Integrating Self-Directed Learning and Intelligent Tutoring:
A Research Agenda for Educational Reform

AERA Symposium Proposal

Organizers/Speakers:
Sharon J. Derry, University of Wisconsin-Madison
Gerhard Fischer, University of Colorado, Boulder

Speakers:
Allan Collins, Northwestern University
Ken Koedinger, Carnegie Mellon University
Mitchel Resnick, MIT Media Lab

Discussant: Roy Pea, Stanford University

Abstract

Tutoring has a long and prominent history in the world of research on computers as learning technologies. AERA symposia over the past two decades have charted its progression from programmed instruction to computer-aided instruction to intelligent tutoring systems. A new challenge for intelligent tutoring research today is increasing its relevance to the goals and capabilities of *self-directed learners* in technology-rich environments. The purpose of this symposium is to explore the possibility of evolving a concept of intelligent tutoring for self-directed learning. We have invited leading researchers and educators who have worked within different paradigms (emphasizing self-directed learning or intelligent tutoring) to explore the possibility of creating a synergy that will exploit the best of each approach.

Symposium Proposal

Purpose of Program

Tutoring has a long and prominent history in the world of research on computers as learning technologies. AERA symposia over the past two decades have charted its progression from programmed instruction to computer-aided instruction to intelligent tutoring systems often called "*cognitive tutors*" (Anderson, Corbett, Koedinger, & Pelletier, 1995) because of their theoretical grounding in cognitive science. An interesting challenge for the intelligent tutoring field today is increasing its relevance to the goals and capabilities of *self-directed learners* engaged in personally meaningful tasks, especially those operating in new kinds of Internet learning environments and online communities of interest that are now rapidly gaining ground on a global scale.

Self-directed learning is often discussed from the viewpoint of constructionism (Harel & Papert, 1991), a framework sometimes placed in opposition to the intelligent tutoring movement. In this symposium we will consider the differences and similarities between the two world views, exploring the idea that approaches evolved through intelligent tutoring research might point to ways of significantly improving and supporting self-directed learning.

We have invited leading researchers and educators who have worked within different paradigms (emphasizing self-directed learning or intelligent tutoring) to explore the possibility of creating a synthesis that will build on the history of research from both traditions and, in a merged form, better serve the rapidly changing needs of public education.

Research in the intelligent tutoring paradigm has studied human tutoring as a basis for evolving machine-based tutors with capabilities matching the impressive success of human tutors (Bloom, 1984; Schofield, 1995). Directly encoded learning steps (applied at different rates for different individuals) were replaced with stored knowledge about specific domains, and with sophisticated programs that used this knowledge to infer student models, diagnose student difficulties, and construct personalized tutorial dialogues. Like human tutors, some machine-based intelligent tutors resulting from this work are highly successful according to many standards of assessment (Anderson et al., 1995; Schofield, 1995). But to the extent that current tutorial approaches emphasize mostly pre-determined curricula and learning goals that are established without consideration for the interests of specific learners at specific times, this represents an incomplete and inadequate paradigm for schooling of the future (Bruner, 1996; Fischer, this symposium).

Advocates of self-directed learning argue for alternative models of schooling that emphasize learning in the context of personally meaningful activity and socially-relevant problem solving, in which the main goals are largely determined by learners themselves. Self-directed learning is of increasing importance in today's world of ubiquitous computing and rapid growth of ever-available Internet information resources and the concomitant emergence of models for schooling based on communities of work and interest.

Self-directed learning can be characterized as follows: humans are engaged in some goal-directed activity; they experience a breakdown, impasse, or conceptual collision, and they learn through a process of reflection and information-seeking that is carried out for the purpose of resolving the difficulty and continuing the activity. Schön calls this *reflection-in-action* (if learning occurs in real time during activity), and *reflection-on-action* (when learning occurs through later study while looking back on the consequences of activity) (Schön, 1983; Schön, 1987). Because this process of self-reflection is difficult, a human coach, mentor or teacher must assist learners in reflecting and searching for understanding and knowledge. We are interested in developing models of how intelligent computer tools might provide assistance at points of reflection during self-directed learning.

To be effective, we propose that self-directed learning might be integrated with paradigms derived from the history of research in intelligent tutoring, which can help provide learners with opportunities and support for meeting personal goals and, in addition, acquiring systematic bodies of useful knowledge. Table 1 summarizes some major distinctions and the complementary nature between tutoring and self-directed learning.

Table 1: Intelligent Tutoring and Self-Directed Learning: Some Distinctions and Complementarities

	Tutoring	Self-Directed Learning
Strengths	Focuses on organized body of knowledge; pedagogically and cognitively structured	Focuses on real interests, personally meaningful tasks, high motivation
Weaknesses	Possibly limited relevancy to the interests of the learner or the task at hand	Coverage of important concepts may be missing; demand driven, unstructured learning episodes; lacking coherence
Planning versus situated responses	Advanced planning of learning goals and content; problem selected by the teacher or system; prescriptive	Learning needs arise from situational context; problem is based on personal goals of the student; permissive
Importance over lifetime	In progression from K-12 school to university to lifelong learning, need for tutorial guidance *decreases* in importance	From K-12 school to university to lifelong learning, self-directed learning *increases* in importance
Some unique research challenges	Presentation of organized bodies of knowledge; responsiveness in the teacher-defined context to individual differences	Task identification; context awareness; need for massive number of unpredictable situationally-specific tutoring episodes

A new challenge for instructional technology research is increasing the relevance of intelligent tutoring to the goals and capabilities of self-directed learners, which include not only supporting performance on personally meaningful tasks chosen by learners, but also supporting their need to acquire systematic domain knowledge that will be useful and memorable in other situations, including performances on standards and assessments currently associated with accreditation and formal schooling. The purpose of this symposium is to promote a productive integration among viewpoints that more often than not are characterized in opposition to one another.

Organizers/Speakers, Speakers, and Discussant

The program includes leading scholars involved in related, but different approaches to developing or using technologies in education who have published widely on issues related to this symposium.

Organizers/Speakers

The talks of the following co-organizers will lay conceptual foundations for the symposium.

- ♣ **Sharon Derry**, Professor of Educational Psychology and Learning Science at the University of Wisconsin-Madison, whose career in the scientific development of innovative learning environments includes award-winning work in the intelligent tutoring paradigm;
- ♣ **Gerhard Fischer**, Director of the Center for Lifelong Learning and Design and Professor of Computer Science at the University of Colorado, well-known for his leading work in

the self-directed learning paradigm.

Speakers

- **Allan Collins**, **Northwestern University**, who worked with Jaime Carbonell on the first intelligent tutoring system called Scholar, and later developed a system called Why that tutored using Socratic dialogue. He since has been advocating a more learner-directed approach to the design of computer-based learning environments.
- **Ken Koedinger, CMU**, has been a leading figure / pioneer in developing intelligent tutoring systems. The tutoring systems he has developed with collaborators have found wide-spread distribution in schools.
- **Mitchel Resnick, MIT Media Lab,** is a leading figure in the development of technologies and environments that support self-directed learning. His Lifelong Kindergarten research group developed technologies and ideas underlying the LEGO Mindstorms product, and co-founded the Computer Clubhouse network of after-school learning centers.

Discussant

- **Roy Pea, Stanford University,** has been a leading figure and pioneer in educational application of technology and has in the past challenged some of the claims of the proponents of both camps (Pea, 2004).

Session Format

A two-hour session is requested to provide sufficient time for speakers and audience interaction. The session plan follows:

1. Chair's opening: 5 minutes
2. Talks: 15 minutes each
3. Discussant: 20 minutes
4. Panel discussion. audience interaction: 20 minutes

Speakers' Titles and Summaries

Gerhard Fischer: Enhancing Self-Directed Learning with Contextualized Tutoring

Problem: Learning is more than being taught. Teaching is often *"fitted into a mold in which a single, presumably omniscient teacher explicitly tells or shows presumably unknowing learners something they presumably know nothing about"* (Bruner, 1996). A critical challenge is a reformulation and reconceptualization of this impoverished and misleading conception. While this model may be more realistic for the early grades in schools (Hirsch, 1996), it is obviously inadequate for learning processes as they occur in lifelong learning, where knowledge is distributed among many stakeholders and "the answer" does not exist or is not known.

Presentation and Discussion of Innovative Socio-Technical Environments: There is no media-independent learning - tools, materials, and social arrangements always mediate activity (Pea, 2004). Thinking, learning, working, and collaborating are functions of our media (Bruner, 1996). Cognition is shared not only among minds, but among minds and the structured media within which minds interact.

Beyond "Gift-Wrapping" and "Techno-Determinism." Many current educational uses of technology are restricted to *gift wrapping* (Fischer, 1998); that is, technology is used as an add-on to existing practices rather than as a catalyst for fundamentally rethinking what education and learning should and could be. This approach is not good enough. Students need to practice the cognitive, social, and technical skills necessary for *self-directed, lifelong learning* required for the 21st century (Fischer, 2000). Media and technologies for learning must not only deliver predigested information to individuals, but also provide support and resources for discussion, social debate and collaborative design.

Challenges: Some of the fundamental challenges for enhancing self-directed learning with contextualized tutoring will be discussed, including: domain representations, task modeling, user models, context awareness, and open source libraries of tutoring episodes.

Sharon Derry: Connecting Practice and Theory through Contextual Tutoring

Problem: How to help bring organized conceptual bodies of knowledge, such as those taught in typical courses, (e.g., learning sciences, physiology, calculus) to bear on professional practice (e.g., teaching, medical practice, engineering) in ways that help that practice to be more intelligent and informed (Derry et al., 2005).

I will cite arguments and examples from several fields illustrating some reasons why this integration is problematic and difficult to accomplish, showing that such integration involves creating new forms of tacit understanding that are neither directly represented by the conceptual domain or the domain of practice, and that in some cases represents apparent epistemological conflicts between the two types of domains.

Instructional Design Theories: I will briefly review and contrast several instructional design models and illustrative cases that assume different conceptualizations and solutions for this problem, including: problem-based learning (PBL) (Hmelo, 1998); Cognitive Flexibility Hypertext (CFT) systems (Spiro, Collins, Thota, & Feltovich, 2003); and cognitive apprenticeship (Collins, Brown, & Newman, 1989).

Implications for Contextualized Tutoring: I will explore the implications of this analysis for the development of contextualized tutoring in the context of a specific "use case" from my own research in designing online course environments that help teacher-learners create practice-based conceptual knowledge in foundational subjects such as cognitive science, and in domain subjects such as algebra and statistics (Derry et al., 2005; Derry, Levin, Osana, Jones, & Peterson, 2000).

Allan Collins: Characteristics of Interactive Learning Environments

I will describe characteristics of interactive learning environments (Collins, Neville, & Bielaczyc, 2000), many grounded in the intelligent tutoring tradition, that support learning in ways that *schools cannot easily provide*:

- ♣ **Realistic simulations**, forcing learners to figure out what to do and take on roles in novel situations. Simulations allow learners to try out different courses of action.
- ♣ **Animation** allows learners to see processes as they unfold; processes that they often cannot view otherwise.
- ♣ **Voice** can explain what is happening and why at the same time it happens.
- ♣ **Video** conveys what situations look like, providing rich contextual information needed for recognizing objects and places.

- ♣ **Diverse knowledge sources** include digital resources available over electronic networks, adults who serve as mentors or experts, students from around the world, and the varieties of help that systems offer.
- ♣ **Multiple representations** refer to the ability of these systems to present different characterizations of the same situation or process simultaneously.
- ♣ **Interaction** allows learners to see the consequences of their actions. Interaction provides the feedback from the world that is crucial to all learning.
- ♣ **Scaffolding** is the support the system gives learners in carrying out different activities in a problematic situation. Scaffolding helps learners carry out tasks that are beyond their capabilities. Scaffolding fades naturally as students need less support.
- ♣ **Reflection** encourages learners to look back on their performance in a situation, and compare their performance to other performances, such as their own previous performances, and those of experts and others like themselves.

These are capabilities of interactive learning environments that *human teachers do not have*. They foster a constructivist approach where students, rather than teachers, do most of the work. Instead of modeling systems on human tutors, we are learning to design to exploit the strengths of the medium.

Ken Koedinger: Cognitive Tutoring

The key idea of Cognitive Tutoring is helping students acquire problem solving or reasoning processes by tracking students as they reason, providing individualized instructional feedback and assistance. Cognitive Tutoring is a kind of computer-based coaching or "cognitive apprenticeship" approach to supporting learning.

For what kinds of reasoning activities can a Cognitive Tutor be created? The original Cognitive Tutors supported learning of programming and mathematics. These have been quite successful both in raising student achievement and in widespread adoption; for instance, the full-year Cognitive Tutor Algebra course is in use in some 2000 US schools. In recent years, Cognitive Tutors are being created for a wide variety of domains from science to language learning, including for genetics, chemistry, economics, and French.

We have used a combination of two strategies to apply Cognitive Tutors for domains where student reasoning steps are difficult to interpret, like forming a hypothesis about a genetic process. One strategy is to improve the Artificial Intelligence behind the system. For instance, to assess and provide feedback on students' explanations of their reasoning in geometry we created natural language systems that could understand typical correct and incorrect student explanations. A second strategy is to cleverly constrain the graphical user interface. A good interface design preserves the "cognitive essence" of the reasoning process while making reasoning steps computer readable.

The general point is that the kinds of learning domains Cognitive Tutors can be applied to depends on the creativity of the instructional designer and the slow-but-steady advance of Artificial Intelligence, for instance, for text comprehension, speech, and hand-writing recognition.

We have begun to apply Cognitive Tutors to domain-independent reasoning skills including reflective or "meta-cognitive" strategies for learning like self-explanation, error self-correction, and instructional help-seeking skills.

Mitchel Resnick: Mentoring and Self-Directed Learning

I will discuss strategies for supporting self-directed learning, drawing on examples and experiences from the Computer Clubhouse project, a network of after-school centers where youth (ages 10-18) from low-income communities learn to express themselves creatively with new technologies. Over the past decade, the Clubhouse network has grown to more than 100 centers in 20 countries. The educational approach of Computer Clubhouses is based on four guiding principles:

- ***Support Learning through Designing*****:** As Clubhouse members create their animations, robots, music videos, and other interactive projects, they learn about processes of design and invention: how to conceptualize a project, how to make use of the materials available, how to persist and find alternatives when things go wrong.
- ***Help Learners Build on their Own Interests*****:** When people care about what they are working on, they're willing to work longer and harder, and they learn more in the process. Clubhouses provide support and structure to help youth identify their interests, turn them into meaningful projects, and learn from the experience.
- ***Cultivate Emergent Communities*****:** At Clubhouses, design teams form informally, coalescing around common interests. Communities are dynamic and flexible, evolving to meet the needs of the project and the interests of the participants.
- ***Create an Environment of Trust and Respect*****:** The goal is to create an environment in which participants feel safe to try new things, experiment, and take risks.

Mentors play a key role in implementing these guiding principles at Computer Clubhouses. Mentors act as coaches, catalysts, consultants, and role models, helping Clubhouse members learn to be better learners. In my presentation, I will describe how mentors help support self-directed learning at Computer Clubhouses – and I will discuss whether "intelligent tutors" could play similar roles. (Hint: I am skeptical.)

References

Anderson, J. R., Corbett, A. T., Koedinger, K. R., & Pelletier, R. (1995). Cognitive tutors: Lessons learned. *Journal of The Learning Sciences, 4*(2), 167-207.

Bloom, B. S. (1984). The 2 Sigma problem: The search for methods of group instruction as effective as one-to-one tutoring. *Educational Researcher, 13*(6), 4-16.

Bruner, J. (1996). *The Culture of Education.*Cambridge, MA: Harvard University Press.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprecticeship: Teaching the crafts of reading, writing, and mathematics. In L. B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 453-494). Hillsdale NJ: Erlbaum.

Collins, A., Neville, P., & Bielaczyc, K. (2000). The role of different media in designing learning environments. *International Journal of Artificial Intelligence in Education, 11*, 144-162.

Derry, S. J., Hmelo-Silver, C. E., Feltovich, J., Nagarajan, A., Chernobilsky, E., & Halfpap, B. (2005). Making a mesh of it: A STELLAR approach to teacher professional development. In *Proceedings of Computer Support for Collaborative Learning (CSCL) 2005, Taipei, Taiwan*. Mahwah, NJ: Erlbaum.

Derry, S. J., Levin, J. R., Osana, H., Jones, M. S., & Peterson, M. (2000). Fostering students' statistical and scientific thinking: Lessons learned from an innovative college course. *American Educational Research Journal, 37*, 747-773.

Fischer, G. (1998). Making learning a part of life--beyond the 'gift wrapping' approach of technology. In P. Alheit & E. Kammler (Eds.), *Lifelong learning and its impact on social and regional development* (pp. 435-462). Bremen, Germany: Donat Verlag.

Fischer, G. (2000). Lifelong learning -- More than training. *Journal of Interactive Learning Research, Special Issue on Intelligent Systems/Tools in Training and Life-Long learning (Eds: Riichiro Mozohuchi and Piet A. M. Kommers), 11*(3/4), 265-294.

Harel, I., & Papert, S. (Eds.). (1991). *Constructionism*.Norwood, NJ: Ablex Publishing Corporation.

Hirsch, E. D. (1996). *The schools we need and why we don't have them*.New York: Doubleday.

Hmelo, C. E. (1998). Problem-based learning: Effects on the early acquisition of cognitive skill in medicine. *Journal of the Learning Sciences, 7*, 173-208.

Pea, R. D. (2004). The Social and Technological Dimensions of Scaffolding and Related Theoretical Concepts for Learning, Education, and Human Activity. *The Journal of the Learning Sciences, 13*(3), 423-451.

Schofield, J. W. (1995). *Computers and Classroom Culture*.Cambridge: Cambridge University Press.

Schön, D. A. (1983). *The Reflective Practitioner: How Professionals Think in Action*.New York: Basic Books.

Schön, D. A. (1987). *Educating the Reflective Practitioner*.San Francisco, CA: Jossey-Bass.

Spiro, R. J., Collins, B. P., Thota, J. J., & Feltovich, P. J. (2003). Cognitive flexibility theory: Hypermedia for complex learning, adaptive knowledge application, and experience acceleration. *Educational Technology, 43*, 5-10.