assessments. This session culminated the efforts of the CILT Design Principles Project. The interest generated at the session and the previous related activities demonstrated the need to continue developing the Design Principles Database and supporting the design-based research community.

Research Activities

The Design Principles Database and the activities surrounding its construction provide an opportunity to better understand how design knowledge is synthesized in the field of learning sciences. We set out to understand how the Design Principles Database and, in particular, the online workshop promoted community building and synthesis of design knowledge. In one study (Kali, Spitulnik, & Linn, in preparation), we examine how the activities of the workshop and the framework embedded in the Design Principles Database support designers in sharing and synthesizing their knowledge. We briefly summarize the methods, analyses, and findings of this case study.

Case Study Methods and Analysis

Our analysis centered around the following research questions: How did the Design Principles Database and the activities of the online workshop support designers in (1) contributing new features to the database and (2) synthesizing new design principles between several features. To answer these questions, we analyzed several data sources available from the Design Principles Online Workshop, including records of the online discussions, transcriptions of the two teleconferences, the features and principles contributed by participants, and transcriptions of interviews with three workshop participants.

We coded and categorized the online records and teleconference transcriptions and searched for common patterns in participants' contributions to the discussions. The categories that emerged from the analysis include:

- *Describing* a feature (also functionality and context of use).
- *Explaining* a feature (providing rationale, frameworks, beliefs), or asking for explanation of a feature.
- *Linking or referring* to other features (comparing, contrasting, or asking for comparison).
- *Analyzing* a feature (examining a feature in terms of emergent features and principles).
- *Application* (providing examples related to the application of principles).
- *Theorizing* (posing claims/questions, referring to research in the field, relating the emergent ideas to existing theory).
- *Synthesizing* (grouping, finding commonalities, beginning to describe principle, introduction vocabulary, emergent criteria for principles).
- *Meta discussion* (discussing how principles should be thought about).

To gain deeper insight into the ways design knowledge was synthesized, we focused our analysis on three case study groups. The groups were chosen on the basis of the breadth of the online discussion in which they synthesized their mutual design principles.

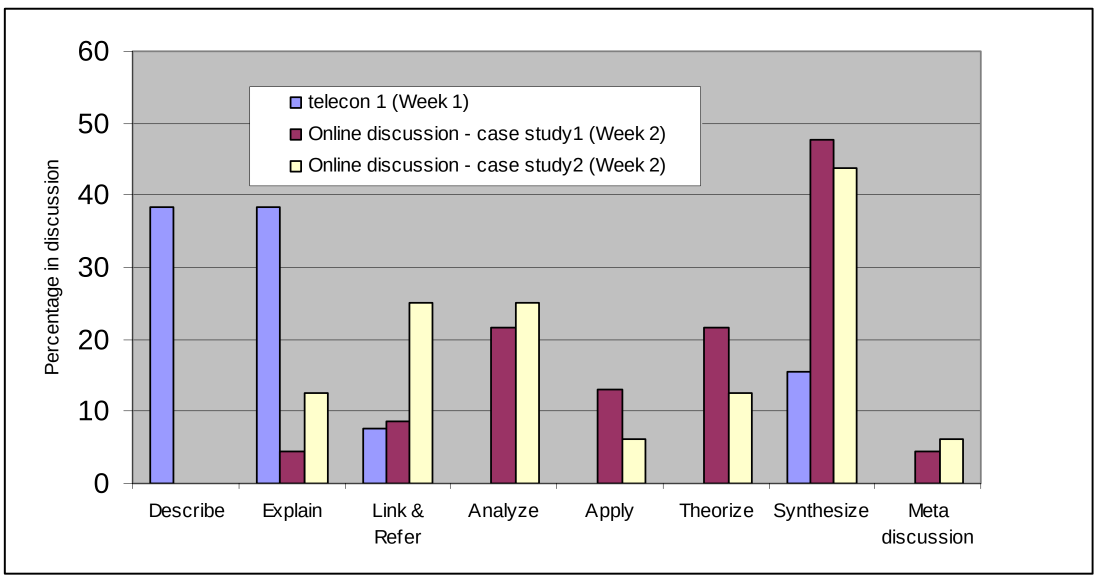
Case Study Findings

The findings are grouped in three areas: (1) the ways participants communicated their features, (2) the ways participants synthesized design knowledge and obstacles in this endeavor, and (3) strategies for leveraging contributions to the database.

Communicating features. The discourse in week one was characterized mainly by participants' descriptions and explanations of features. This pattern is manifested in the abundance of the Describe and Explain categories in Figure 5. When asked to share features at the teleconference, participants frequently intertwined descriptions of a feature's functionality and its context of use with explanations of their rationale in designing it and their theoretical commitments. This finding supports our design decision to embed the rationale within the feature description page in the database.

Synthesizing design knowledge. The discourse in week two of the workshop was characterized by references to other teams' features and by efforts to synthesize design ideas. The representative discussions provided in Figure 5 indicate that participants were more engaged in comparing and linking their features, grouping features into emergent principles, analyzing features in terms of the emergent principles, providing examples from their own research and from related research, and having meta-discussions about principles. This difference can be explained by the different nature of tasks in week one versus week two. The first week of the workshop focused on sharing features, and the second week focused on a collaborative synthesis of design principles. Thus, much of our analysis focused on the second week, so that we could study the ways participants synthesized their design knowledge.

Figure 10. Categorization of sample discussions, Weeks 1 and 2 of the workshop



Our analysis shows that group efforts to synthesize design principles that cut across several mentor-mentee teams yielded different degrees of productivity. Some groups seemed to have convergent discussions that eventually led to well-defined and robust design principles, while other groups' discussions were more divergent. One of our most salient findings, which emerged from the detailed analysis, is the need for groups to negotiate a shared vocabulary.

We describe this need as an obstacle to building design knowledge and contrast the ways participants dealt with this obstacle. Groups that were more productive made a special effort to negotiate meanings of design ideas. They asked for specific explanations of each other's features; they suggested and refined design principles; they questioned diverse aspects of emergent principles; they searched for links of these aspects with their own features and their colleagues' features; they connected emergent ideas with examples and theory; and, finally, they had meta-discussions about the ways design principles should be thought about. This negotiation led to gradual development of a common vocabulary within a group and to gradual refinement of a robust, well-defined design principle.

Leveraging contributions to the database. Interviews conducted after the workshop indicate that activities that require designers (who already put their features and principles in the database) to connect, contrast, and find gaps between their ideas and contrasting ideas are highly effective in leveraging designers' contributions to the database. Interviewees were asked to explain how their principle is different from a related principle in the database, whether it contradicts another principle, and whether it can be tied to some of the other features in the database. Careful examination of their answers shows that designers made significant refinements of their principles (usually to clearly distinguish them from other principles). They also elicited ideas for new features in their own designs and in those created by other designers. In addition, they raised questions that can serve as important research questions in the design field. We anticipate that such type of questioning can stimulate communitywide norms and standards that are likely to make design decisions more evidence based and ultimately more effective.

Next Steps

The outcomes of the study indicate that the Design Principles Database has the potential to serve crucial functions in enabling the field to synthesize the creative contributions of its members. The database can serve as a medium to document design advances and support designers' rationales with a language that connects to rich, powerful examples of important accomplishments in the field.

To take advantage of this potential, we need more activities like the CILT Design Principles Online Workshop that bring designers together to synthesize their knowledge. We also need to explore the role of an editorial board that would look for overarching connections and discontinuities to ensure the quality of the database. We envision the role of the editorial board members as identifying gaps, overlaps, and contradictions in the database, and initiating public discussions around them. Such discussions are likely to leverage design principles, elicit new ideas for software features, and raise new research questions that will advance the educational software design field.

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A Doorway to New Tools and Practices: Supporting Teacher Education, Research, and Development with an Online Netcourse

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About the CILT-PT3 Netcourses

To help advance knowledge and practice in learning sciences, the CILT postdocs undertook to develop and deliver the following online "Netcourses" in eCILT's four theme areas:

1. Technology Supported Assessments (Jason Ravitz, Assessments for Learning)
2. Supporting Student Inquiry (Michele Spitulnik, Ubiquitous Computing)
3. Computer-supported Group Work (Nathan Bos, Community Tools)
4. Culture, Cognition, and Technology (Jim Gray, Community Tools)
5. Uses of Technology for Teaching Spatial Visualization-based Content (Yael Kali, Visualization and Modeling).

Goals for the Netcourses included giving technology leaders in the Department of Education's program, Preparing Tomorrow's Teachers to use Technology (PT3), an introduction to emerging technologies for learning. Because of the online delivery mechanism, participants could show what they were learning to others and potentially reuse parts of the Netcourses in their own institutions (Bransford, 2001; Wiley, 2000).

Before designing and moderating the courses, postdocs took a 12-week Netcourse from the Concord Consortium on methodologies for facilitating online discussions about "moving out of the middle" in a way that supports learning, as taught at the Concord Consortium (concord.org) and Metacourse.com and described by Collison, Elbaum, Haavind, and Tinker (2000). Activities and discussion prompts in this model are informed by an understanding that teacher-focused discussions are typically overwhelming for the teacher and often underwhelming for the student in online settings. The Netcourse designs also sought to maximize the benefits of discussions by using a "structured asynchronous" format (Collison et al., 2000) that gives participants a week to think about what they and their colleagues are doing and saying.

The TSA Netcourse

Technology Supported Assessments (TSA) lasted 6 weeks and ran twice, in the spring and summer of 2001, as part of a U.S. Department of Education PT3 Catalyst Grant involving the Concord Consortium in Concord, Massachusetts, and the University of Virginia. It was structured around weekly Readings, Activities, and Discussions (RAD) initiated by the instructor. Each week, the class read about and made use of one of these research-based tools and discussed its applicability to their work. The syllabus with a list of readings and activities is available online (http://www.bie.org/Ravitz/syllabus.html).

Netcourses like this can serve as a portal, providing multiple entry paths, to new tools and practices. They can make it easier for educators to learn to use online tools and easier for developers and researchers to study this use. One can envision the same Netcourse approach used in different instructional environments, not just *Blackboard*. The designs here took advantage of the functionality in *Blackboard*, but they only require access to Web-based tools and documents and to online discussion capabilities.[19]

In summary, Netcourses can offer a series of "doorways" to various online projects or tools and easy ways to track new users through their participation in the course. The rest of this paper explains how this design can be used to help educators and teacher educators, as well as developers and educational researchers.

Helping Educators and Teacher Educators

The conceptual foundation and educational goals of the course rested on two points:

- The first key point for participating educators that was emphasized throughout the course was that providing timely feedback to learners may be the most essential instructional strategy. "Learning gains from systematic attention to formative assessment were found to be greater than most of those for any other educational intervention" (Black & Wiliam, 1999; see also Bransford, et al., 1999; Rose & Gomez, 2003; Shepard, 1995; Stiggins, 1997).
- The second key point for participating educators is that technology-supported tools offer exciting opportunities for improving formative assessment for teaching and learning. Technology-supported assessments that were reviewed by the class via the Internet included IMMEX (Underdahl, Palacio-Cayetano, & Stevens, 2001), Intelligent Essay Assessor (Foltz, Laham, & Landauer, 1999), CRESST's Knowledge Mapper (Baker, 1998; Ruiz-Primo, 1999), and the Analysis Toolkit of Knowledge Forum (Lamon, Reeve, & Scardamalia, 2001). In each case, there is reason to believe that technology can support teachers and learners through better formative assessments of learning.

In addition to being given instructions for trying a new tool each week, participants also read about the learning theories and research that supported use of the tool. The following quotes and many others suggest that teachers are learning about the key points: the value of formative assessment and how technologies can help.

> I liked the feature (discussed in the article) that identifies anomalous essays for human reading. This technique accommodates the student who takes a non-standard approach to the topic and gives room for individual style and perspective to be treated fairly.
>
> I like the idea that students can assess their work with the system before submitting it for teacher review. This is the kind of control students never had with traditional methods of evaluation, and one that should help empower them while providing teachers some relief.

These quotes also demonstrate that participants are applying what they learn in the readings to their use of the tools. Research suggests that providing structure for learning about online resources, as is done in this Netcourse, is a major improvement over "discovery learning" that

[19] This is an important point because for some developers of reusable materials having to go into *Blackboard* is probably antithetical to what they are trying to do. This does not negate the value of the proposed approach.

might occur otherwise (Mayer, 2004). For additional examples of professional development efforts that involved teachers providing critical review of online resources, see Bannan-Ritland, et al, 2000; Chitwood, et al, 2000; Orril, 2000.

Helping Developers

In the Netcourse, tool providers saw a unique opportunity to interact with educators. Creating a "doorway" to their tools that brings well-informed educators their way is valuable to developers, who are often keenly interested in obtaining high-quality user feedback and design suggestions, or exploring opportunities for extending use of their tools to new audiences. When online feedback is provided as part of pedagogically guided and structured inquiry and the educators who provide feedback are available to discuss and clarify their responses, their contributions have added value.

Several of the tools in the Netcourse did not yet have complete user documentation and training systems in place for online users. For this reason, the developers were particularly keen to see how someone else could teach others to use their tools via the Internet or how someone might manage with scant documentation.

The rest of this section discusses the costs and benefits of the TSA Netcourse design for developers.

To varying extents, special arrangements were needed to support the class. Additional collaboration with developers was required in order to:

- Secure passwords and login access to the tools when necessary.
- Modify a current instructions Web page.
- Secure technical support during the week scheduled for use.
- Obtain or create instructions for using the tool.
- Provide perspective on available readings and research, including discussion prompt ideas.
- Explain opportunities for extending use to interested educators or institutions.

Generally, there was someone from each research and development group who was available to help in these areas. Sometimes there was a researcher, a technical support person, or a professional developer who expressed interest. They were pleased to participate as "guest experts" in *Blackboard* during their assigned week. They monitored and responded to the progress of class participants, offering insights about their work and seeking suggestions on the best way to share it with educators. Some of this happened on the class discussion board where others could see. Sometimes the instructor discussed issues with the developers offline and summarized for the class. One exception communicated only with me in a very helpful manner, but never joined *Blackboard*.

The following is a comment from a developer to the class.

> Hello. Dr. Ravitz invited me to join your discussion group so that I can address any questions that might emerge from your participation and experimentation with our software. So, hello. [snip] While the scoring feature is in place to encourage efficiency and to simulate real world situations, most teachers do not typically pay attention to score in the first few performances of their students. In fact, most teachers tell their students that, initially, they should explore the problem space thoroughly (open up all those little rectangles) so that they know what is available and can make informed decisions in subsequent attempts . . . Have fun with the problem-sets.

In return for the small amount of time spent working with the course author, various developers saw evidence of the following:

- Teacher educators using their tools in their own local PT3 workshops.
- Teachers trying tools with new audiences, e.g., different ages or subjects than described.
- Generation of substantial amounts of user data.
- Evidence of the discussion being informed by their published literature.
- Design suggestions from users, as well as possible bug reports.
- Descriptions of the learning curve for different tools.
- Endorsements and testimonials, like "my kids would love this."
- Teachers overcoming initial hostility to technology—e.g., automated essay grading.

Developers seemed to value hearing about the experiences of educators who were trying their tools for the first time. Perhaps they recognized with Recker, et al. (2002) that obtaining worthwhile feedback from Internet users is very difficult. With little effort, developers can obtain "fresh eyes" on a recurring basis—e.g., potentially every 6 weeks if TSA ran continuously. It would seem to be ideal for developers who are using a "rapid prototyping" or iterative approach to design if they could obtain formative evaluation data from each new cohort that would provide a review of their latest work.

The following quotes illustrate that the Netcourse allowed tools that were presented to be taken up and used, or considered for use, with a variety of new audiences.

> What I would like to do is demonstrate this course itself and the tools which I have been exploring to a small group of faculty registered for the four-day institute next week. None has taken an online course. None has used any tools like the ones we are examining.
>
> Thinking of my second and third grade emerging writers an evaluation tool such as this would have helped them to better develop their essays while freeing me to facilitate more advanced learning.
>
> The director of [our high school's] placement testing program and the director of the writing program (supporting and developing writing intensive courses) just brought in

> their essays on college and long-term life success for LSA evaluation and discussion. . .Whom should we contact if we want to know more?
>
> I sent the site to two of our English professors and am anxious to hear their comments and/or reactions! I would like to experiment with this with my students.

The last three quotes followed experimentation with an online demonstration of automated essay grading—specifically, an essay about college and career planning for high schoolers. It is worth noting that participants at the elementary, high school, and college levels all expressed interest in having such a tool available.

Another apparent benefit was the provision of user feedback, including design suggestions and bug reports. Two examples follow:

> "You might have said more," doesn't provide very clear guidance to a student. Is there the possibility that a teacher can customize the comments section for more specific feedback?
>
> Well, I got frustrated quickly (not with the program but with the topic) so I decided to just guess. My first attempt was wrong so minus 100 points. My second and final attempt also came up as wrong so minus another 100 points—GAME OVER. However, when I journeyed on to the epilogue, the little story said that my second guess was indeed correct. What's going on with that? On a different note, my first reaction is that this activity felt like a game, I imagine that students (middle and high school) would enjoy it a great deal.

Although no substitute to developing their own user communities, the above quotes demonstrate that with a little collaboration from teacher educators, developers could help supplement data collected through the costly and time-consuming process of developing their own development sites.

Helping Research and Evaluation

In this section, we discuss benefits of the TSA Netcourse design to researchers and evaluators. Creating Netcourses in educational technology has the potential to generate a wellspring of knowledge about teaching and learning with technology, not just among individual learners, but across the field. Using the formative assessment component of the tools in TSA, educators could see analyses of their own performance. Their participation in the Netcourse produced artifacts that could be saved and compared with others. Their participation could offer developers access to new sources of pilot and user-testing data. In addition to the data produced by educators, their discussions contain information about how teachers think about assessments of learners and about technology.

Access to data from diverse users could help researchers understand the value of their tools to different populations. Although tool providers may increasingly offer their own Netcourses, the TSA Netcourse is unique in that it presents numerous tools to diverse audiences for comparison. This approach could help identify for whom and under what conditions different online tools and resources are likely to have an impact. Developers could use the Netcourse as a way to experiment with populations of users that they cannot support on their own—e.g., teachers of slightly younger or older students. They may be able to ask questions of these "distant" audiences that they would not want to ask at their own pilot sites. They could also guide data collection and discussion in the Netcourse toward answering central research and evaluation questions.

The following quote demonstrates the ability to of this approach to generate large amounts of data, not just from original Netcourse participants but from their reuse in their local institutions.

> Faculty benefited from working together this morning during a Faculty Institute presentation. Earlier [someone] wrote she thought middle and high school students would enjoy the program. Another talked about "stressing out" as they worked to resolve the question… Well [here you should have seen] twenty instructors—including two nursing faculty, two chemists, and two biologists—sitting around four tables learning about this biology problem.

The Netcourse provided a wealth of qualitative data about the use of different technology-supported assessments, but it did not collect systematic data for comparing the experiences of educators with the different tools. One way to address this issue would be to review tools by using a common framework for judging qualities of technology-supported assessments. Such a comparison could be based on a conceptual framework for teachers that would support long-term understanding (West et al., 1991). One effort that could lead to such a shared framework is the establishment of a database of design principles (Kali, et al., 2002). Using these principles, or another basis for comparison, one class could focus on user interface issues; another may focus on evidence of student impacts; it does not matter. One can envision Netcourses with tools and methodologies related to topics other than assessment—e.g., interactive gaming experiments (Bos, 2004) or Causal Mapper tools (2003). Having educators share their artifacts from and analyses of online resources would help meet the call for a decade of rigorous educational technology scholarship (Haertel & Means, 2000).

Discussion

Participants in the Netcourse were leaders in their institutions. They were able to reuse modules as professional development instructors in their organizations. Sometimes, participants became particularly interested in one tool that had special applicability for them. Questions arise about how flexibly one can experiment with reuse of one part of the Netcourse—that is, without requiring enrollment in the full Netcourse. A recent FIPSE grant received by the Buck Institute for Education to provide online project-based learning training (www.pbl-online.org) is experimenting with making parts of the course available to those who do not want full credit for participation.

Looking toward the future with ubiquitous computing, one imagines that handhelds could extend the observation and feedback of educators who are using particular methods—away from the computer screen and into the classroom or field. In this way, online teacher professional development may continue to advance scholarship in learning by providing a "doorway," not just to online tools and methods but into classrooms and communities.

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Assessments for Learning

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Assessing students' learning is a vital component of our educational system, but using it as a learning opportunity is fundamental. The leadership of the Center for Innovative Learning Technologies (CILT) recognized the need to focus on the issues and opportunities related to assessment in education and the potential role technology can play to support it. In 1999, the CILT Technology Support for Assessment Theme conducted its first workshop to establish a community interested in developing the next generation of innovations for the field and generate seed grants to begin work to achieve this new vision. The workshop brought together a diverse group of expertise in educational research, cognitive science, standardized assessments, teaching and developers of commercial products to discuss the current state of the art of assessment and define the short and long term goals of the theme. The group highlighted that assessments of student learning provide vital information about our educational system that assists policy makers, administrators, teachers, parents and other consumers of this result to make important decisions for our educational system. Therefore, defining reliable and verifiable assessment methods and analysis techniques are critical. Also, technology can engage students in learning activities that allow them to express the complexity of their understanding in different ways. Several of the participants had powerful examples that illustrated the possibilities. Finally, the group highlighted the role of assessment to improve student learning as a fundamental component of instruction. This focus on the learner and instruction is what captured the imagination of many of the participants.

Black and Wiliams' (1998) recent article illustrates how formative assessments can result in the strongest learning gains compared to other form of instructional interventions. Bransford et. al. (1999) emphasizes that effective learning environments focus on the knowledge to be learned, on issues related to the learners acquisition of the knowledge, and on assessments to monitor students' level of achievement of this knowledge. The emphasis on learning, instruction and assessment became a strong focus for many of the participants at the first workshop. Also, the focus on student learning has a stronger alignment with the goals of the other thrusts. Therefore, the theme was renamed to Assessments for Learning to capture the current vision of the theme.

The concentration on Assessments for Learning raises a number of questions such as, how is instruction designed to include effective formative assessment in a classroom? How is formative assessment used outside the classroom? How can technology support the formative assessment? How can teachers adapt their instruction to include formative assessment in their instructional practice? The work of the CILT leadership and the AL seed grants organized a number of projects over the years to explore issues related to each of these questions. This report summaries this work by organizing the discussion around major areas including:

- The establishment of learning environments that use formative assessments (network technology in classrooms to improve student conceptual understanding)
- The assessment of students preparation for future learning—knowledge, problem solving, discourse and collaboration

- Future directions for assessments for learning by expanding our learning objectives we want to measure with technology.

Each section attempts to expand on the meaning formative assessment, its relationship to instruction and the impact on teaching.

Establishing Learning Environments that Use Formative Assessment

A decade old technology called Classtalk (Abrahamson et al., 19989) provides an elegant example of how technology can be used to engage a large number of students in learning difficult concepts. Instructors in physics and chemistry have used small handheld devices that allow students to respond to a professor's questions during class. For example, Mazur (1992) would pose questions that required a qualitative application of physics principles. Students would answer the multiple choice question using a small handheld device that was connected to the instructor's computer. The computer could rapidly aggregate the data and present the result in the form of a histogram for the entire class to see. Good pedagogical questions would result in a large variance in the student responses. This served many purposes. First seeing the results helped students realize that they might not really know the answer and that they are not along. In addition, it helps the professor see that the class still needs more instruction and can use this opportunity as a teachable moment by starting a class discussion about the rationale for why one answer is more appropriate that another. Or students could turn to their neighbor and try to explain to them why their answer is right. This process of responding to the question, obtaining feedback and then explaining their answer requires students to be much more generative in their learning experience and to take action to refine their thinking. Also, in some situations the process of generating an explanation helps students articulate questions they need to address in order to answer the question better. The students may be primed to learn through a lecture now that they have struggled with a problem and identified what they need to know.

The Classtalk technology later acquired by Texas Instruments has progressed toward simple wireless units that are inexpensive for schools and college departments to purchase. Therefore, more and more schools are experimenting with using them. The students report enjoying the immediate feedback and the instructors are often amazed when the student displays misconceptions even when the instructor gave an outstanding lecture on the material. However, the addition of this technology introduces several new dynamics to an instructor's pedagogical methods which may require adaptation. First, the construction of interesting questions that engage students is not a trivial task. Also, instructors may have a difficult time knowing what instructional activity to use to remediate students' misconceptions. The addition of more information can pose interesting opportunities for learning and new challenges for instruction. However, the simplicity of the technology reduces the overhead for entry into using formative assessment methods into a classroom, which provides an excellent starting point for many teachers.

More advanced technologies are emerging to allow student to also respond to short, or long, answer questions (e.g., silicon chalk (2003)[20]; keneducation (2003)[21]; VSAS, Rosselli and Brophy, 2002). The use of short answer increases the complexity of what students need to generate for

[20] http://www.silicon-chalk.com/Documentation/WhitePaper-Vision.pdf 2002
[21] http://kenyan.8m.com/keneducation.htm

an answer. Instead of recognizing an answer from a list of possible choices, now students need to articulate a response to the question. For example, in a computer science class student could create short programs using basic fundamental constructs, such as, looping using either a for, while or do statement. Roselli conducted a class session with 120 computer science students each with a laptop running SiliconChalk software. Rosellii gave the students several minutes to write the code, then their submission were sent to his computer. He was able to quickly scan for examples of common errors, then asked various students to comment on the strengths and weakness of the various approaches. Although the results are preliminary, he found the students had scored much higher on their second exam than in prior years. In addition, he felt he was able to cover more material because the students have mastered these basic concepts earlier in the course. The use of formative assessments may take more time to give students feedback when they are having trouble; however, the improvement of learning by more of the students could lead to more coverage of the materials and overall deeper understanding.

The Assessment for Learning Theme sponsored a seed grant to Abrahamson to write a small NSF grant to organize a workshop to shape the research and vision for these technologies. The first round was not successful, but Abrahamson teamed with Roschelle at SRI to resubmit and the conducted a workshop in March of 2004 called CATAALYST (Penuel et al., 2004). Participants in this workshop included instructors who use the classroom communication systems, educational researchers and several commercial vendors of these systems. Although many in the group had years of experience using the technology many of the participants had not met each other. This meeting served as an excellent opportunity to compare ideas and to discuss a research and technical vision for the future. Also, it opened the range of possibilities for thinking about the kinds of activities can be used to ask students to generate and receive feedback. For example, Wilensky, Stroup and Kaput have been working on participatory simulations as a pedagogical approach to using the systems described above. However, now students make decision about how to behave in a simulation, then class time is used to make sense of the observations students make when the simulation is running. This illustrates yet another level of conceptual complexity that increases both the necessary domain knowledge and pedagogical content knowledge of a teacher.

These systems demonstrate great potential for supporting students' learning and facilitating teacher mediated classroom activities. The increased capabilities of the technologies lead to opportunities to engage in even richer learning activities that target deeper conceptual understanding. However, with the increased capabilities come an increase in equipment, cost, and pedagogical knowledge necessary to make it work. However, the potential outcome for student learning is huge.

Structuring and Assessing Students' Discourse and Writing

Verbal and written literacy is at the foundation of all our learning activities in school. Students who have certain literacy abilities can begin to express their reasoning and argumentation using their language skills in classroom discourse or through a computer with a keyboard or digital pen. The Assessments for Learning Theme funded seed grant participants to evaluate methods for facilitating students discourse as the class attempts to build new knowledge within a domain, and to define the issues associated with designing instruction to make it a natural part of the teaching process.

One seed grant by Goldman and Duschl (2000) compared structured classroom discourse with structured on-line discourse to track the evolution of students' development of inquiry and argumentation skills. Teachers in the Project SEPIA (Science Education through Portfolio Instruction)[22] guide classroom discourse using a variety of prompts to engage students in a systematic inquiry to investigate scientific phenomenon such as buoyancy. In this classroom learning environment, the curriculum unit uses instructional methods designed to maximize the opportunities for formative assessments (Duschl & Gitomer, 1997). Teachers are able to encourage students to articulate their understanding of specific concepts, then work with the class to build and refine this understanding to a more formal level. Similarly, teachers in the Schools For Thought (SFT, Zech et. al., 2000) project used a software program called Knowledge Forum (KF) (Scardamalia et. al., 2003) to support students' online discussions. In the Knowledge Forum learning environment students' inquiry is guided by metacognitive prompts similar to the verbal prompts teachers would use in the SEPIA learning environment. Several hypotheses about the advantage of the KF are, 1) the process engages all the students, 2) the students can articulate their arguments in pieces that are represented as discrete objects on the screen, such as, "My theory is…", then they can rearrange these pieces as they refine their thoughts, and 3) teachers can inspect these records and increase the level of discourse in these discussion areas. The KF technology provides students with a tool to help them maintain their line of reasoning from one class session to another, and provides a permanent record that can be analyzed by researchers. Both the SEPIA and KF learning environments include the use of formative assessments as a natural part of their pedagogical method. Therefore, teachers develop their ability to interact with their students to build their knowledge about a concept and their inquiry skills. The comparison of instructional methods provides vital information for how to structure classroom discourse and methods for teachers to guide instruction to specific learning goals. This deconstruction of the process could provide important insights on how to automate the analysis process to assist new teachers who are still learning how to manage effective discourse in the classroom.

Duschl and Goldman used a second seed grant to investigate the potential of automatically evaluating discourse using latent semantic analysis (LSA, Landauer et at. 1998). LSA is a statistical method for comparing text passages that has captured the imagination of many CILT investigators. The most popular application had been to grade essays that students construct as part of Educational Testing System's (ETS) collection of standardized assessments. The process compares students work with a large database of writing samples around the same topic area. A statistical correlation between all the passages provides a similarity index indicating how well the students match the more expert writing. Duschl and Goldman wanted to leverage this technology to compare students' works in the large database of students samples stored in the Knowledge Forum database. The size of the seed grant limited the ability to create a prototype of this system. However, the design team was able to work with the company exploring the commercial potential of the technology to identify the issues and opportunities for accomplishing this vision for the formative assessment tool. As more financial and personnel resources become available, then the project may be able to be pursued further to investigate the viability of this approach.

[22] http://www.udel.edu/msmith/sepia.html

Several other seed grants were funded to explore formative assessment opportunities in emerging technology such as on-line discussion forums (less structured than KF) and shared white boards on wireless tabletPC technologies. Cuthbert et al. formed a partnership with several investigators to establish a shared set of criteria and dimensions for analyzing on-line discussion spaces and constructing tools to support the learning process. In this learning environment the specific context and role of a mediator are not as well established as in the Ducshl and Goldman study. Research shows that the discussion areas can be viable learning spaces, but what are the specific conditions for learning that this technology is supporting and how can it be analyzed to provide an indication of learning by individuals and the group? Therefore, this team of researchers forged new ground to open the investigation and began to frame the research in the field.

Another interesting emerging technology is wireless tabletPCs that can easily share information in real time. The pen input device provides a natural and efficient mechanism for learners to express themselves with both words and pen gestures during face-to-face discussions. AL cosponsored a grant with Ubiquitous Computing (UC) to understand how a group can share and merge their ideas with this technology. This seed grant tested the usability of the system with a group of students engaged in a design activity. The use of the technology presents an exciting new research area to understand how the simultaneous expression of thoughts through verbal conversation and non verbal actions by all the members of the group enhance the expressiveness of the conversation and the knowledge co-constructed by the group. These kinds of group dynamics have not been studied and need to be understood in ways that we understand the pedagogical support for scientific discourse in SEPIA classroom and Knowledge forums. The ubiquity of wireless and mobile technologies is progressing and research needs to be conducted to investigate its potential in facilitating the real time interactions between students engage in face to face conversations and facilitated by a competent teacher.

Developing Adaptive and Dynamic Assessment for Learning

The focus on assessments for learning is of critical importance to designing learning and instruction. Also important is having clear learning objectives for students and instructional methods that prepare learners for future learning. This section shifts the focus a bit from straight formative assessments to explore new dimensions of assessment that are needed to be part of our educational focus and integral to our instructional methods.

Standardized assessments have long been in the public discussion because they play a dominant role in making important decision including educational policy, funding for schools, teachers' merit pay, where parents choose to live etc. These tests provide a reliable indicator for the success of our educational system to prepare students to achieve the learning outcomes measured by these tests. Researchers with these testing companies, e.g., ETS, have defined innovative test questions that target various levels of students' language literacy, analytical abilities, computational skills and reasoning strategies (e.g., Bennett, 1998). Therefore, these tests can be an assessment of students' learning of basic skills valued by the public. For example, the Third International Mathematics and Science Study (TIMSS,1996) illustrates that US students lag behind the rest of the world on certain portions of the mathematical and scientific understanding items. Many of the test items (that have been released) are designed to test students' abilities to answer multi-step problems requiring the use of relationships between properties and symbolic computation in order to achieve a correct answer. However, what is uncertain is to what extent might these kinds of tests measure all the abilities we value as expressed by the national standards such as the mathematics standards defined by the National Council for Teaching Mathematics (NCTM, 1989). One seed grant sponsored by the Assessments for Learning theme designed a method to align test questions, like items from the TIMMS, with cognitive strategies that are expressed in national standards (Koedinger and Seeley, 2000). This work served several purposes. First, it confirmed that the TIMSS targets important outcomes of learning by our students. Therefore, we can use these items to help identify where our students need assistance based on the items they are lagging on. Second, this gives instructional designers and technology designers, assistance in identifying what skills to target in their instructional design and potential measure they can use to evaluate the potential of their innovation to improve students' learning. Standardized tests clearly provide a needed service to assisting our evaluation of students learning for a range of abilities.

A general concern about relying on these summative assessments is that they can mask our vision for how to achieve higher goals for our educational system. That is, our goals for instruction may focus too heavily on strategies for good test taking rather than developing the necessary cognitive and life skills necessary to succeed later in life. Therefore, without clearly defined learning outcomes beyond these test indicators of students' learning our teachers and administrators may tend to focus on the results of these tests to guide their decision making for how they teach and how they allocate funds. The issue is not that standardized tests are poor measures, invalid, or do not measure valued outcomes. The problem is that the tests measure only a portion of the desired outcomes for educational system, which may lead to an imbalanced focus on highly specialized knowledge that does not transfer well to contexts outside of school. Also, the results of these tests do not necessarily provide teachers with information on how to change their instruction based on the needs of their students. The Assessments for Learning Theme recognized the need to define additional learning outcomes for our instruction and innovative assessment methods that can inform teachers about the effectiveness of their instruction and help learners monitor their learning toward desired outcomes. From the early years of CILT, the Assessments for Learning theme pursued a vision for defining what to assess and identifying innovative methods to capture evidence of students' learning that could be used to inform instruction at the classroom level and at the administrative level.

In 2000, in conjunction with this vision for CILT, John Bransford worked with Dan Schwartz to identify several important distinctions about transfer of knowledge and how these distinctions impact our goals for instruction and assessment. They highlighted how summative assessments are designed to measure students' ability to efficiently and fluently apply what they know to familiar questions without the use of any additional resources. These sequestered problem solving (SPS) activities only capture students' ability to apply what they currently know to a narrow context. This type of testing does not necessarily demonstrate students' ability to learn new knowledge to solve novel problems within a domain (e.g., general science, mathematics etc.), or learn a new domain (e.g., engineering, chemistry, mechanics, biology). This emphasizes how a dimension of transfer that Bransford and Schwartz (1999) describe as Preparation for Future Learning (PLF). This dimension relates to how students generalize their knowledge and use it to think about new domains. For example, they describe a comparison of middle school students and college undergraduate students' ability to design a recovery plan for the bald eagle (Burgess, 1998). Neither group could define the specific details or approach to the plan compared with an expert's descriptions. This kind of sequestered problem solving activities suggests they did not know anything about eagles or animal habitats. However, in the second part of the study, the students were asked to generate questions they think would help them design a recovery plan. In this case, the middle school students focused on specific attributes of the eagle, such as what they eat and where they live. The undergraduates focused more on a systems level by generating questions about what is needed in an ecosystem and what other animals might also need to be part of the recovery plan. In this second study we see that students know a lot more about the context and domain than the first assessment might imply. Bransford and Schwartz suggest that it important to differentiate between these two dimensions of transfer so that we are clear about what we are actually measuring and how we talk about these measures. Their articulation of this difference in transfer has provided insight into the field of transfer that could have a significant impact on how instruction is designed and learning is assessed. Instruction need to offer students multiple opportunities to test what they know, receive feedback and refine their thinking. Assessments for learning are designed to achieve this goal and the theme has sought multiple examples of this through its seed grants.

This notion of testing a person's preparedness to learn, or reason, in new situations had emerged in the initial CILT Assessments for Learning workshop in 1999. A work group formed to explore the idea of dynamic assessments as way to measure a person's ability to learn. The dynamics of the assessment related to an assessments ability to either inform how to tailor instruction to the learner or testing the learners ability to dynamically (adaptively) reason with current knowledge to form new knowledge. For example, Hunt and Minstrell demonstrated their computer program, called Diagnoser, that can dynamically assign instructional lessons in physics based on students' current level of conceptual understanding (Hunt and Minstrell, 1994). The program uses Minstrell's work that classifies students' conceptual understanding of physics principles into specific "facets" of knowledge. "Facets" of knowledge represent common conceptions students display as they develop their conceptual understanding of physics. For example, an initial level of reasoning by a student, i.e., a low facet, might be "more batteries make a light burn brighter". As students become more knowledgeable with physics concepts, then they move from these observational descriptions to more conceptual facets such as "an increase in voltage will make the light burn brighter". The Diagnoser program identifies students current conceptual facet knowledge by asking a series of questions designed to target specific facets of physics understanding. Through an item analysis of the responses the program can diagnose students' thinking, and then based on this analysis offer instruction designed to help student refine their understanding to a more precise (higher) level of facet. This progressive refinement of test, teach with feedback and retest helps students develop a stronger conceptual understanding of the material so they are better able to transfer this knowledge to future settings.

The IMMEX (Interactive MultiMedia Exercises, 2003) computer program provides an assessment experiences that is more in line measuring preparation for future learning. Ron Stevens (1991) originally designed the IMMEX system to evaluate his immunology students' ability to diagnose patients' pathology and treat it. The IMMEX system now includes problem sets for a range of domain areas beyond immunology. The system presents a problem for students to solve, such as, diagnosing a patient's given case history and symptoms presented. Then, IMMEX provides a menu of resources students can use to gather information they need to make a valid solution to a problem (e.g., diagnosis). The process of gathering information and analyzing this information to make the next decision could be an indication of a students' preparation for learning in similar problem solving situations. This is similar to the students who could pose question about what more they would like to know about how to design a recovery plan for the bald eagle mentioned earlier. Therefore, if we track a person's decision making process through the list of resources, then we may be able to measure their ability to transfer what they know to reason about new context.

The IMMEX system tracks students' selections of resources and can compare these choices with expert's choices using non parametric statistical methods (a neural network). If students engage in a number of these problems sets, then tracking their problem solving strategies could provide an indication of their development from naive learners toward more systematic problem solvers. This kind of experience requires learners to reason with what they know to make decisions about what more they would need to know to make a better decision. Used over multiple problem sets, the system could gather information about the student's performance and give feedback to either them or their instructor. The learners and instructors can use this information to take steps to improve students' performance on the next trial with the system.

Technology innovations like Diagnoser and IMMEX illustrate the ability to engage students in learning activities that provide them multiple opportunities to test and refine what they know over time. Also, these programs demonstrate how important it is to have clear goals for instruction and what it means to be successful in that domain. For example, Minstrell's facets of physics knowledge provide developmental metrics of students learning over time. These metrics can be used for diagnostic purposes for designing instruction, as well as, students' progress toward a more refined understanding of the domain. IMMEX potentially can provide a metric of students' problem solving skills within a particular domain area. Students' ability to select the appropriate sequence of resources can be an indication of their understanding of what the resources provide and how knowing that information will assist in solving the given problem. Both these examples illustrate how technology can capture meaningful data about students' understanding that can be used to inform instruction. The focus for the seed grants explored ways to capture students' data related to this idea of measuring their development toward specific skills and ability and how these measures can be used to inform instruction.

Summary

Designing instruction to support formative assessments requires pedagogical methods that encourage students to share what they know and relies on teachers to evaluate students' thinking about concepts based on students' actions. These actions can include students' verbal or written explanation for how to solve problems, formulation of logical arguments based on evidence, application of math and science principles to explain an observable phenomenon, or the design something to achieve a specific function. The coordination of these students' actions can be a complex activity to manage (Bruer, 1993; Duschl & Gitomer, 1997), and knowing how to evaluate and respond to students' articulation of ideas can be a challenging skill to develop. Participants in the CILT community have extensive experience designing learning environments that support these kinds of generative learning environments and research what is necessary to support students' learning and optimize teachers' instructions. The Assessments for Learning Theme has been researching opportunities to use technology tools to support learning environments that embed formative assessments as part of their instructional practice.

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Reflections on CILT as a Collaboratory: Moving from Affiliation to Collaboration

NATHAN BOS, University of Michigan

I personally benefited from CILT's strongest feature—promoting affiliation—from the very beginning. I was hanging around outside of an empty ballroom at the 1999 AERA conference in New Orleans, waiting for the SIG-ATL (Special Interest Group on Advanced Technologies for Learning) meeting to start and thinking about changing my flight to go home early. This was the first AERA meeting I had attended in 3 years, but it felt like 10. Most of my professional work at that point was no longer in education, and I had already changed the line at the top of my vita to say "Researcher in human-computer interaction." I was attending AERA that year on something of a whim and was regretting it. I wasn't presenting anything; I had already made the rounds of old Michigan colleagues and friends; and I was not having much luck finding anyone else I knew or anyone I really wanted to talk to. It was my good fortune that Chris Hoadley also showed up for that meeting a little early, recognized me, and decided to make a pitch for the open postdoc position with the CILT project. This intriguing project fit with my interest in collaboration and technology and also seemed like a great way to connect, or reconnect, with researchers in the learning science community. CILT's strongest feature was its ability to promote affiliation, both within the core learning sciences (LS) community and in its near proximity.

A few months later, I found myself at SRI International in Menlo Park interviewing for the CILT postdoc position. Jeremy Roschelle asked me the most interesting question of the day: "What do you mean by collaboration?" Implied in his question was that the term was overused and becoming devoid of meaning. I had no doubt just used the word flippantly, probably in a context where I could have interchanged the words *cooperation*, *affiliation*, or even simply *communication* with no loss of precision. It was a great question. I came up with a pretty good answer: Collaboration is group work where the whole is greater than the sum of its parts.

At almost the same time that my work with CILT began, an equally fascinating new project had just been awarded at Michigan. Gary Olson and colleagues were beginning the "Science of Collaboratories" (SOC) project, a 5-year grant to review the phenomena of scientific collaboratories to identify successes and failures and recommend new directions. While most people familiar with the term think of collaboratories as very high-tech, instrument-intensive science projects, the SOC project quickly decided it would focus much more broadly. SOC would review a wide variety of scientific collaborations taking place over distance, using many different technology configurations in many different scientific subfields. Whether they knew it or not (and Roy Pea, one of CILT's co-PIs, was certainly familiar with this line of work), CILT was a collaboratory.

I maintained peripheral contact with the SOC group throughout the 18 months that I worked for CILT and took a position managing data collection for SOC in 2002, after I finished with CILT. CILT is now one of about 50 collaboratory projects that SOC has analyzed in moderate detail and has an entry in the "Collaboratories at a Glance" database (see http://www.scienceofcollaboratories.org/Resources/colisting.php). (The VaNTH collaboratory, described in the report by Bransford, and Pea's earlier CoVis project are the other LS projects already in the database. This project is ongoing, and suggestions are welcome!)

What is a collaboratory? The National Academies of Science *National Collaboratories* report (NRC, 1993) was influential in sketching a blueprint for how science of the future might be conducted in "laboratories without walls." This book describes ambitious projects in progress in oceanography, space physics, and molecular biology, among others. Part of the SOC project was to do a thorough follow-up on these projects and some others that took on the collaboratory label early on. The success of these first-generation collaboratories tended to come in two areas: software development and training. Their nearly universal shortcoming, unfortunately, was failure to create sustained use among scientific practitioners.

Typically, these projects spent several years and hundreds of work hours building from scratch early versions of tools that are now much more common: remote access instrument controls, shared online databases, real-time collaboration tools, and asynchronous professional networking resources. These software efforts contributed to the rapid development of the telecommunications tools that are now transforming how all kinds of work get done. The second major contribution of these projects was in training personnel. Collaboratory projects trained cadres of young researchers to think of collaboration as an essential part of their work. The SOC project has found and interviewed many early participants who have since become "serial collaborationists", participating or advising in many projects that picked up where original collaboratories left off.

It is important to recognize these successes, but it also important to learn from the failures of the first-generation collaboratories. Once they moved out of development into production mode, these projects typically had much more trouble than they anticipated in getting practitioners to use them, and failed almost universally in creating self-sustaining, highly productive scientific communities. A variety of reasons can be cited. Sometimes there was bad luck or unexpected competition, but equally often there were fundamental mismatches with the culture and practices of the scientific communities that they sought to transform. Preoccupied with the job of building cutting-edge software, projects gave inadequate attention to critical dimensions such as usability, usefulness, accessibility, governance structures, incentive systems, and intellectual property protection.

I consider CILT a second-generation collaboratory. CILT also had the goal of promoting large-scale, geographically distributed science. But CILT's methods relied less on technology, and CILT was organizationally more sophisticated than earlier collaboratories. In contrast to earlier attempts, CILT was quite successful in attracting and maintaining an interested community. CILT conferences were well attended and energetic year after year. Faculty, postdocs, and graduate students were not overly difficult to recruit; CILT presentations and workshops were well attended; people signed up to attend CILT online courses and register themselves for the CILTKN database. Moreover, this initial interest did seem to sustain itself over the course of the project.

The SOC project came up with a classification for collaboratories whose main goal is promoting professional affiliation. Borrowing Etienne Wenger's (1999) term, we call them Community of Practice collaboratories. But CILT's stated goals went well beyond this. And, truthfully, nobody would call CILT a success if all that was achieved was a community of practice. Good affiliation mechanisms already exist within the LS community in the form of conferences (AERA, ICLS, CSCL) and journals where people in and outside of the field exchange information and form relationships. Although the feat of recruiting an engaged community did put CILT ahead of many other collaboratories, to be counted as a success CILT always recognized that it would have to move beyond affiliation to high-functioning collaboration.

Going beyond affiliation to collaboration usually requires "forcing functions"—shared projects that push groups beyond pleasantries to high-stakes negotiation, compromise, and (hopefully) collaboration. Vimla Patel's evaluation of the InterMed collaboratory is a nice case study of this process (Shortliffe, Patel, Cimino, Barnett, & Greenes, 1998). InterMed, like CILT and most other collaboratories, was a geographically distributed project involving a group that had similar interests and a history of affiliation, but little collaboration. InterMed's project was to encode expert diagnostic capabilities of clinicians in computer-readable guidelines. The product is not relevant to CILT, but the process is. Patel described how in the first stages of the project participants were friendly and affiliative but worked mostly in parallel. They were separate groups with similar foci working on similar but not integrated projects. The rubber hit the road when deadlines came up and the project had to make hard choices (Aim results for researchers or practitioners? Use cutting-edge or proven technology? Create an incomplete but general solution, or "get the job done" for a subset of problems?). These tough decisions created conflict and attrition in the InterMed group, but the group that survived this process formed a strong, well-integrated core that stuck together through the original and several subsequent projects.

At CILT conferences, forcing functions took the form of dozens of colored sticky notes affixed to large, wall-hanging sheets of paper. The "CILT method," as one of our attendees dubbed it, is a means of moving from brainstorming ideas to affiliation to focused discussion groups and perhaps beyond. (I've used the "CILT method" since, e.g., at a faculty workshop at the University of Michigan Business School.) From the participant's point of view, this is what happened. The first decision is which theme group to attend. In the rooms, after some preliminaries and introductions, the group brainstorms topics of interest. Each topic gets its own sheet of paper hanging on the wall, until the walls are covered. Some consolidation is done to match similar ideas. Then, participants vote on ideas. Sticky notes are usually the ballot of choice; typically each person gets three to five sticky notes, which they put on the idea sheets they prefer. Once voting is completed, facilitators will identify which ideas got the most votes and assign a group leader. Attendees then "vote with their feet" to choose an idea group, and groups develop the idea further for 30 minutes or so. Groups that have enough energy and coherence to want to continue could then apply for CILT seed grants. Seed grants provided money to fund another meeting or two between participants and require an end product—perhaps a report, a design, or something else.

I found this method of funneling people into problem-focused groups quite ingenious, and something that no other collaboratory we have come across has enacted. It helps move a group beyond discussion to action, yet is decentralized and nonhierarchical enough for participants to avoid feeling bullied or manipulated.[23]

[23] CILT PI Roy Pea reports that it has now been picked up by industry groups for retreats, and at other non-CILT workshops. It is a lightweight process that fits a comfortable niche, incorporating bottom-up and top-down elements.

I participated in or observed a number of seed-grant groups. Many persisted only as long as the conference session; others turned into yearlong discussions. The one that took on the most energy was the "Playspace" group, which met a number of times and applied for an NSF grant together. This grant was not fortunate enough to be funded, but the seed grant gave me and a group of like-minded others a chance to explore an area of curiosity in much more depth than we otherwise would have. Next year, I will be teaching a master's-level course on educational gaming and simulations, and the syllabus strongly reflects the ideas and articles covered by that group.

As a unique and interesting forcing function for group collaboration, the CILT conference/seed-grant system is featured prominently in the write-up of CILT for the SOC collaboratories database. The seed-grant system was certainly not perfect and was too underfunded to produce anything spectacular, but it seemed to me to have a lot of potential.

In contrast, the lack of forcing functions at the top level of the CILT organization represented (in my view) CILT's biggest weaknesses. Looking at the organizational structure for CILT, one notices a recurrence of the number four. There were four locations (SRI, Berkeley, Nashville, Concord), four themes, and much of the time four PI's and four postdocs. This symmetry makes sense on some levels, but a key lesson of collaboratories is that geography is a very powerful fragmenting force. The four-part symmetry of CILT made it far too easy for the project to split into four parallel, loosely affiliated but noninteracting projects instead of one collaboration.

Contributing to the fragmentation problem was the number of themes—two would have been a lot. As designed, the four themes encompassed a large portion of the learning sciences. This was a benefit in recruitment and in promoting affiliation. Almost everyone could find something they were interested in at the conferences and other offerings. But ultimately this comprehensiveness limited the focus and quality of the collaboration. Postdocs and PIs worked on conceptually separate projects and did not have enough reason to talk to each other.

The broad scope of the project also probably limited the effectiveness of the seed grants. These groups covered the waterfront of educational topics, which made them interesting to survey but also gave them very little to talk about with each other or with core CILT personnel. The seed grants all had individual strengths and bright spots, but as a group there was little opportunity for the whole to become greater than the sum of its parts.

CILT's organizers were aware of these shortcomings and did try various means to compensate for them. The Synergy project, a successful CILT spinoff, was created in direct response to this perceived fragmentation. And there are other examples of successful cross-site collaborations happening under the CILT umbrella. Still, the forces of fragmentation were quite apparent in most CILT work that I took part in. Geographic separation is always a factor, and when it is reinforced by preexisting institutional differences, personnel differences, and thematic separation, it can be too much to overcome.

I'm still grateful that I ran into Chris Hoadley and CILT that evening in New Orleans. On a personal level, it is rare that a month goes by without my having some contact with an acquaintance or colleague whom I got to know through CILT. I've borrowed many ideas from CILT contacts and CILT programs. Speaking as a collaboratory researcher, in my mind CILT is on the list of successful "collaboratory" projects that have pushed the envelope of distributed scientific research, providing both ideas and a community that will continue to develop.

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Postdoctoral Professional Development

JAMES H. GRAY, Leapfrog Enterprises

Introduction

Children's learning, development, and technology use have long been at the core of my research interests. The CILT postdoctoral scholar program supported expansion of these core interests in significant new directions. Knowledge of emerging technologies, collaborative design, and a professional network of individuals and institutions provided an invaluable apprenticeship in the practice of learning technology innovation. The impact of CILT on my work is most evident two areas: (1) a planned program of research and development on tools for enhancing children's social intelligences, and (2) in my current work as Research Manager for LeapFrog Enterprises, Inc. conducting studies of usability, engagement, and learning with interactive products for children from infancy to adolescence.

My tenure as postdoctoral scholar for Community Tools began in 1999, soon after completing a doctorate in human development and psychology at the Harvard University Graduate School of Education (HGSE). At that time, CILT presented an opportunity to deepen my knowledge of cutting-edge learning technologies beyond previous experience researching and teaching interactive media design at the Rochester Institute of Technology and my dissertation study of online social understanding among young adolescents. It also offered the prospect of integrating my long-term study of child development with insights from the field of learning technology design and the sciences of learning, toward the goal of defining a new program of research and development.

Tools for Learning Communities

Leadership in the Community Tools theme was one of the main CILT activities that supported professional development related to my professional goals. In collaboration with Roy Pea and Jeremy Roschelle, I organized and conducted theme workshops in 1999, 2000, and 2002. Each workshop included reports from previous seed grant projects, collectively defining the focus for the next round of grants, and soliciting applications. Follow-on activities involved coaching grant writers, evaluating candidate applications, and guiding grant recipients in the completion of their projects. The vision and work of our theme team addressed three general classes of tools: collaborative representations, network improvement, and socio-cognitive scaffolding.

Through theme activities, I interacted with hundreds of individuals working in areas related to tools for learning communities, and worked closely with dozens of researchers on specific concepts. Projects that had particular impact on my professional knowledge include innovations in basic technologies such as interoperable components for shared active representations, knowledge mining tools, metadata for interoperability among knowledge building environments, and annotation tools for rich media and digital video. Seed projects on educational technology entrepreneurship and playful learning through technology were especially relevant to the work I pursued after leaving CILT.

Projects explicitly focused on the goal of having positive social effects on technology-based learning communities include "connecting values to the internet" and the "equity project". I further explored the first topic—values—through participation in a NSF-sponsored workshop on Value Sensitive Design. The topic of equity and diversity was incorporated in the conference-wide theme of Technology, Equity and K–14 Learning at CILT2000. I addressed this theme more deeply in a NetCourse on Culture, Cognition, and Technology described below.

Designing online communities for learning and development formed the central focus of my work with the CILT Community Tools theme. Initial exposure to key concepts of this theme began with a seed project on "defining the next generation of online teacher learning" and culminated in a book co-edited with Sasha Barab and Rob Kling, published in 2004 by Cambridge University Press. In addition to editing, I wrote a chapter on the sociocultural analysis of teachers' online professional development, based on the Researching Online Communities (ROC) project that I led as a CILT postdoc. Other community-oriented activities included direct participation in two seed grants, the Early Career Networked Improvement Community and the Digital Video Inquiry Collaboratory.

Virtually all of my experiences with the innovative technologies detailed above included significant professional networking and collaborative processes. For example, our Community Tool theme workshops are designed around a group process that begins with 15-20 researchers quickly sharing previous project innovations through "firehose" talks, meeting in common-interest groups, and then drafting initial seed grant proposals. To receive funding, every seed grant recipient was required to establish new collaborative working relationships across institutional boundaries. Even the book project included an especially collaborative approach to coordinating the chapter topics through both online community tools and two face-to-face meetings of the authors.

Peer Collaborations

Another particularly formative experience as a CILT postdoctoral researcher was work on the Synergy project and other activities pursued collaboratively with fellow postdocs. My primary activity for Synergy was a study of classroom software design from the perspective of two collaborating teachers. Planning and implementing this study involved ongoing collaboration with Sherry Hsi and Eric Baumgarter, based at the University of California at Berkeley, and occasional coordination with Sean Brophy, at Vanderbilt University. Under the guidance of Marcia Linn, this experience was especially valuable as a practical application of collaborative software design in an educational setting. Like the ROC research project, it involved analysis of teacher professional development in relation to various learning technology tools. Expanding knowledge and skills in this area was particularly important to me, since teacher professional development is an essential component of most school-based learning technology innovation.

Collaboration with the other postdocs extended well beyond implementation of the Synergy project in the San Francisco Bay Area to include meetings in each of the partner institutions, and presentations at AERA, CSCL, and CILT conferences. The value of working together on these activities included knowledge of similarities and differences among diverse research settings in terms of their history, products, staff, norms and practices, and research approaches.

CILT Leadership: Legitimate Peripheral Participation

Collaborations among CILT participants extended beyond my primary affiliations with postdocs and the Community Tools theme team to include other CILT PIs and project staff at their local institutions. Especially valuable contacts include the WISE project at UC Berkeley;

various projects at Vanderbilt learning Technology Center; Virtual High School, Modeling Across the Curriculum, and MOOM at the Concord Consortium; Media-X and the Learning, Design, and Technology program at Stanford University. The most extensive contact with other project staff occurred at the Center for Technology in Learning at SRI International, where I spent the bulk of my time as a postdoctoral researcher. The most influential experiences here include research with Mark Schlager, Judi Fusco, and Deborah Tatar on Tapped In, project development work with William Penuel on vStreets and a technology implementation study in collaboration with Stanford University's John Gardner Center for Youth and their Communities, and research proposal development with Phil Vahey and colleagues for the Thinking With Data project.

The benefit of these contacts goes beyond knowledge of project concepts and procedures, to include professional networking, informal institutional affiliations, and socialization into the ways of thinking and acting in the various communities of practice pursuing research on the learning sciences and technology design. These kinds of socialization and acquisition of tacit knowledge also occurred during regular CILT leadership activities. Joining the PIs and other staff at the CILT teleconferences and "ciltphone" (e-mail list) communications involved being at times both a peripheral and central participant in the decision-making processes of CILT. Similarly, the opportunity to participate in an NSF planning workshop provided insight into the strategies used by senior leaders in the field to set long term research directions. While the value of these various activities is not always immediately apparent, it seems to involve the kind of long-term formative process that is theorized to be at the core of apprenticeship models of professional learning and development.

NetCourse: Culture, Cognition, and Technology

Along with the Synergy project and Community Tool theme activities, the NetCourse initiative was a key avenue for linking my previous research and teaching experience, long term career direction, and CILT goals. To address issues of the "digital divide" and a desire by CILT leadership to help move the field to greater awareness of diversity and equity, CILT200 was organized around the theme of Technology, Equity and K–14 Learning. As an extension of this theme, I designed and led two netcourses on Culture, Cognition, and Technology. This topic built directly on a course I taught at HGSE, with adaptations to address the needs of online pedagogy and the CILT community students who took the course. This activity contributed to my professional development in two ways. First, it provided experience designing and teaching an online course, familiarity with online courseware, and knowledge off the Moving Out Of the Middle (MOOM) approach to online course facilitation. Second, since all netcourse activities were coordinated through the Concord Consortium, this project offered an especially strong opportunity to work closely with CC staff and learn about the organization's approaches to research and practice.

Tools to Enhance the Social Intelligences

After completing the postdoc, I pursued a program of research and development that integrated my CILT experience with interests in children's social development. I began with a few basic design principles such as making thinking visible, scaffolding complex thinking, and coordinating learning conversations. Building on these, I defined a set of four elements essential to understanding the social world from the perspective of many social sciences, humanities, and education. My goal was to find or create an institutional home in which I could expand this work through a project to develop Tools to Enhance the Social Intelligences (TESI).

Over the course of one year, while working as an independent consultant, I explored a wide variety of potential venues for this and related projects. In addition to exploring university-based venues for this work, I established working relationships with a wide variety of local individuals and institutions with compatible goals. These included a professor of history and education (Sam Wineberg), an educational filmmaker (Tim Olsen), an established social learning technology company (RippleEffects), an early stage start-up (Learning Friends), the interactive media division of a public television/radio station (KQED), and a non-profit educational organization (Facing History and Ourselves) where I participated in multiple workshops and a grant planning process. I also extended my work with the Stanford University Gardner Center, where I was employed as a consultant to complete a technology implementation study of handheld computers for youth community research.

Corporate Setting

More recently, I put specific plans for TESI on hold as I considered alternative routes to my long term goals, and ultimately accepted a position as Research Manager for LeapFrog Enterprises, Inc. LeapFrog has rapidly established itself as the third largest toy company in the United States. With a strong focus on literacy and language, globally-oriented growth, and a wide range of technology-enhanced learning products designed for children from infancy to adolescence, it is a setting that complements my goals in many ways.

Like TESI, conducting research at LeapFrog requires a blend of my expertise in children's learning and development with knowledge of innovative learning technology design. A few of the more apparent ways that CILT shapes my current work includes theory and exemplars of learning with handheld computing technologies, the iterative and highly collaborative process of design-oriented research, and the potential value of community tools for enhancing collaborative processes. For example, I am exploring the use of digital video exemplars to foster reflection, discussion, and learning through shared viewing and annotation.

Future

While it is too early to know where my career path will lead next, it will certainly continue to focus on research and development of technology tools for children's learning and development. I might pursue these goals at LeapFrog for many years, move to another corporate environment, or seek a university appointment after publishing more of my work. Similarly, I might use my additional research and management experience to establish an entrepreneurial venture like TESI.

In any case, my tenure as a CILT postdoctoral scholar will continue to shape my work. The theories and methods I refined for studying online professional development are likely to be useful again. The value of bridging academic and corporate perspectives on educational technology will be applicable in a wide variety of settings. Certainly, I will continue to draw on many of the design principles and innovative projects now familiar to me. However, perhaps the key lesson learned from CILT is that I cannot achieve my career goals alone. To establish a project like TESI, I will depend on the knowledge acquired through participation in our CILT community as I organize collaborative gatherings, design research projects, approach potential funders, and share new knowledge with colleagues and the field at large.

Analysis by CILT Project Managers

CILT Industry Alliance Partnership

PHILIP VAHEY, Center for Technology in Learning, (with Roy Pea, Stanford University)

Introduction

With a few notable exceptions, educational research has not had a significant impact on the use of technology in K–12 schools in the United States. As but one indicator, attendance at several conferences on educational technology venture funding and companies during 2001–04 revealed that federal policies and their impact on product sales, funding and marketing are highlighted, but learning sciences research results or demand for research knowledge for product and services development goes unmentioned. It has been estimated that, with the possible exception of graphing calculators, there has not been a single research-based educational technology that has reached five percent of our nation's classrooms (see Fishman, 2002). Even the most successful of web-based environments, which can claim thousands of teacher users, reaches only a fraction of a percent of all educators.

A profile of teachers who could be characterized as *innovators* or *early adopters* (Moore, 1991) shows that they do not wait for complete solutions or for a strong research base before using technology in their own classroom. Instead, these teachers rely on their own intuition and vision in imagining how technologies can improve their teaching practices, and often neither the teachers' intuitions nor the technologies' implementation are based on research in education. One example of this type of technology adoption includes the use of the World Wide Web in 1994, which led to NetDay in 1995, well before there was a strong research base on the most effective uses of the Internet in education. Another example was the early adoption of handheld computers by entire school districts in 1999–2000 (such as the Orland Park district in Illinois), before there was a base of research on the effective use of handheld computers in education. The choices of the early adopters are important, because it is their use of technology that influences how technologies are used on a wider scale. If the use of these innovators and early adopters runs counter to findings from research, research may take a back seat: it is the actual use of technologies in the classroom, shared by teachers and instructional leaders at practitioner meetings and by word-of-mouth that is most likely to influence other teachers.

Teachers who are in the *early majority*, (Moore, 1991), the ones who will lead to large-scale adoption of technologies at the school level, have a different profile. Recommendations from researchers to reach this group include providing full curricular materials (Soloway, 1999), designing for local adaptability (Fishman, 2002), and aligning curricular goals with current assessments (Shephard, 2000). Until the recent *No Child Left Behind* legislation, alignment with research was not high on the list of priorities.

Educational researchers are in a double-bind: some teachers adopt technologies before there is a consistent research base on the use of those technologies, while others adopt educational innovations once they are more fully integrated into curricular materials, locally adaptable and aligned with assessments. How, then, can researchers *both* ensure that their innovations meet the requirements of *most* teachers, while also meeting the timetable of the few, influential, early adopters?

One possible way to resolve this situation is through collaboration between educational research and innovation leaders in industry: through collaboration researchers may be able to influence the technology that is introduced in most classrooms, while industry keeps the research community and early adopters apprised of the most recent and relevant technologies. To work, the relationship discussed has to be a reciprocal relationship between industry and research, and focused on research, not on philanthropy. We describe and analyze the results of the Center for Innovative Learning Technologies' Industry Alliance Program, created with this vision in mind.

The goal of CILT can be found in its slogan: *uniting people, technology, and powerful ideas for learning*. While research in the learning sciences and educational research was carried out under the auspices of CILT, much of CILT's effort was in supporting productive collaborations among researchers, schools, informal education institutions, and industry.

The Industry Alliance Program: CILT's Early Vision

In late 1997 several converging factors influenced the design of the Industry Alliance Program (IAP). In terms of research, a key factor was the maturation of the field of Learning Sciences: the *Journal of the Learning Sciences* had become one of the most respected journals in the field of educational research, the Computer Supported Collaborative Learning (CSCL) conference had become one of the most important conferences in the field, and the National Academy of Sciences was starting work on the seminal *How People Learn* panel, co-chaired by CILT Co-PI John Bransford and including CILT PI Roy Pea and Co-PI Barbara Means. CILT PI's were active in all of these efforts. In addition, there was a general feeling that new models were needed to move educational technology research out of the lab, and into broader classroom adoption. Partnerships with Industry provided a clear path for wider dissemination of research results, and a prospective incremental source of research funding for CILT's work. We were optimistic of raising up to $1 Million per year in industry partner funding to help advance the research projects of the Center.

In terms of technology, a key factor was the *rise of the Internet*. Both established and new educational technology companies were looking to the Internet to dramatically change content delivery, student access to information, and perhaps most importantly, models of student work. NetDay had recently taken place, schools were beginning to use the Internet almost routinely, and there was a general feeling that the Internet could, properly used, "change everything". The technology development cycle had been rapidly diminishing, to the point where new technologies were available to consumers and schools before researchers and practitioners had a chance to understand their educational implications. It was clear that researchers would have to be working closely with industry from the beginning stages of technology development to impact the technologies that entered the classroom,

In economic terms, a key factor was the advent of the *New Economy*. In 1997 new technologies were coming out at a breakneck pace, there was a seemingly endless supply of venture capital, and stock prices for technology companies were rising astronomically. Many new technologies being developed were touted as having great promise for education, but most technologists or venture capitalists did not have a background in the educational use of such technologies. Without a mechanism for collaboration between industry and the learning sciences, technologies would find their way into the classroom, but their positive impact would not be assured nor maximized.

CILT sought to leverage the convergence of these factors. CILT's efforts in this regard began while CILT was a finalist for National Science Foundation funding. In July of 1997, Roy pea, CILT's PI, convened at SRI International a large workshop with representatives from over 40 companies, including hardware, software, media, entertainment, education, and telecommunications companies[24] to understand how CILT could best work with industry to ensure wide-reaching impact on educational technologies.

A key outcome of this meeting was a validation of findings from prior evaluations of productive partnerships between research and industry, such as the National Science Foundation Engineering Research Centers (NSF, 1997): The most effective partnerships are based on a true collaboration model, and work in a "more is better" fashion: the more effort that an industry partner puts into the partnership, the more benefits that partner will receive. To foster significant collaboration between industry and research, CILT steered away from models that provided only surface contact between industry and educational research.

Learning from this workshop, CILT developed a set of requirements designed to ensure true collaboration. The first was that industry partnerships be made with the company's corporate arm: many large companies have created philanthropic institutions that fund education implementation efforts. However, these philanthropic institutions do not influence corporate strategy, significantly limiting the influence of such a partnership. CILT also required that companies commit significant resources to a long-term relationship. This requirement was created to help buffer the relationship from short-term budgetary or market pressures. By enforcing these requirements while providing a mechanism for collaboration between the leaders in the technology industry and educational technology research, CILT hoped to build a self-sustaining organization that could have a positive impact on educational research and practice. Specifically, CILT decided upon a "layered" approach to collaboration, in which companies could choose between becoming a *Senior Member* (contribute $100K/year to CILT for three years) or an *Associate Member* (contribute $10K annually to CILT), with concomitant benefits (such as advising CILT on its priorities and new directions, participation in CILT workshops, and priority access to CILT-based research).

CILT also realized that Intellectual Property (IP) could cause significant confusion for industry and academic partners. In fact, IP had already come up as an important aspect of creating the original agreement between the CILT "Core Four" universities and non-profits. To minimize confusion about IP issues, after extensive review of NSF center industry partner programs and consultation with Dr. William Spencer, who led the SemaTech consortium of semi-conductor industry members, the decision was made that all IP developed under CILT funding would not be owned by any organization, but would be made publicly available ("open IP"). CILT decided to model itself on pre-competitive research organizations. That is, work funded directly by CILT

[24] Note that CILT did not consider textbook publishers or publishers of other non-technology based curriculum materials to be potential productive partners. Based on prior experience and more recent conversations, we believed that textbook companies were very resistant to change. While we will not delve into the many reasons behind this, some included economic (considered technology to compete with textbooks), logistical (they didn't know how to sell, nor provide technical support for technology products), and structural (they had finely honed processes for state adoption of textbooks, and did not have that expertise for technology solutions).

would be undertaken in the spirit of overcoming fundamental obstacles that would otherwise prevent a technology from becoming educationally productive, with all findings being published and openly available to all. Besides in principle making the CILT industry program easier to manage, since there would be one IP policy, not a series of special case contracts to be developed and negotiated, we felt we would avoid the impression that CILT researchers were available as co-developers for hire to create products for industry.

As an important corollary to the decision for CILT to position itself as a pre-competitive organization, CILT explicitly did not consider business models appropriate for potential industry partners. While this decision was the most rational choice for CILT core partners, and for work with other researchers, the lack of alignment between CILT and the business interests of industry caused significant problems for the IAP as will be discussed below.

The Industry Alliance Program: Early Lessons Learned

In 1998 CILT began courting companies in earnest, and there appeared to be interest in companies joining CILT. CILT engaged in conversations with industry leaders such as Intel, Sun Microsystems, IBM, AT&T, Cisco, Oracle, Apple, 3Com (specifically their Palm Computing division), Texas Instruments, Hewlett Packard, Xerox, Autodesk and SBC, start-up companies such as NetSchools and Handspring, and education companies such as Knowledge Universe, CCC, PASCO, Turner Learning, Children's Television Workshop, LearningInMotion, LucasLearning, TRO/Plato and ETC (later acquired by Knowledge Universe). Intel was soon signed up as a Senior Industry Partner, and more partners seemed imminent. Only Intel was ultimately able to fund a CILT partnership, and other companies were having a difficult time finding ways to fit CILT funding into their educational priorities. As we engaged in prolonged negotiations with potential partners, we began to notice a set of recurring difficulties that prevented companies from becoming full CILT partners. In retrospect many of these difficulties appear to be based on CILT's positioning as pre-competitive organization: because CILT did not attempt, by design, to align itself with companies' product development plans, it was difficult for companies to find a compelling reason to provide monetary support to CILT. Specific difficulties can be characterized as follows, and are representative of the problems that plague large-scale efforts to introduce effective pedagogies into classrooms:

- **Companies with existing labs had difficulty justifying external research** (e.g., HP and AT&T). Corporate labs were coming under pressure to "productize" their research. These labs felt that their main challenge was not a lack of good ideas, but a lack of processes for determining which projects were the best candidates for commercialization, and then creating commercialization plans. In retrospect, this may have been a false dichotomy. It seems likely that the research that was taking place in corporate labs would have been synergistic with the research that was taking place in academic institutions, and the combination could have led to truly innovative and educationally more effective products. However, because CILT was "pre-competitive" and could not consider the understanding of products or business models within its purview, there was no mechanism for fully exploring the types of business models required by the labs, and how these business models could leverage CILT as CILT expertise in the creation of new products. Individual collaborations between industry CILT participants and individual researchers took place, as we will see later on.

- **Companies had existing education projects, and CILT could not be funded within existing education umbrellas** (e.g., Cisco, IBM). Many companies have specific criteria for funding educational research. These companies tend to have a range of programs, designed to fund initiatives across a spectrum of relevant work in education. For instance, a company may provide grants to local schools to integrate technology in the classroom, fund foundations to close the digital divide, sponsor research in Universities, and provide significant resources for a company "branded" initiative (such as the Cisco Academy or Intel's Teach to the Future). However, an unknown multi-institutional virtual educational research center that is not a legal entity, which provides access to research and researchers, may not fit into the categories that the company has deemed acceptable for funding using education dollars. If and how their funding was maximally educationally effective was not always the largest concern of philanthropic, "brand name", funding.

- **Some companies could offer in-kind support, but not monetary support** (e.g., Sun, Palm, and ImagiWorks). Most companies consider education a very difficult market sector, with low profit margins. Thus, companies scrutinize non-philanthropic efforts to study the return on investment (ROI). A long-term research-based collaboration with a multi-institutional virtual educational research center does not have a clear path to increased individual ROI. That said, companies were willing to provide in-kind contributions." Sun a server for the CILT website, and Palm and ImagiWorks provided equipment for the CILT Synergy project.

- **Startups cannot spend money on tasks deemed non-essential by investors** (e.g., Handspring and Netschools). Some of CILT's most enthusiastic contacts were from small startup companies that understood the value and competitive advantage of incorporating findings from educational research into their products. However, these same companies, while often being rich in stock options, were not also rich with funding. At least one company explicitly raised the idea of funding their CILT membership through stock options. However, as a consortium of four separate non-profit entities, CILT could not create a legal entity that could have been the recipient of such stock options.

- **Intellectual property.** An underlying theme throughout discussions with both researchers and industry was intellectual property. Almost all firms stated that the pre-competitive IP agreement was a roadblock to collaboration with CILT as a virtual institution. Many firms did not see education as requiring the long-term research and testing required in areas in which firms engage in pre-competitive IP agreements, such as genetics, bio-pharmaceuticals, or high speed computing. Many researchers were concerned about the IP implications for projects on which they had invested years, when such ideas could be productized.

There were additional issues within the overall research community that prevented CILT from being as desirable a partner for industry as was possible. Some of these factors included:

- **A lack of incentives for researchers.** Researchers are on a budget and timeline for publishing results of their work in peer-reviewed publication outlets to receive academic credit, and for reporting progress to their funding agency. Although many researchers do want to see their projects or findings widely disseminated, and although many researchers do see industry collaboration as one of the most effective means of dissemination, it takes significant commitment of time to collaborate with industry. Because CILT itself could not offer any fiscal incentives to researchers to collaborate with industry, it was in retrospect overly optimistic to think that researchers would have put in the effort necessary to collaborate with industry through CILT. There was also some fear that industry would learn about researchers' ideas and commercialize them without attribution.

- **A lack of centralized authority.** Because CILT was a multi-institutional virtual center, there was no centralized authority that could coax collaboration from researchers. Instead, if an industry representative thought that a particular member of CILT was conducting interesting research, they would have to find a way to work with that researcher directly, as CILT could provide guidance and help "grease the skids", but CILT could not ensure that any particular collaboration would take place.

This is not to say that the IAP program was a failure. In fact, CILT's collaboration with industry was a differentiating factor that made CILT unique among educational research institutional arrangements. CILT's lone senior member, Intel, played an active role in CILT, providing guidance as part of CILT's advisory board, playing an active role in CILT conferences and workshops, and calling upon CILT researchers to provide advice on directions for Intel's education website.

Additionally, CILT workshops drew a significant number of industry attendees. Industry participation was key to the success of CILT workshops, as both industry representatives and academic researchers reported that industry participation greatly improved the quality of CILT events. It was obvious that CILT was filling a "convening" need for both industry and academic research, although CILT's initial model of industry partnership was not sustainable. CILT then turned to other potential collaboration models, finally settling on a model based on industry sponsorship of CILT activities, industry participation in CILT activities such as workshops and conferences, and opportunistic joint projects.

Successful Modes of CILT Industry Collaboration

Increase Workshop and Conference Participation

The most productive collaborations with industry occurred through the main CILT mechanisms: workshops and conferences. CILT purposely involved industry more deeply in the CILT conferences, offering industry sponsorships and specific sessions where industry representatives could demonstrate their latest technologies. While a small minority of researchers expressed concern at the increased presence of industry, most researchers welcomed the opportunity to learn more about current industry trends while interacting directly with industry representatives (and that industry funding provided nicer facilities, snacks and beverages was appreciated). By the end of the CILT project over 15% of workshop and conference participants were from industry, representing 50 companies. Eighteen companies sponsored CILT conferences, and over 20 companies participated in seed grants. Attendees continued to give CILT very high ratings; providing a forum for industry and researchers to collaborate was a highly valued aspect of CILT that was generally recognized as unique.

Conducting special events targeted to the needs of industry and research

Based on the success of the conferences, CILT conducted targeted events, with the intent of meeting specific needs of both industry and research. The most prominent of these events was the CILT Handheld Design for Education Contest, funded by Palm.

The contest aimed to bring attention to the possibilities of handheld computers for educational purposes. Although CILT had been moving forward on its ubiquitous computing theme, the use of handheld computers was still not considered mainstream when the contest took place. CILT recruited a mix of industry representatives, researchers, and practitioners to participate as judges, including Mike Lorion, who was the newly appointed Vice President of Education at Palm, Jeff Hawkins, inventor of the Palm and founder of Handspring, Elliot Soloway of the University of Michigan and a current leader in the use of handheld computers in education, Kristina Hooper-Woolsey, Apple Distinguished Scientist and Former Director of the Apple Multimedia Lab, and others including teachers and students. The contest was announced in September of 1999, with an awards event that took place at the Exploratorium in March of 2000, with sponsors Palm Computing, Handspring, Learnlots, DataViz, Puma Technology, Handango, and the Exploratorium. Some of the winning applications have since become market leaders in educational software (Four. Zero and Due Yesterday), and another has become influential in the use of handheld technology for science and collaboration (Geney, from Simon Fraser University). It was at the awards ceremony that, while CILT researchers and Mike Lorion were discussing the potential of handheld use in education, the seeds of the Palm Education Pioneer program (PEP) created at SRI"s center for Technology in Learning, were sown.

CILT as "Research Broker"

Based on industry's eager participation in seed grants, CILT looked at fostering research relationships with industry partners based on mutual interest, and not depending only on the happenstance meetings at a CILT conference. CILT called this role one of "research broker." As a research broker, CILT would attempt to match the interests of industry representatives with those of the research community. To pilot this idea CILT initially concentrated on research at the Core Four institutions, and industry representatives that had expressed an interest in collaboration.

CILT had an early success in matching up PASCO with an SRI-led research program called ChemSense. PASCO is a leading supplier of educational probes and sensors, and PASCO was interested more fully understanding how these sensors could be used in cutting edge curricula. ChemSense was starting to consider the uses of probes and sensors in linking classroom-based labs to simulation software. Due to CILT's extensive networking role in both the research and industry community, CILT was able to broker a successful arrangement between these two groups.

Other attempts at brokering relationships were not as successful. For instance, CILT expended significant effort in attempting to broker a relationship between Turner Learning and researchers at Vanderbilt University, but a relationship never materialized. In another instance, it became apparent that there was potential synergy between work at AT&T labs on representing social networks, and the interest of the CILTKN to represent the network of its members. Although several attempts were made at finding productive collaborations, no true collaboration was ever formed. Instead, AT&T simply provided the source code to CILTKN to use as part of its portfolio of tools, a far cry for the original expectations of CILTKN and AT&T labs working together on representing social networks.

Our initial analysis reveals several flaws with the Research Broker model. The first is a mismatch between industry and research objectives. (Also see findings from CILT PI Roy Pea's National Academy of Sciences report from a workshop of his "Committee on Improving Learning with Information Technologies," Pritchard, 2002). Because CILT did not have a way to investigate, understand, and respond to a company's business model, relationships were hit or miss: the relationship with PASCO succeeded because PASCO had a direct interest in learning more about how their products were being used in the field. Other relationships were not as successful because it was not clear how working with research would provide a near term benefit to the industry representative. This, combined with already existing concerns about CILT's IP model, was a significant barrier to industry participation.

Similarly, there was a lack of incentives for researchers to work with industry. As discussed above, CILT could not offer any particular incentives to a researcher to work with industry, other than any incentives that could be offered by the industry partner itself. This is in comparison to other centers of research, where participation in the center carries significant benefits for the researcher, and collaborating with industry where appropriate is one of the requirements for participating in the center.

Finally, there is a mismatch between the timeframes in which industry and research work. The most obvious of these mismatches can be found in funding cycles. Researchers spend several months writing a proposal, then six months waiting for a response, and then another month or two in final negotiations with the funding agency (in the best case: if the project is not funded, researchers may then go back to rewriting the proposal, etc.). This type of long-term conditional funding is not compatible with the budget cycles of many companies, which make funding decisions and expect to immediately start work on a project. CILT did not have resources sufficient for the brokering function, and could not help overcome scheduling incompatibilities.

We will mention two examples of CILT brokering outcomes which we were able to document. Most of the collaborations and conversations that resulted from CILT conferences and seed grants are hard to document. The Palm Education Pioneers program was a direct outgrowth of CILT: CILT provided the forum to begin discussions between Palm and SRI International. PEP has since become a landmark study, providing an initial understanding of effective uses of handheld computers in the classroom. (For example, see the 2003 CoSN report at http://www.cosn.org/resources/compendium/3.pdf which draws heavily on the PEP evaluation. In addition, see Stroup & Petrosino, 2003). CILT's interactions with Intel resulted in Intel adopting a CILT technology tool, the Causal Mapping Tool. Intel looked to CILT for occasional guidance for its education website. Intel was interested in providing free, general purpose tools that supported higher order thinking, and saw the Causal Mapping Tool as a direct fit. Due to CILT's open IP policy, and Intel's standing as a Senior Industry Member, Intel had access to the source code, and they hired CILT researchers as consultant to advice on the re-creation of this tool for Intel's purposes. This tool is now called Seeing Reason and is available at http://www97.intel.com/scripts-seeingreason/index.asp

Lessons Learned

Through its successes as well as its disappointments, CILT has learned valuable lessons for future attempts at research/industry collaborations in educational technology. We have learned that industry is best engaged with clearly identifiable projects, whose researchers have a stake in the collaboration.

While this may seem self evident, we note that CILT did not have any of these characteristics at the beginning: instead, CILT was relying on the power of research-based ideas to sway industry into modifying products and plans to incorporate best known practices. We have since learned that any institution responsible for forming collaborations (such as CILT) must play an active role in understanding the needs of industry, and have resources to diminish the discrepancy in timeframes.

While these findings may be important in areas other than educational technology (see Postscript for a summary of findings from other fields), we note that educational technology is a particularly difficult arena for collaboration. Educational technology currently has very low profit margins, in part because K–12 education is very fragmented market to sell into, which limits corporate investment. Additionally, it is not clear to many companies how research can help them improve their products: and while the recent passage of NCLB has attuned industry to the importance of "research", NCLB emphasizes "horse race" research based on standardized test results, not research on design or research that challenges what can or should be taught in schools. We may find that when the research community speaks of "research" and when educational technology industry developers speak of "research", they have different models of research in mind, further limiting successful collaboration.

CILT has also shown that industry can be productively engaged in very short-term projects, such as participating in collaborative conferences and workshops. These collaborative workshops and conferences filled an important need for industry and academia, but did not have the significant impact on early-stage technologies that was originally envisioned. While participation in conferences or workshops may not lead directly to the types of long-term and deep collaboration that we were ideally striving for, conferences and workshops provide a low-risk, low-cost manner for industry and research to stay abreast of each others' latest developments in a more substantial manner than simply attending a less focused conference, such as NECC.

Finally, we learned that researchers also need incentives to work with industry. Researchers' goals, responsibilities, objectives, and timelines are often mismatched with those of industry. In order to create productive relationships with industry, it is important that there be a reason for researchers to overcome these obstacles. CILT, without any centralized authority, was not able to provide incentives in a way that other research centers have been able to. Furthermore, CILT was hampered in courting industry since its efforts were spread throughout all of CILT, but the gains were realized solely by those who found ways of participating with industry, and eventually, by the field at large.

Postscript

Since the 1980s, after a series of bills (the Baye-Dole, Stevensen-Wydler and Federal Technology Transfer Acts) were enacted, federal laboratories and the private sector have put significant effort into partnering to advance the competitiveness of industry while furthering the agencies' mission. Recent analyses of these efforts (U.S. Dept of Commerce, 2000 and 2002) have shed light on some of the most important aspects of public/private partnerships, and provide a comparison with CILT's experience in creating productive public/private partnerships in the educational arena. The summary provided here can only indicate the main findings of these detailed reports, and the interested reader is encouraged to refer to the original publications.

Intellectual Property. Clear intellectual property agreements are vital to effective technology transfer, and such agreements can help to bridge the different expectations faced by the public and private sectors. Additionally, industry's interest in working with protected intellectual property is often more nuanced than the academic community might expect, as industry values a wide range of knowledge-sharing practices including gaining nonproprietary access to knowledge and hiring graduate students with a core set of skills, as well as proprietary licensing of patented technologies. Before determining if a technology should be protected (typically through patenting) it is incumbent upon the federal laboratory to consider "whether patenting will enhance the potential for dissemination and use of the technology. In some situations broad access to the technology is the most effective way to ensure widespread use. In other situations, the exclusivity provided by a patent may be necessary to encourage its development and use" (US Dept. of Commerce, 2000). For example, if a technology is ready to go to market, and widespread adoption is critical to the success of the technology, the Laboratory may work on a nonexclusive basis with industry partners to incorporate the technology into products without a patent or licensing agreement. However, in cases where significant effort is still required before a technology can have a market impact, a patent and corresponding license may be the most effective way to ensure that a particular industry partner can commit the resources needed to further the development of the technology into a marketable product. In each case it is vital that the mission of the federal laboratory, the needs of industry, and the best interests of the public are taken into account.

Finding the appropriate partner. It is difficult for companies in the private sector to identify the federal laboratory that most meets their need. While larger companies may have the resources to investigate the different laboratories, small companies typically lack such resources and if they contact the laboratories at all it is based on personal contacts or geographical proximity. The federal laboratories have begun experimenting with a Web-based resource to help potential industry partners determine the most appropriate labs and technologies for their needs (see http://www.federallabs.org/). Challenges to such an approach include ensuring that potential users of the system can navigate effectively, and ensuring that information is kept up-to-date.

Technology transfer requires effort. Those labs with the most successful technology transfer policies have integrated technology transfer into their planning, budgeting, and execution strategies, and have personnel dedicated to the area of technology transfer. The evaluation of Engineering Research Centers (NSF, 1997) has found that the more effort that an industry partner puts into the partnership, the more benefits that partner will receive. For a public/private partnership to succeed, both parties must be fully behind the effort, and must allocate significant resources to the partnership.

While each of these implications is relevant to the educational research community, we must also contend with a unique set of market issues. The education technology market has low profitability and is slow to adopt new technologies. As a result, the education industry is less likely to see the benefits of a long-term relationship with research (compared with, say a pharmaceutical company collaborating with researchers at the National Institute of Health on a new drug).

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Table 3. Industry Involvement

Industry Sponsorship of Events	Industry in Seed Grants
*Intel	Better Education, Inc.
AlphaSmart	Bricolage Interactive Design
Classroom Connect	Casio, Inc.
DataViz	Corporation for National Research Initiatives
Exploratorium	EdMark
Handango.com	ETS
HandSpring	FamiliarTales, Inc.
IKON	Hewlett Packard
InFocus	IDEO
Knowledge Kids Network	Intel
Learnlots.com	Interactive Learning Design
Lightspan	Joint Venture Silicon Valley
NetSchools	Key Curriculum Press
Oracle	Little Planet Publishing
Palm	Logal Software
PASCO	MetaCourse
Puma Technology	Oracle
Psion	Rapport Systems
RiverDeep	RiverDeep, Inc
Sun	SG-Systems
Teacher Universe	StageCast
TeachScape	Stottler Henke Association, Inc
Tech Museum of Innovation	Talaria, Inc.
Texas Instruments	The Exploratorium
	The Odyssey
	Trivantis

CILT: An Industry Perspective

CHARLES PATTON, Hewlett-Packard, now at Center for Technology in Learning

In order to best highlight the change in relationship between the educational technology industry and NSF-sponsored educational technology research, a change wrought in no small measure by CILT, it will be useful to recall the situation a decade ago.

In [September] of 199[4], I participated in an NSF-sponsored workshop at Georgetown University. The driving motivation for this workshop was the observation that, with all the money invested by the National Science Foundation (NSF) in the Applications of Advanced Technologies (AAT) program, and all the spectacular research done through this program, little of the work survived past the end of grant funding to have a self-sustaining impact on education. Much of the work ended up, as one participant put it "in a box on a dusty bookshelf somewhere." This workshop brought together a substantial fraction of the AAT principal investigators (with their technology demos, talks, and posters,) and a reasonable sampling of companies with potential interest in commercializing the results of the research. These companies were, by and large, educational publishers some of whom were software-only publishers, but most of whom had both text and software offerings.

Although I was acquainted with quite a few of the AAT projects and their principal investigators, I came at the request of Ed Murphy, who was at that time President of PWS Publishing and with whom I had been working to craft a strategy to move from a textbook-plus-software model to a model supporting the electronic delivery of content. My "dual citizenship" in these two communities provided me an interesting vantage point from which to view the workshop.

On an emotional level, the workshop might best be described as something akin to a junior high dance—with the boys lined up on one side and the girls on the other, and neither side quite ready to make a move despite the encouragement of the adults. Eventually, however, they took to mingling and demos were presented and business cards distributed. In side conversations with researchers, however, I heard recurring themes that these commercial people didn't really understand education, technology, or research; that all they really wanted to do was to make a quick buck; that they lacked vision for where these technologies could go in the future; that, when it came down to it, they were unwilling to value the technology fairly.

Similarly, in side conversations with publishers I heard recurring themes that the researchers had no realistic concept of what kind of offering would actually be saleable; that the software, while adequate for a research prototype, was completely lacking in many of the standard (and boring) prerequisites of commercial software and would need to be redeveloped from scratch; that the researchers were so committed to their vision of the product that they were unwilling to consider alternatives.

As might be expected with the two sides so thoroughly misunderstanding one another, few concrete deals emerged from this effort. The larger lessons—that businesses could benefit from a relevant understanding of education and research, that research could benefit from a relevant understanding of the demands of the marketplace, and that both could benefit from an earlier-stage, and ongoing, open exchange—these lived on and were embodied in CILT.

CILT Business Models

From the industry perspective (I participated in CILT activities as a representative of Texas Instruments) it seemed that these lessons were the only 'givens' in the first CILT workshop. The organizers took the bold (and risky) step of empowering the conferees, researchers and commercial folks alike, with the responsibility of shaping how CILT would operate to achieve these important benefits. Though risky (and CILT certainly had its share of rough edges and dead ends) this move quickly established to the commercial folks that CILT was not another "fashion show" of research, nor was it another sales opportunity.

The former model, epitomized by the now-defunct MIT Media Lab, was widely viewed as the standard practice of the time. The business proposition for such a practice is that companies with a desire to transform themselves through disruptive technologies could pay up front to get an early peek at the shape of the future as envisioned by creative minds, unconstrained by business realities. However, no one in the business of educational technology at the time seriously held beliefs that any technology innovation in the education sector would have promise on the same scale as, say, color fax machines.

The latter model, epitomized by a trade show booth at an academic conference, was (and is) widely view as standard practice. The business proposition for such a practice is to heighten brand-awareness among a group that might, or might not, influence purchasers down the road. In any case, companies are hard-pressed not to "show the flag" at public gatherings at which their competitors might have a presence. However, the CILT organizers made it very clear through the participatory, workshop format that sales opportunities at CILT would be quite limited.

Instead of these standard models, the organizers aimed for CILT to become a learning community of researchers and commercial folks with a shared goal of improving education through technology (and getting research grants, and selling products…)

With both the standard business propositions ruled out, and without another neatly packaged business proposition expounded by CILT itself, the companies had to craft their own business proposition for participating in CILT and the strength of their own business proposition dictated the depth of their involvement in CILT.

Through my conversations with various industry participants, I noted two kinds of business propositions that emerged, each a sublimation of one of the standard models, and both related to the learnings from the AAT event.

Some industry participants held that if they could understand, in detail, the ways in which researchers reconceptualized, refactored, and articulated the core issues in teaching and learning with technology then they could uncover and capture significant latent needs of their target customers, needs that they might only discern late, or never, through their normal channels. Although they could, alternatively, go to research conferences or read research papers, in both those cases the main audience is other researchers, not commercial folks. As a consequence, both the language and the focus of the presentations in these venues are more likely to make them less usable than at presentations and conversations at CILT, where commercial folks were key participants.

Identifying and clearly articulating important latent needs of your customers provides the company with a key competitive advantage. In fact there are few (if any) examples of commercially successful technology in which such identification was not the critical success factor—certainly more important than the technology itself.

Some industry participants thought about the business proposition rather differently. CILT, they thought, represented a collection of really smart and potentially very influential people, people who could and almost surely would greatly influence the national conversation on technology in education. If, through CILT, they could elevate the research status of their own concerns—concerns such as adoptability, ease-of-use, form-factors, efficacy, and total cost of ownership—then they could expect these to surface more strongly in the national conversation than they could ever hope to achieve by themselves.

While it might seem that influencing the national conversation on technology is a rather indirect approach to achieving a competitive advantage, raising the perceived importance of a solution aspect (especially one in which a company holds a key advantage) is a well-understood and well-respect marketing approach.

Note that these two business models have opposite models of influence: in the first model, it is the companies' understanding of the latent needs of the market that is being influenced by the researchers; in the second, it is the researchers' views on the relative importance (research worthiness) of various solution aspects that is being influenced by the commercial folks. It is a credit to the CILT project that companies viewed one or the other or both of these models as being supported by the structure of the project. I conjecture that the extent of a company's participation is closely correlated with the extent to which one of these models resonated with business priorities and that had CILT organizers had espoused and explained the models more vigorously, there would have been even greater commercial participation.

There are several examples of more-or-less direct CILT outcomes that had a traceable impact on one or more of the companies involved with CILT. Their success illustrates the dynamics of these business models.

Datagotchi and PEP

One outcome of CILT with a traceable impact in industry was the "Datagotchi Deep Dive" activity and subsequent report. In this activity, CILT organized an intensive session that brought together a small, but diverse, set of participants to sketch out the design of a product, the Datagotchi, in a single day. The structure of the event was a "deep dive," which is a brainstorming process developed by the design firm IDEO (and facilitated by them in this case as well). In a deep dive, the participants are given the mandate to sketch a visionary product for a target group of customers (in this case, middle-school math and science students.) Although it is only to be sketched, the participants are encouraged to be very concrete and explicit (even to the point of carving Styrofoam models) about details that count, leaving the rest to brief explanations. Further, they are to provide vivid narratives about the contexts of use of the product, narratives that illustrate how the design scenario addresses important issues. In this case, the narratives covered several days of students' experiences, in class and out of class, and also brought in the teachers' and parents' perspectives.

While it might seem that this deep dive would have been an ideal venue for coming up with the latest and greatest inventions (and indeed, some of the features envisioned in the deep dive have since shown up in research prototypes) it was neither viewed nor used as a source of inventions in the companies about which I have knowledge. It was viewed instead much more in keeping with the first business model: revealing important latent needs. Because the deep dive illustrated not just an interesting idea, but a hypothesized solution shown in context, the deep dive revealed a lot about what researchers feel are deep needs in educational technology and revealed them in a way that can be rather easily validated with real customers. This combination of factors (along with the playfulness and creativity so evident in the report) gave this report an extensive readership at, for example, Texas Instruments and quite significantly raised the credibility of the CILT endeavor in the eyes of commercial participants.

A second CILT outcome with traceable impact was the Palm Educational Pioneers (PEP) program and report. In this SRI-administered program, teachers and researchers applied for support, in the form of classroom sets of Palm handheld computers, on the basis of the strength of their vision of how the devices would be most useful in the classroom and how they would go about documenting how well or poorly it all turned out.

This quite clearly supported the model of discovering latent needs, since the applicants described their view of their needs in the application process itself. But perhaps more interestingly, the PEP report delivered even more powerfully on the second business model: influencing the national conversation on educational technology. The PEP report functioned as preliminary research on a broad range of topics concerning handheld computers in the classroom (e.g., shared set versus individual ownership use models) that are of significant interest to commercial folks. Cited more than a dozen times in original research papers, the PEP report evidently provided many researchers an opportunity to think seriously about handheld devices in the classroom.

Although there were many other more diffuse and less traceable outcomes of the interaction of the commercial folks with CILT, it is my impression that those which had an impact all partook of one or the other (or both) of these implicit business models.

Intellectual Property

A reflection of the fact that commercial participants needed to craft their own business proposition for being involved with CILT was the apparent impedance mismatch between the commercial folks and the researchers regarding intellectual property. Even though there was a lot of effort devoted to crafting IP terms (and a lot of attempted innovation on the part of researchers) the results were at best neutral from an industry perspective. My observation here is that the companies with which I was associated thought very differently about intellectual property in CILT-like situations than did the researchers.

In particular, without other well-defined business objectives, the first corporate priority with regard to intellectual property agreements was, and is, to safeguard the company against litigation. It should be noted that it is rather standard corporate policy to turn away at the door anyone who arrives claiming to have a great idea for the company, at least if they are unwilling to sign away all claims on the idea before presenting it. Although the public forum aspects of CILT lessened this concern, it certainly did not eliminate it and researchers wanting to talk specifically about intellectual property terms (which must automatically bring in the lawyers) actually heightened the concern.

The second corporate priority with regard to intellectual property arrangements, again in the absence of countervailing business objectives, was, and is, to insure that their actions don't inadvertently 'impair' their existing intellectual property. Would anything they did with CILT stop them from enforcing their intellectual property rights against some as yet undiscovered infringer? Would anything they did with CILT prevent them from asserting to some potential licensee that they had clear title to the intellectual property? These are the kinds of questions that surface in such a discussion.

To this observer it appeared that the researchers, perhaps smitten with the tech boom and certainly enamored of the open source movement, choose to discuss business objectives solely in intellectual property terms. This approach invoked the default corporate intellectual property priorities without having first solidified an understanding of shared, concrete business objectives that could be used to make a convincing argument that the CILT-related benefits to the organization were well worth the intellectual property risks.

Conclusions

Although CILT did not manage to achieve self-sustaining industry funding in perpetuity, and might therefore be liable to the "in a box on a dusty shelf" characterization, it is undeniable that the relationship between the education technology industry and NSF-sponsored educational technology research has changed significantly over the course of the CILT project and beyond. On the one hand, many of those same AAT researchers (and many others besides) now have industry partners and are continuing to have earlier-stage open exchange of ideas, issues, and concerns with those partners. On the industry side, there is a much broader awareness of the opportunities and challenges of working with researchers and an evolving understanding of what industry-research business models are workable in the educational technology context. Taken together, I believe that these have positioned the educational technology industry and educational technology research to work together much more effectively toward improving education.

CILT Conferences and Workshops

LINDA SHEAR, Center for Technology in Learning

One of CILT's primary missions was to build community among the people who are or will be drivers in the learning technology field. The desired community crosses boundaries of professional focus (including researchers, educators, developers from industry, and policymakers) as well as boundaries of experience (we seek to bring together today's leaders with those of tomorrow).

Although the concept of community is so core to the Center, we were wary of using that term because of its breadth. "Community" has become a catch-all construct that describes many different sorts of relationships and interactions between groups of people, whether face-to-face or remote and whether cursory or deep. At CILT, we had a much more specific vision. When we say community we think of active collaboration, in the manner of the best "collaboratories"[25]: not only do people know each other and each other's work, but they share resources, collaborate on projects, and think together about critical directions for future research and development. Clearly, this definition of community benefits the field as a whole, as it promotes work that builds on collective rather than individual skills, vision, and resources. In addition, it offers individuals the benefit of expanded professional horizons in the form of networks, partners, and opportunities for professional growth that might not otherwise have been available to them.

The CILT project has developed several mechanisms to catalyze this type of active collaboration. Over the course of the project we honed a design for workshops and conferences that go far beyond information sharing; these are the topic of this paper. This section also contains papers that discuss other important mechanisms for fostering active collaboration, including seed grants (funding for specific collaborative work that begins to tackle important problems identified in workshops), the CILT Knowledge Network (a broader online tool for maintaining and extending community), and the Industry Alliance Program (a program to work directly with members of industry as active participants in the CILT collaboration).

CILT Workshops

At the heart of CILT's approach to community-building was a format for workshops that are designed specifically for fostering active collaboration. In contrast to workshops with a primary goal of specific knowledge- or skill-building or conferences with a primary goal of information sharing, CILT's workshops were intended to encourage participants to initiate collaborative work on topics of mutual interest and recognized importance.

CILT's workshops have primarily been used as a meeting of theme team groups: for example, participants may all work in the area of ubiquitous technologies or tools for visualization and modeling. This thematic focus is essential for setting a session scope that is broad enough to promote variety of ideas yet specific enough to offer focus and common ground.

[25] See Nathan Bos' chapter in this publication.

CILT workshops generally lasted two days, with time to get to know who is in the room, agree on important next steps for the field, and break into small groups to begin work on specific next steps. The workshop model has several design components:

- *"Firehose" talks and demos (first morning)*. Firehoses are 5-minute long, time-limited introductions to each participant's work and partnership needs. Unlike a typical research presentation, in which the presenter communicates as much as possible about the methods and findings of the research program, we instead ask participants to offer brief introductions for potential collaborators, presenting enough information to catalyze future more in-depth conversations among individuals or small groups with common interests. For these purposes, we have found that five minutes is an appropriate time limit: long enough for an effective introduction, but brief enough to introduce a broad range of the work represented in the room in a short period of time. We have also found it important, for purposes of maintaining the energy of the session, to enforce the five-minute limit consistently and clearly. Concurrent demos and poster sessions are an additional mechanism for participants to share information on what they do.

- *Panel discussions (first morning)*. This mechanism was sometimes used to introduce broader issues or discussions of the state of the field that serve as important grounding for the groupwork that follows.

- *Facilitated brainstorm of important future directions (first afternoon)*. The activities of the morning serve to develop a collective vision of the current state of the field, based on the work of practitioners and on panel discussions and other focusing remarks. The next core element of the workshop was agenda-setting: discussion of strategic next steps to advance understanding, development, and/or implementation. This step is accomplished through a facilitated brainstorm, based on the ideas of individuals or small teams that are then captured for consideration by the larger group. For example, people might offer ideas for new technology development to address an important need in the field, or for practical assessment strategies to make visible the student learning that results from a class of tools. It is important that individual ideas are captured in ways that allow ideas to be re-organized and grouped; we find colored 5x7 pads of stickie paper to be useful for this purpose.

- *Prioritization and voting (first afternoon).* In a facilitated discussion, the brainstormed ideas were amplified or refined through group reflection and organized into a draft set of categories, usually by CILT workshop leaders. We have used several techniques to prioritize the categories once established; asking everyone to vote with colored stickie dots is one particularly interactive way to make votes visible. It is important that the charge to the group at this stage is to agree on directions for research / development / implementation that are most important to the field, not those that are of greatest personal interest to a given participant.

- *Group formation and planning (first afternoon, second morning).* Following on the activities that were deemed most important for the field to pursue, we then asked individuals to form groups based on interest and begin to sketch out a specific course of action. "Voting with feet" is the easiest way to form these groups: people simply collect around the posted category of ideas they feel the most affinity for, and they then collectively work to define and refine the central features of the categories of interest.

A critical design feature of CILT workshops was the "seed grant": a small amount of funding available through a competitive proposal process to jumpstart the collaborative project that the team envisions during the workshop. Seed grants are selected according to a number of criteria that include evaluation of the importance of the project goals to furthering the agenda developed during the workshop. In this way they offer a concrete incentive that helps productive collaborative action to continue beyond the initial face-to-face meeting. Seed grants are described further in a subsequent paper.

- *Wrapup (second afternoon):* CILT workshops end with groups reporting their progress back to the larger gathering for further refinement of ideas, as well as group confirmation of the "big ideas" that were generated by the agenda-setting process.

Evolution of CILT Workshops and Conferences

Over the course of the CILT project, workshops were conducted in a number of formats. In CILT's first year, each of the four theme teams held a separate workshop with roughly 100 participants each. These gatherings were free of charge and by invitation, primarily including participants that were known by CILT leaders to do important work in the field but also open beyond, in that invitees forwarded invites to colleagues at other institutions. These initial workshops served to hone the overall workshop method and to establish known communities of practitioners in each of the theme team areas.

In 1999 and 2000, the four separate workshops were combined into a larger conference, partly for what we hoped would be conservation of labor and partly to allow networking across the separate theme communities. The schedule for each conference included plenary sessions—for example, a panel of policymakers talking about important drivers of learning technology implementation, or a presentation from a visionary leader in the learning technology field—as well as workshops, where for the central day and a half of the conference theme teams gathered in separate rooms for a workshop that followed the pattern described above.

The conference format, we found, had a number of pros and cons. Participants generally liked the plenary sessions that they could all experience without traveling to multiple workshops, and they liked the opportunity to meet people with a broader range of expertise. The leadership team liked the fact that they could all work together to plan the conference, rather than each team member being responsible for hosting his or her own workshop. An additional benefit was that broader-based advertising attracted participants working in a given area that were not already known to the leadership team, expanding the CILT community in ways that invitation-only workshops could not accomplish.

However, conference costs were significant. Each conference attracted approximately 350 participants: the right number to allow for manageable theme team sessions, but few enough that little economy of scale was achieved. The conferences required considerable central coordination (both within the CILT team and through hired services) for registration and housing, marketing, industry sponsorships, evening events and receptions, and a myriad of administrative issues. We also found some challenges related to CILT-specific designs when we looked at major hotels as venues: for example, CILT workshop facilitation tends to be very visual, and not all hotels are amenable to hanging things on the walls or to the extensive technology requirements of demos and widespread internet access. Overall, despite the registration fees paid by participants and the sponsorships offered by industry, we found it difficult to host a conference of this scale for less than $80,000.

Even with the larger conference structure, theme team workshops remained the core of activity and the unique attraction of CILT. For ease of coordination, in later years of the project we returned to the model of separate workshops for themes. These tended to be in specific topical areas of growing interest (for example, there was a workshop on design principles for learning technologies and one on handheld technologies).

Results

Overall, conference evaluations from participants were extremely favorable, with the highest ratings in areas in which CILT proposed to be unique. For example, 69% of CILT2000 attendees who completed paper-based or online conference evaluations rated the "quality of interactions/networking opportunities" as a 1 ("exceptional") on a four-point scale. Participants from different branches of the field (e.g., industry, research) commented frequently that they had in-depth interactions with people they would not otherwise have met, and early-career researchers commented on the doors that had been opened. Another uniqueness highlighted by many was the richness of ideas exchanged; said one participant, "This was not a conference—this was a think tank!"

Workshop results are also measured through a number of other means. For example, seed grant projects that were initiated at the workshops produced a number of fruits ranging from the development of new tools to symposia or workshops that brought CILT's ideas to new groups of people (e.g., at the SITE conference for teacher educators). Seed grant outcomes are discussed in a subsequent paper. In addition, the CILT workshop model has been replicated several times for a range of purposes, including expanding on particular research ideas or companies wishing to incent important collaborative research on topics related to their product lines.

Nevertheless, there were several issues that remained a challenge throughout the project. The most salient is that the workshop structure—setting an agenda for future work and incentivating collaboration with seed grant funds—appeared to be more attractive to researchers than to the other core groups we hoped to engage (educators, industry representatives, and policymakers). Educators did not always have the time or inclination to engage in longterm research, an issue that is also reflected in the early failure of the planned School Partner Program. Industry developers were often hoping to further proprietary products under development, so CILT's model of pre-competitive work with open IP was not always appealing (see the separate paper on IP issues for further discussion). Policymakers liked the open sharing of ideas, but their goals rarely included specific group work toward a project in research, development, or implementation. In short, while CILT conferences and workshops made significant progress toward assembling a community that crossed traditional silos of research, industry, policy, and practice, work is still needed to develop a model that has equal appeal to the full range of participants we sought to include.

Seed Grants

MELISSA KOCH, Center for Technology in Learning

CILT developed a process for encouraging, selecting, and managing seed grants. The seed grant program was designed to foster collaborations on synthetic and exploratory work, provide opportunities for early-career researchers, and promote projects that build on multi-institutional expertise. CILT's collaborative workshops and conferences were catalysts for seed grant collaborations; these events provided opportunities to assess the progress of the field, define research agendas, and initiate new partnerships. Since its inception, CILT has supported 60 seed grants involving approximately 169 institutions and totaling $617,369. Five overarching themes plus cross themes in the learning sciences were addressed by seed grantees: Visualization & Modeling; Ubiquitous Computing; Community Tools; Assessments for Learning; and Teacher Professional Development

Grant Process

During the CILT ABR period, the CILT team documented and institutionalized the seed grant selection criteria and management practices so that others could learn from and replicate the program. The selection criteria required that successful proposals contain the following:

- Cross-institutional collaborations that build on each organization's strengths.
- Innovative work important to the field.
- Opportunities for early-career researchers.
- How they extend one of CILT's current themes, connect to emergent themes, or identify important cross-cutting ideas.
- How a small amount of funding will enable future work.

The management process used by CILT for the seed grants was:

- CILT distributed seed grant RFPs and guidelines at CILT conferences, workshops, and posted them at www.cilt.org.
- CILT used the selection criteria and developed key identifiers of success to select seed grantees.
- SRI managed contracting and funds.
- Postdocs monitored seed grants.
- CILT developed seed grant reporting formats for interim and final reports.

While there was continuous improvement during CILT's existence, this process was not wholly effective in administering the seed grants, as will be discussed in the following section.

In addition to the structure and artifacts important to running a seed grant program, CILT has identified key characteristics and research goals to encourage in future seed grant proposals and to use as a guide in awarding these future seed grants. We have found that all successful

CILT seed grants have at least four of the following characteristics plus one or more of the goals listed below:

Characteristics of Successful Seed Grants

- Committed partners, to whom this project is personally important and exciting. The group has momentum.
- CILT Team or a team member is interested and invested in the topic.
- Well-defined scope and goals, realistic for the time and budget available.
- A project deliverable that offers an effective dissemination mechanism for whatever is learned.
- A project deliverable that advances next steps (e.g., a proposal for a larger follow-on project).

Generative Seed Grant Goals

- Clarify and synthesize a topic to enable research to move forward in the field.
- Extend the work of a CILT theme to include a broader group.
- Explore an innovative application of technology in education or in a new educational context.
- Network a community working to accomplish one of the above goals.

Summaries of all seed grants can be found on the CILT web site, http://cilt.org

Seed Grants as a Mechanism for Fostering Targeted Collaborations

Given the importance that seed grants have as a mechanism for transforming the nature of research interaction within the field, and the central role in their award played by postdocs, key findings from the telephone survey of seed grantees and relevant comments extracted from the interviews with postdoctoral scholars are useful. As one postdoc phrased it, "The really important thing that CILT has done has been to support a new generation of researchers, most of who are within 5-7 years of degree. If you look around at who has received seed grants, it's mostly younger researchers who came to CILT conferences and initiated collaborations. And obviously, the CILT postdocs are part of this cohort. I think it's also led to a more coordinated research agenda among these researchers, who have the opportunity to see what each other are doing and plan strategically together to set an agenda for the next several years."

A worthwhile suggestion advanced by the postdocs, was that the seed grant work be cumulative; for example, themed seeds should collaborate on a book for dissemination to the field. The need for seed grants is generally recognized, but, based on feedback from the Year 4 evaluation, it is not yet clear what the best mechanism for administering them is.

The number of partners on individual projects varied from 1 to 25. Partnerships included representatives from 169 institutions (see map in the Executive Summary: universities and research centers, industry, schools and educational agencies, and other agencies, primarily museums and foundations).

While most grantees said that they were satisfied or very satisfied with the seed grants, many noted specific issues that they found frustrating. These issues were related to the size of the grant in relationship to grant requirements; contracting difficulties across institutions, usually related to intellectual property policies; and, support available from the CILT leadership team. A significant comment offered was: "The whole idea of CILT is great and ambitious and it strikes me as an important effort. Seed grant is an effective mechanism for hooking people up who would otherwise not hook up. But people have institutional constraints that make collaboration hard to sustain. Seed grants are so small that they are hard to support in an extended way. It is a good idea to support collaborations that are organic. It fills a nice niche and if we could figure out how to make that niche bigger, it would serve so much more. Maybe real money ($30,000 or $35,000) from NSF would help meet the goals of CILT. CILT helped support people intellectually but not collaboratively."

When asked if the seed grants had impacted the career development of anyone who worked on the grant, including principal investigators, partners, and any graduate students, 84% of responses were positive; the grantees felt that work on the grant project had benefited the career development of one or more people working on the project. 27% of the responses specifically mentioned graduate students [and in one instance an undergraduate student] as developing important career skills through their participation. Comments included that participation in the grant project improved careers by leading to other funded proposals; helping early career researchers forge connections to more established researchers; developing software development skills; increasing visibility in their university and at a national conference, opportunity for a graduate student to explore a new research area. For another early career researcher, the opportunity to be a principal investigator on a project was an important benefit. For several grantees, the benefits were less tangible but nonetheless important: the support of a nurturing environment; developing a broader understanding; and being part of a larger community. Negative responses referred to the difficulty in separating the impact of the seed grant from that of other funding sources. The opportunity the seed grant process provided in terms of exposure to new ideas, as well as the ability to network with senior people were mentioned as more diffuse benefits of the seed grant process, of particular importance to young researchers whose topic leaves them somewhat isolated in their own institution.

Regarding research itself, seed grants were found valuable in that they could fund topics that were important to the field but difficult to fund otherwise; could provide time for planning future collaborations; could bring together people from diverse arenas; and, could jump start projects by supporting critical partnerships. Grantees also felt that seed grants may lead to uncommon syntheses of ideas; reduce isolation of researchers by emphasizing collaboration; encourage diverse partnerships and audiences for work as ideas are being developed; support experimentation with strategies that could impact the classroom in the future; and, support investigations of the issue of equity. A telling comment was "I don't think I would have pursued the same list our authors for our book. I think I would have felt more isolated. [I am] starting to think less about how I can build my own things and more about how can we as a field make convincing arguments to the public and each other. Lots of new collaborative partnerships."

Reflection on the Seed Grant Process

The CILT seed grant process was a unique approach to tackling important problems that might escape a funder's research agenda. The bottom-up, community-based approach to idea generation ensured that the problem was in response to a felt need in the research community. One potential downside of this approach, however, is a narrow view limited by the lack of participation of stakeholders (e.g., school community). The no-strings-attached approach to funding (except for equity considerations in 2000) presented opportunities for innovation, yet due to the small size of the grants, those that succeeded were tied to other funded work that could bolster the deliverables. Successful seed grants were ones that could create artifacts or practices for the community (such as the design principles database) within a small budget. These capitalized on the desire of researchers to participate in efforts to extend the knowledge base of the field without necessarily being funded to do so.

In reviewing the seed grant collaborations, one notices a lot of university to university and university to industry collaborations, but not many that involved schools. This suggests that the stakeholders for the work were the research community itself or the funding agencies.

In addition to being motivated by the chance to work on new ideas, researchers were motivated by opportunities to collaborate, publication prospects, proposal opportunities, and working in a new area. These factors all suggest a special benefit of seed grant to newer researchers. For those researchers farther along in their careers, the seed grant requirements seemed too much for the funding levels, and some resented postdocs telling them what to do. These perceptions would need to be addressed in future seed grant administration.

Limitations on intellectual property (IP) ownership and possible deterrents to the tenure process (e.g., being distracted by a project that is not leading to a publication) likely biased the seed grant ideas to efforts that were for the good of the community versus one university or industry. Additionally, the small size of the grants discouraged entirely innovative work. In many cases, however, these perceived limitations did not overweigh the excitement of collaborating with people that a researcher would not normally have contact with. Still, people found it hard to collaborate. As some expressed it, the seed grant was something small and outside their normal area of work, conducted with new collaborators who are remote without support for face-to-face meetings.

Overall, however, the seed grant process was productive. The seed grant size allowed for work on specific topics in a short period of time, and focused on collaboration from the beginning. Recipients of CILT seed grants also noted that seed grants were flexible in their ability to fund ideas in their early stages of development that would have been difficult to fund otherwise. The majority of the seed grantees have continued or plan to continue their work beyond the seed grant funding and submitted follow on proposals to NSF or other sources, or have led to community-wide activities.