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SUPPORTING SELF-DIRECTED LEARNERS AND LEARNING COMMUNITIES WITH SOCIOTECHNICAL ENVIRONMENTS

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Making learning part of life is an essential challenge for inventing the future of our societies. Lifelong learning is a necessity rather than a possibility or a luxury to be considered. Self-directed learning (often occurring as learning on demand in response to breakdowns) is the dominant form of lifelong learning. The power of the unaided individual mind is highly overrated. Although society often thinks of creative individuals as working in isolation, learning and creativity result in large part from the interaction and collaboration with other individuals. Much human creativity is social, and learning communities are needed to cope with the challenges of making learning part of life.

This paper articulates existing problems in our current and future world requiring lifelong and self-directed learning and learning communities. It defines conceptual frameworks and it describes four innovative computational environments: (1) domain-oriented design environments, (2) critiquing systems, (3) the Envisionment and Discovery Collaboratory, and (4) Caretta. The paper concludes by providing a set of challenges for the future use of technology to enhance learning based on the conceptual frameworks and the experience and assessment of our system development efforts.

Keywords: Self-directed learning; lifelong learning; learning on demand; collaborative learning; integration of working and learning; critiquing; breakdowns; simulation; change; symmetry of ignorance; gift-wrapping approach of using technology; sociotechnical environments; meta-design.

1. Introduction

Learning can no longer be dichotomized into a place and time to *acquire* knowledge (school) and a place and time to *apply* knowledge (the workplace) (Gardner, 1991). Today's population is flooded with more information than it can handle, and tomorrow's workers will need to know far more than any individual can retain. Lifelong learning needs to promote effective educational opportunities in the many learning settings through which people pass, including home, school, work, and the larger political community.

Professional work cannot simply proceed from a fixed educational background; rather, education must be smoothly incorporated as part of work activities. Similarly, learning takes place not only at all ages and in virtually all professions; it increasingly takes place among heterogeneous groups of people in families, clubs, and virtual communities. Insights gained from these individual situations need to be developed into broad and effective theories of learning, innovative and intelligent systems, practices, and assessments across many professional genres. A lifelong learning approach permits integration of the best features of school, community, home, and workplace learning.

Today's society is characterized by increased professional specialization (Levy & Murnane, 2004); changes in marketplaces (local and global are no longer clearly distinguished); and new technologies for information sharing, communication, and collaboration, made possible by Internet technologies and specialized applications. The skills required in these environments are more than the basic skills traditionally taught in schools, such as reading, writing, and mathematics. The new skills include coping with incompletely specified problems, communicating in heterogeneous teams, developing shared understanding, evolving knowledge artifacts, working at a distance, and making use of Internet-based and specialized collaboration technologies (National-Research-Council, 1999). In this complex environment, described as the "knowledge society" (Brown & Duguid, 2000; Drucker, 1994), *learning communities* (Rogoff *et al.*, 1998) provide the contexts for performing individual activities. For example, a physician may read an x-ray and consult a colleague at another hospital for an opinion before making a diagnosis, an employee in an automobile manufacturing plant may communicate with a colleague at a plant elsewhere in the world regarding the appropriate alloy for wheel bearings, and two architects may work with an engineer to develop a new type of lightweight building material to serve as the bearing for an opera house under construction (Arias *et al.*, 2000; Engeström, 2001).

This paper identifies problems of the information age that learners face in the world today. It argues for an emphasis on lifelong learning and for the importance of self-directed learning and learning communities to create mindsets and cultures that embrace lifelong learning. Lifelong learning is more than adult education and/or training (Fischer, 2000) — it is a mindset and a habit for people to acquire. Lifelong learning creates the challenge to understand, explore, and support new essential dimensions of learning, such as: (1) self-directed learning, (2) learning on demand, (3) collaborative learning, and (4) organizational learning for several reasons: individual human minds are limited and collaboration is inevitable to tackle the complex problems in the real world, knowledge learned in school education may soon become obsolete, and new knowledge required in workplace situations should be voluntary and effectively acquired. To enhance these approaches, new media and innovative technologies are needed based on the concept of *meta-design*

(Fischer & Giaccardi, 2005; Fischer *et al.*, 2004a) that empowers users to act as designers and be creative.

This paper argues that sociotechnical environments are needed to support these forms of learning effectively. It describes four examples of sociotechnical environments that the authors and their collaborators have developed over the last decade: (1) *domain-oriented design environments*, (2) *critiquing systems*, (3) *the Envisionment and Discovery Collaboratory*, and (4) *Caretta*. The paper concludes by providing a set of challenges for the future use of technology to enhance learning based on these conceptual frameworks and the experience and assessment of our system development efforts.

The arguments and the research presented in this paper are influenced by an *integrated East/West view* about technology-enhanced learning derived, on the one hand, from the respective work environments of the authors and, on the other hand, from their collaboration during the last decade.

2. Problems in the Information Age

Self-directed learning and learning communities that promote and support lifelong learning with sociotechnical environments are inevitable due to the following requirements:

- **Lack of creativity and innovation.** Societies and countries of the future will be successful not "because their people work harder, but because they work smarter." Creativity and innovation are considered essential capabilities for working smarter in knowledge societies (Drucker, 1994; Friedman, 2005); thus, an important challenge is how these capabilities can be learned and practiced. An implicit assumption is that self-directed and lifelong learning can influence the creativity and innovation potential of individuals, groups, organizations, and countries.
- **Coping with change.** Most people see schooling as a period of their lives that prepares them for work in a profession or for a change of career. This view has not enabled people to cope well with the following situations: (1) most people change careers three or four times in their lives, even though what they learned in school was designed to prepare them for their first career; (2) the pace of change is so fast that technologies and skills to use them become obsolete within 5 to 10 years; (3) university graduates are not well prepared for work; (4) companies have trouble institutionalizing what has been learned (e.g. in the form of organizational memories) so the departures of particular employees will not disable the companies' capabilities; and (5) although employers and workers alike realize that they must learn new things, they often don't feel they have the time to do so.
- **School-to-work transition is insufficiently supported.** If the world of working and living (1) relies on collaboration, creativity, definition, and framing of problems; (2) deals with uncertainty, change, and distributed cognition; and (3) augments and empowers humans with powerful technological tools, then the schools and universities need to prepare students to function in this world.

Industrial-age models of education and work are inadequate to prepare students to compete in the knowledge-based workplace. A major objective of a lifelong learning approach is to reduce the gap between school and workplace learning.

- **Quality employment.** The current dislocation problem experienced by workers (Rifkin, 1995) is one example of an increasingly societal trend. Workers in the growing service and information sector will face an accelerating rate of change in the knowledge and skills necessary to stay competitive. Traditional paradigms of education and training will not, in themselves, be sufficient to meet this increasingly important need. Additional infrastructure must be developed that allows people to learn on the job, and knowledgeable experts need to communicate and extend their knowledge within and across domains.

These requirements, derived from broad social perspectives, require that sociotechnical environments for supporting learning need to be designed by considering the following issues:

- **Information is not a scarce resource.** "Dumping" even more decontextualized information on people is not a step forward in a world where most people already suffer from too much information. Instead, technology should provide ways to "say the 'right' thing at the 'right' time in the 'right' way to the 'right' person." Information consumes human attention, so a wealth of information creates a poverty of human attention (Simon, 1996).
- **"Ease of use" is not the greatest challenge, nor is it the most desirable goal for new technologies.** Usable technologies that are not useful for the needs and concerns of people are of no value. Rather than assuming that people should and will be able to do everything without a substantial learning effort, we should be designing computational environments that provide a low threshold for getting started and a high ceiling to allow skilled users to do the things they want to do.
- **Computers by themselves will not change education.** There is no empirical evidence for the assumption that education has changed by using computers, based on the last 30 years of experience with, for example, computer-assisted instruction, computer-based training, or intelligent tutoring systems. Technology is no "Deus ex machina" taking care of education. Instructionist approaches are not changed by the fact that information is disseminated by an intelligent tutoring system. The content, value, and quality of information and knowledge are not improved just because information is offered in multimedia or over the Internet. Media itself does not turn irrelevant or erroneous information into more relevant information.
- **The single or most important objective of computational media is not reducing the cost of education.** Although we should not ignore any opportunity to use technology to lessen the cost of education, we should not lose sight of an objective that is of equal if not greater importance: increasing the *quality* of education.

- **The "super couch-potato" consumer should not be the target for the educated and informed citizen of the future.** One of the major innovations that many powerful interest groups push with the information superhighway is a future in which people show their creativity and engagement by selecting one of at least 500 TV channels with a remote control. The major technical challenge derived from this perspective becomes the design of a "user-friendly" remote control. Rather than serving as the "reproductive organ of a consumer society" (Illich, 1971), educational institutions must fight this trend by cultivating "designers," that is, by creating mindsets and habits that help people to become empowered and willing to actively contribute to the design of their lives and communities (Fischer, 2002).

3. Lifelong Learning, Self-Directed Learning, and Learning Communities

Most current uses of technology to support lifelong learning are restricted to a "*gift wrapping*" approach: they are used as an add-on to existing practices rather than as a catalyst for fundamentally rethinking what education and learning should be about in the next century. "Old" frameworks, such as instructionism, fixed curriculum, memorization, decontextualized learning, and so forth, are not changed by technology itself. This is true whether we use computer-based training, intelligent tutoring systems, multimedia presentations, or the Internet. Computational media and environments need to be developed to support "new" frameworks for lifelong learning, such as integration of working and learning, learning on demand, self-directed learning, information contextualized to the task at hand, (intrinsic) motivation, collaborative learning, and organizational learning.

Moving beyond the "*gift-wrapping approach*," Fischer (Fischer, 1998) implies that:

- We should explore the fundamentally new possibilities and limitations of computational media on how we think, create, work, learn, and collaborate. It simply isn't good enough to spend money on new technologies and then to use them in old ways. New tools should not just help people do cognitive jobs more easily but in the same way they used to. New tools should also lead to fundamental alterations in the way problems are solved.
- We should change mindsets, such as seeing and understanding breakdowns and symmetry of ignorance as opportunities rather than as things to be avoided.
- Teachers should understand their roles not only as truth-tellers and oracles, but as coaches, facilitators, mentors, and learners.

3.1. *Lifelong learning*

A *theory of lifelong learning* (Dohmen, 1996) must investigate new approaches to learning required by the profound and accelerating changes in the nature of work and education. These changes include (1) an increasing prevalence of "high-technology" jobs requiring support for learning on demand because complete coverage of concepts is impossible; (2) the inevitability of change in the course of a professional lifetime, which necessitates lifelong learning; and (3) the deepening (and disquieting) division between the opportunities offered to the educated and to the uneducated.

Lifelong learning is a continuous engagement in acquiring and applying knowledge and skills in the context of self-directed learning activities and should be grounded in descriptive and prescriptive goals, for example:

- Learning should take place in the context of authentic, complex problems (because learners will refuse to quietly listen to someone else's answers to someone else's questions) (Bruner, 1996).
- Learning should be embedded in the pursuit of intrinsically rewarding activities (Csikszentmihalyi, 1990).
- Informal learning activities are equally important in lifelong learning and in formal learning activities (Bransford, 2005).
- Learning often takes place without teaching (Illich, 1971; Wenger, 1998).
- Learning-on-demand needs to be supported because change is inevitable, complete coverage is impossible, and obsolescence is unavoidable (Fischer, 1991).
- Organizational and collaborative learning must be supported because the individual human mind is limited (Arias *et al.*, 2000).
- Skills and processes that support learning as a lifetime habit must be developed (Gardner, 1991).
- Lifelong learning is more than training and more than school learning (Fischer, 2000).

Table 1 presents a high-level comparison between school and workplace learning that illustrates some of the major differences. In the standard "instructionist" classroom environment, students are generally unable to see the relevance of what they learn because the material presented is disembodied from everyday experience, the material to be learned is formulated externally by teachers and curriculum developers, and problems have an artificially "closed," well-defined nature (i.e. there is one correct answer and one prescribed process for obtaining that answer). These limitations of formal education have led to complaints from corporations that even graduates from the best schools lack the practical design experience needed to perform their jobs.

Although there is a growing awareness of the need for more integration of working and learning (e.g. "on-the-job" training programs, performance support systems, and simulation environments (Gery, 1997), many corporate education and training programs have been modeled after school learning. Employees attend lectures and seminars in which decontextualized knowledge is presented to them by instructors who often know little about the real problems encountered in the workplace. Conventional studies of workplace learning have concentrated on activities employers

Table 1. A Comparison of different conceptualizations of school and workplace learning.

	School Learning	Workplace Learning
Emphasis	"Basic" skills	Education embedded in ongoing work activities
Potential drawbacks	Decontextualized, not situated	Important concepts are not encountered
Problems	Given	Constructed
New topics	Defined by curricula	Arise incidentally from work situations
Structure	Pedagogic or "logical" structure	Work activity
Roles	Expert-novice model	Reciprocal learning
Teachers/trainers	Expound subject matter	Engage in work practice
Mode	Instructionism (knowledge absorption)	Constructionism (knowledge construction)
Answer and method	Given	Must be devised/designed

have explicitly organized for the purpose of training. This type of "workplace training" suffers from the same phenomenon of decontextualization as does the school-based environment on which it is modeled. Detterman (Detterman & Sternberg, 1993) (in reviewing earlier summaries of the literature on workplace training by Baldwin and Ford), wrote: *"American businesses have a major stake in fostering transfer of training, since they spend up to $100 billion each year to train workers. Yet the estimate is that not more than 10% of training transfers to the job. So business wastes $90 billion each year because of lack of transfer."*

These observations collectively point toward a need for weaving the process of learning into ongoing, self-directed, work-related activities. As a source of examples, informal workplace learning — the "apprenticeship" — style education typical of medical doctors, Ph.D. students, and some craftspeople (Lave & Wenger, 1991) — presents features that are interesting for our research goals of supporting learning on demand.

3.2. *Self-directed learning*

In traditional classrooms in schools where knowledge transmission from a teacher to students based on instructionist approaches has been conducted, students are not required to be active learners and can be passive recipients: all the information or knowledge related to learning is automatically given through a teacher irrespective of the students' needs or problems, if they even are in their classrooms. In such situations, learners are not motivated to learn. In contrast, if learners solve their own problems for their own sake, they try to actively acquire required knowledge and skills. Therefore, active learning happens when learners are self-directed to learn for themselves through their demands to solve authentic or personally meaningful problems.

Most learning that takes place outside of an instructionist classroom can be characterized as follows: humans are engaged in some activity (some action such as working, collaboratively solving a problem, or playing), they experience a breakdown, and they reflect about the breakdown (e.g. the piece of lacking knowledge, the misunderstanding about the consequences of some of their assumptions). Schön (Schön, 1983) called this *reflection-in-action*. Because self-reflection is difficult, a human coach, a design critic, or a teacher can help the learner to identify the breakdown situation and to provide task-relevant information for reflection (Fischer & Nakakoji, 1992). Our own work has explored the possibility using computational critics (Fischer *et al.*, 1998) to provide some of this support when humans are not present. Critics make argumentation serve design; that is, they support learners in their own activities.

Self-directed learning can be characterized as follows:

- It is less structured than instructionist learning.
- It is in many cases a group or joint activity.
- The goal is motivated from the learner's point of view.
- The activity is captivating and fun and there are frequent "flow" experiences (Csikszentmihalyi, 1990).
- The activities are self-paced.
- The learner has a choice of topic, time, and place.

This brief characterization illustrates how self-directed learning differs from *intelligent tutoring systems* (Anderson *et al.*, 1995), in which the problem is given by the teacher or the system, and *interactive learning environments* (such as LOGO (Papert, 1980)), in which no support is given when a learner is stuck. Interactive learning environments support autonomous learning; in order to support self-directed learning, they need to be augmented with mechanisms that can offer help, support, and reflection for learners who get stuck or who do not know how to proceed. Engagement and support for self-directed learning is critical when learning becomes an integral part of life — driven by a desire and need to understand something, or to get something done instead of merely solving a problem given in a classroom setting. A lifelong learning perspective implies that schools and universities need to prepare learners to engage in self-directed learning processes because this is what they will have to do in their professional and private lives outside the classroom.

It is advantageous for both motivation and the ability to acquire new knowledge that students be able to direct their own learning (Fischer, 1991). Self-directed learning de-emphasizes teaching as a process in which a teacher tells something to a passive learner. Rather, it focuses on mutual dialogs and joint knowledge construction, enhanced by the creation, discussion, and evolution of artifacts.

Many industrial training programs assume forms of self-directed learning (Scribner & Sachs, 1991) in which workers are given a brief introduction to a complex, computer-controlled system and are then expected to complete their training on the job. As the stage of life and background knowledge of learners, as well as their goals, become increasingly varied, the need for self-directed learning will become even more important.

In schools and in professional training courses modeled after schools, learning is often restricted to the solution of well-defined problems. Lifelong learning includes training approaches and also transcends them by supporting learning in the context of realistic, open-ended, ill-defined problems. In our environments, learners explore information spaces relevant to a *self-chosen* task at hand; for example, learning on demand provides learner-centered alternatives to teacher-centered tutoring systems, and it augments open-ended, unsupported learning environments by providing advice, assistance, and guidance, if needed, in breakdown situations.

3.3. *Learning communities*

The power of the unaided individual mind is highly overrated. Although society often thinks of creative individuals as working in isolation, intelligence and creativity result in large part from interaction and collaboration with other individuals. Much human creativity is social, arising from activities that take place in a context in which interaction with other people and the artifacts that embody collective knowledge are essential contributors. We need to invent alternative social organizations and new media that will permit the flourishing of deep interdisciplinary specialties (Derry, 2005), as argued for by Campbell (Campbell, 2005): "*Even within disciplines, disciplinary competence is not achieved in individual minds, but as a collective achievement made possible by the overlap of narrow specialties.*" The *fish-scale model* (trying to achieve "*collective comprehensiveness through overlapping patterns of unique narrowness*") proposed by Campbell provides a viable path toward a new competence, based on the integration of individual and social creativity (Fischer *et al.*, 2005).

The goal is to go beyond the isolated image of the reflective practitioner (Schön, 1983) and move toward the sustainability and development of *reflective communities* (Fischer, 2005). Supporting reflective practitioners is important, but it is not enough because complex design problems require more knowledge than any single person possesses, and the knowledge relevant to a problem is usually distributed among stakeholders. Bringing different and often controversial points of view together to create a shared understanding among stakeholders can lead to new insights, new ideas, and new artifacts. The challenge for the future will be not only to develop new frameworks, new media, and new social environments to support reflective practitioners, but also to support *reflective communities* by overcoming the limitations of the individual human mind. Simon (Simon, 1996) argued that when a domain reaches a point at which the knowledge for skillful professional practice cannot be acquired in a decade, specialization increases, collaboration becomes a necessity, and practitioners make increasing use of media supporting *distributed intelligence* (Hollan *et al.*, 2001; Pea, 2004; Salomon, 1993). Design is a prime example of such a domain (Arias *et al.*, 2000).

Reflective Communities: Coping with the Demands of Knowledge Work. The objective to educate "Renaissance scholars" (such as Leonardo da Vinci, who was equally adept in the arts and the sciences (Shneiderman, 2002) is not a reasonable objective for the 21st century (Buxton, 2002) — rather, the challenge is to exploit the creative potential of "*Renaissance communities*." Numerous sources provide overwhelming evidence that individual, disciplinary competence is limited, but the potential of a community is limitless:

- "While the Western belief in individualism romanticizes this perception of the solitary creative process, the reality is that scientific and artistic forms emerge from the joint thinking, passionate conversations, emotional connections, and shared struggles common in meaningful relationships" (John-Steiner, 2000).
- "Nobody knows who the last Renaissance man really was, but sometime after Leonardo da Vinci, it became impossible to learn enough about all the arts and the sciences to be an expert in more than a small fraction of them" (Csikszentmihalyi, 1996).
- "None of us is as smart as all of us" (Bennis, 1997).
- "Linux was the first project to make a conscious and successful effort to use the entire world as a talent pool" (Raymond & Young, 2001).

4. Sociotechnical Environments to Support Self-Directed Learners and Learning Communities

4.1. *Sociotechnical environments*

Over the last decade we have developed *sociotechnical environments* (Mumford, 1987) that can be characterized as follows:

- They are needed because the deep and enduring changes of our ages are *not just technological but social and cultural as well*. Changes in complex environments are not primarily dictated by technology; rather, they are the result of an incremental shift in human behavior and social organization (Florida, 2002).
- They are composed *both* of computers, networks, and software, *and* of people, procedures, policies, laws, the flow of material and finished goods, and many other aspects.
- They require a *co-design* of social and technical systems, and use models and concepts that focus not only on the artifact but exploit the social context in which the systems will be used;
- They have as a critical component *meta-design* because it gives the users the design power to modify and evolve the technical systems according to their needs.
- They are for people, not for a single person, and should support not only a person but also a group of people; however, the results of group activities come from each person's contributions. Therefore, how to design the environments for supporting both individual and social activities by enhancing rather than disturbing them mutually is a critical issue (Fischer *et al.*, 2005).

We need new ways of thinking and new approaches in which we address the basic question associated with distributed intelligence and the design of sociotechnical systems (Landauer, 1988; Norman, 1993): *Which tasks or components of tasks are or should be reserved for educated human minds, and which can and should be taken over or aided by cognitive artifacts?*.

Our research efforts are directed to exploit the power of innovative technologies based on reliable and ubiquitous computing environments and an increasing level of technological fluency to help people lead more productive, rewarding, and enjoyable lives. One of the major roles for new media and new technology is not to deliver predigested information to individuals, but to provide the opportunity and resources for engaging in meaningful activity, for participating in social debate and discussion, for creating shared understanding among stakeholders, and for framing and solving authentic problems. This global perspective leads to the following *requirements for sociotechnical environments in support of self-directed learning and learning communities*:

- Users, not the system, set most of the goals.
- The vocabulary, tools, functions, and practices supported by the system come from the working environment, where they are natural and appropriate.
- The mode of operation emphasizes learning from breakdowns and from fulfilling commitments.
- Tools must appear directly relevant to help with the problem at hand; they must not generate further breakdowns.
- Although learning environments may have some built-in expertise, users will find most expert knowledge by locating other people who have that knowledge.
- Systems should support not only the individual's solo performance, but also his or her work in cooperation with others and while belonging to different groups at the same time; that is, systems should support the improvement of collective knowledge as well as individual knowledge.
- Learning experiences should be enriched; supporting physical interactions (interacting with people in a physical world or objects) seems to be one effective way.

4.2. *Meta-design*

In a world that is not predictable, improvisation, evolution, and innovation are more than luxuries — they are necessities. The challenge of design is not a matter of getting rid of the emergent, but rather of including it and making it an opportunity for more creative and more adequate solutions to problems.

To support self-directed learners and to bring social creativity alive in learning communities, sociotechnical environments are needed that support new forms of collaborative design. *Meta-design* (Fischer & Giaccardi, 2005; Fischer *et al.*, 2004a) characterizes objectives, techniques, and processes to allow users to act as designers and be creative. By empowering users to engage in creating knowledge rather than restricting them to the consumption of existing knowledge, meta-design supports self-directed learning in learning communities. Meta-design shares some important objectives with *user-centered* (Norman & Draper, 1986) and *participatory design* (Schuler & Namioka, 1993), but it transcends these objectives in several important dimensions. Meta-design shifts control over the design process from designers to users, and it empowers users to create and contribute their own visions and objectives.

The need for meta-design is founded on the observation that design requires open systems that users can modify and evolve. Because problems cannot be completely anticipated at design time when the system is developed, users at use time will encounter mismatches between their problems and the support that a system provides. These mismatches will lead to *breakdowns* (Fischer *et al.*, 1998) that serve as potential sources for new insights, new knowledge, and new understanding. Meta-design advocates a shift in focus from finished products or complete solutions to conditions for users to fix mismatches when they are discovered during use.

Meta-design extends the traditional notion of system design beyond the original development of a system (Henderson & Kyng, 1991) to include an ongoing process in which stakeholders become co-designers — not only at design time, but throughout the whole existence of the system (Morch, 1997). A necessary, although not sufficient, condition for users to become co-designers is that software systems include advanced features that permit users to create complex customizations and extensions. Rather than presenting users with closed systems, meta-design approaches provide them with opportunities, tools, and social reward structures to extend the system to fit their needs.

Supporting Self-Directed Learning and Learning Communities with Meta-Design. To motivate people to become active contributors and designers and to share their knowledge requires a new "design culture" involving a *mindset* change (Fischer, 2002) and principles of social capital accumulation (Fischer *et al.*, 2004b; Florida, 2002; Putnam, 2000). But before new social mindsets and expectations can emerge, users' active participation must be a function of simple motivational mechanisms and activities considered *personally meaningful*.

To encourage and sustain self-directed learning in sociotechnical environments requires that learners can engage in *personally meaningful activities* and that they are recognized and rewarded for their contributions by accumulating social capital. Social capital is based on specific benefits that flow from the trust, reciprocity, information, and cooperation associated with social networks. Sustaining *personally meaningful activities* is essential for the success of unselfconscious design (Fischer, 2002). People are willing to spend considerable effort on projects that are important to them, so the value dimension for truly personal meaningful activities is more important than the effort dimension (Hatano & Inagaki, 1973). Although new technologies and new media are important for self-directed learning, the most fundamental contributing factors are *social structures and mindsets*.

Making All Voices Heard. For self-directed learning in learning communities to succeed, the following questions need to be answered: (1) from an individual perspective: "*Am I interested enough and am I willing to make the additional effort and time so my voice is heard?*" and (2) from a social perspective: "*How can we encourage individuals to contribute to the good and progress of all of us?*" These questions indicate the importance of motivation and rewards in persuading people to make their voices heard. The following criteria and features of sociotechnical systems are important dimensions for motivation (Fischer *et al.*, 2004b):

- Making changes must seem possible for the skill and experience level of specific users.
- Changes must be technically possible (a central objective of our meta-design approach).
- Benefits must be perceived; e.g. individuals must perceive a direct benefit in contributing that is large enough to outweigh the effort.
- The effort required to contribute must be minimal so that it will not interfere with getting the real work done.

Exploiting the strength of learning communities necessitates the "synergy of many," and this kind of synergy is facilitated by meta-design. However, a tension exists between creativity and organization. A defining characteristic of social creativity is that it transcends individual creativity, and thus it requires some form of organization. On the one hand, elements of organization can and frequently do stifle creativity (Florida, 2002). On the other hand, historical precedents show that *too many voices* can be worse than having only a few choices.

4.3. *Cultural issues on self-directed learning and learning communities*

One of the preconditions for successful self-directed learning and learning communities is the *individuality* of different learners: they actively externalize their own ideas and contribute to their respective learning communities, which return feedback for their reflection and further learning. However, in Eastern cultures, especially in the Japanese culture, learners' individuality in collaborative situations has been underestimated. Actually, collaborative learning has yet not been successful in many Japanese schools. Japanese learners tend to yield to the judgment or authority of the group and end up "leaving matters to others," "following others blindly," and "allowing the high-handed behavior of a strongman" (Kusunoki *et al.*, 2000).

Another problem for self-directed learning and learning communities in Eastern cultures is the hierarchical *inequality* between teachers and students: in Japan and China: teachers are always the instructors, and there is almost no opportunity to learn mutually or interchange roles between teachers and students. For example, students in China are taught to respect their instructors and are required to be listeners and followers. Students and instructors are never at the same level, preventing students and instructors from becoming co-learners embedded in learning communities. We have ample anecdotal evidence that students from Japan or China are astonished by the heated (but constructive) arguments among teachers and students in classrooms in the United States.

To support self-directed learners or learning communities, computational media and technologies must be designed to enhance each learner's active participation and commitment to his or her group. These new media should serve not only as teaching aids for teachers, but also for enhancing a learner's individuality through active discussions as well as for promoting role exchanges between teachers and learners.

5. Examples

This section describes four innovative sociotechnical environments developed in our laboratories over the last decade: (1) domain-oriented design environments (DODEs), (2) critiquing systems, (3) the Envisionment and Discovery Collaboratory (EDC), and (4) Caretta. Together, they illustrate our conceptual framework focused on self-directed learning and learning communities as follows: (1) DODEs allow learners to pursue their own tasks within a domain; (2) critiquing systems analyze artifacts constructed by learners, provide feedback, and support learning on demand; (3) the EDC allows communities to explore complex design problems and helps the participating stakeholders to articulate their tacit knowledge; and (4) Caretta emphasizes the integration of individual and collaborative activities.

5.1. *Domain-oriented design environments*

Domain-oriented design environments (Fischer, 1994) have proven to be powerful and versatile environments for learning that address the limitations of intelligent tutoring systems and interactive learning environments, and provide multiple learning opportunities. Pursuing this line of research, we have emphasized research directions and techniques that augment and complement human intelligence with rich computational environments, including critics, agents, assistants, adaptable and adaptive tools, information access, and information delivery mechanisms (Terveen, 1995).

DODEs are collections of interrelated tools and information repositories that provide specific support for communicating about and exploring concepts within a domain. Example domains that we have explored include kitchen design, graphical user interface layout, voice messaging for phone systems, local area network design, and lunar habitat design. Design environments have the following major components:

- The *construction component* is the principal medium for modeling a design. It provides a palette of domain-oriented design units, which can be arranged in a work area by using direct manipulation. Design units represent primitive elements

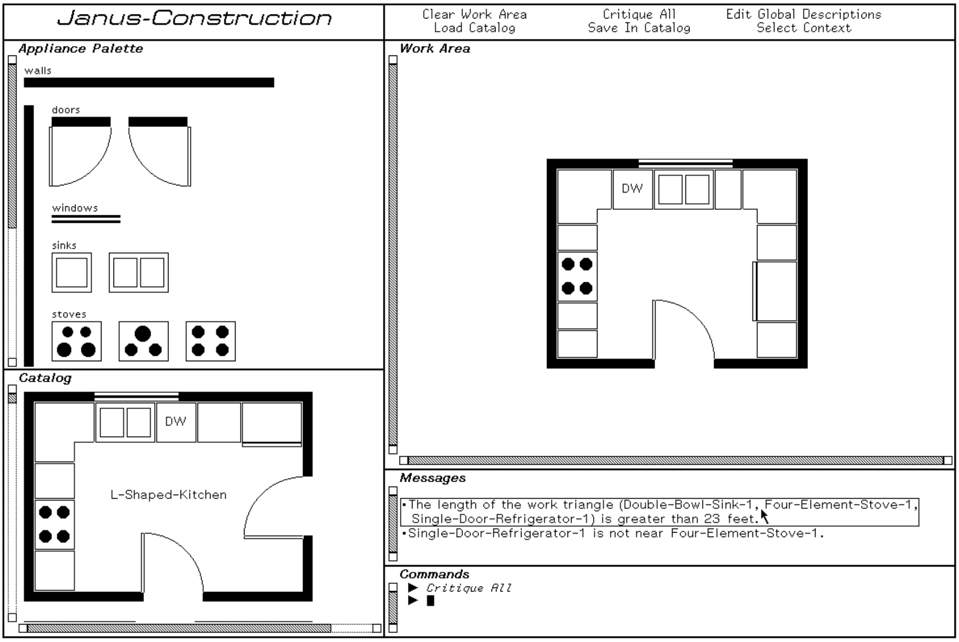

Fig. 1. JANUS-CONSTRUCTION — The Work Triangle Critic. The construction component of JANUS has an *Appliance Palette* of kitchen design objects and a *Work Area* for constructing kitchen flow plans. Critic messages are displayed in the Messages window. Selecting a critic message takes the designer to the argumentation component (see Fig. 2).

in the construction of a design, such as sinks and stoves in the domain of kitchen design. Critics can be tied to these domain-oriented design units and to relationships among design units.

- The *specification component* allows designers to describe the abstract characteristics of the design they have in mind. The specifications are expected to be modified and augmented during the design process, rather than to be fully articulated at the beginning. The specification provides the system with an explicit representation of the user's goals. This information can be used to tailor both the critic suggestions put forth and the accompanying explanations to the user's task at hand.
- The *argumentative hypermedia component* contains design rationale. Users can annotate and add argumentation as it emerges during the design process. Argumentation is a valuable component in a critic's explanation; it identifies the pros and cons of following a critic suggestion and helps the user to understand the consequences of following the suggestion.
- The *catalog component* provides a collection of previously constructed designs. These illustrate examples within the space of possible designs in the domain and support reuse and case-based reasoning (Kolodner, 1993). Catalog entries are also important components in a critic's explanation. Often a critic does not suggest a

course of action but instead points out a deficiency in the current design; catalog entries can then be used as specific examples illustrating sample solutions that address a deficiency noted by a critic.
- The *simulation component* supports users in their understanding of the behavior of a component or a complete artifact.

DODEs derive their power from the *integration* of these components. When used in combination, each component augments the values of the others in a synergistic manner.

In contrast to general-purpose environments, specific domain-oriented design systems are instantiated from a generic, domain-independent architecture (using the "*seeding, evolutionary growth, reseeding*" process model (Fischer *et al.*, 2001)) to support users in a specific domain. They provide specific functionality for manipulating, exploring, and communicating about domain entities. All of these components are not static entities in DODEs. As users interact with the environment, they create and compose new artifacts that themselves become part of the system. DODEs support self-directed learners based on the assumption that learning is affected as much by motivational issues (Csikszentmihalyi, 1990) as by cognitive issues — requiring environments that let people experience and understand why they should learn and contribute something. Each of the following aspects should increase the motivation to learn (Collins *et al.*, 1989):

- Learning is actively desired and controlled by the learner — supported in DODEs by allowing learners to engage in self-directed learning activities.
- The information is easier to find and people are successful in finding and using it — supported in DODEs by critics.
- Learners must be able to see the benefit to their current working situations of learning something new (Carroll & Rosson, 1987) — supported in DODEs by learning-on-demand, which lets users access new knowledge in the context of actual problem situations and by information delivery.
- Environments are intrinsically motivating, so users can achieve large effects with reasonably small efforts — supported in DODEs by human problem-domain interaction, which allows designers to create artifacts from design ideas with a reasonable amount of effort.

5.2. *Critiquing systems*

In many lifelong learning situations, human understanding evolves through a process of critiquing existing knowledge and consequently expanding the store of knowledge. Critiquing is a dialog in which the interjection of a reasoned opinion about a product or action triggers further reflection on or changes to the artifact being designed. Our work has focused on applying this successful human critiquing paradigm to human-computer interaction. Computer-based critiquing systems are most effective

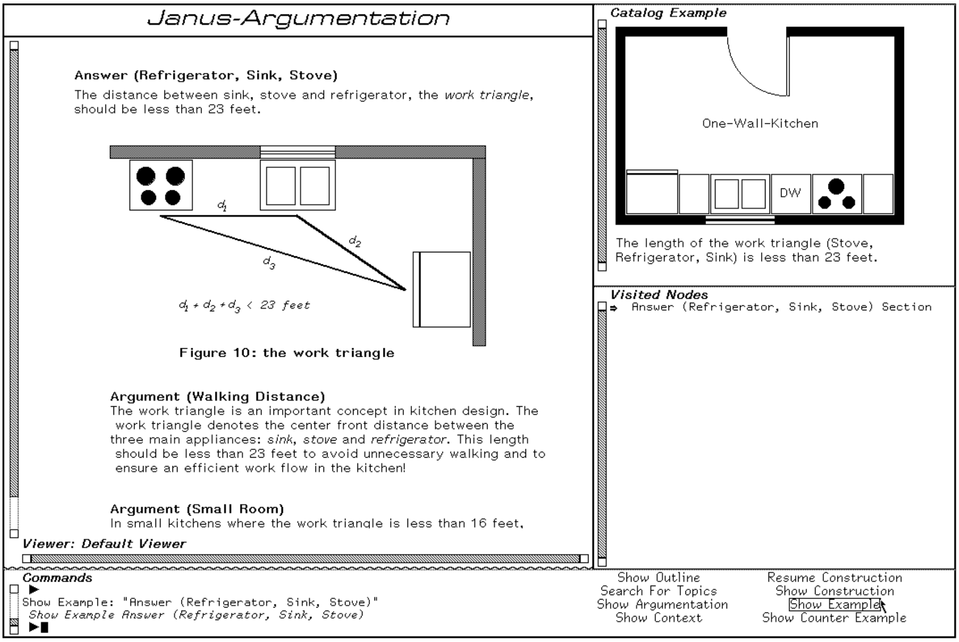

Fig. 2. JANUS-ARGUMENTATION — Rationale for the Work Triangle Rule. The main window of JANUS-ARGUMENTATION presents issue-based information about a critiquing rule, in this case the "work triangle rule." Graphical representations help to contextualize and clarify the textual answers and arguments. Further clarification is presented in the *Catalog Example* window (top right), which displays a catalog entry illustrating the critiquing rule.

when they are embedded in domain-oriented design environments. *Embedded critics* (Fischer *et al.*, 1998) play a number of important roles in such design environments:

- They increase the designer's understanding of design situations by pointing out problematic situations early in the design process.
- They support the integration of problem framing and problem solving by providing a linkage between the design specification and the design construction.
- They help designers access relevant information in the large information spaces provided by DODEs.

Figure 3 illustrates the process model underlying critiquing: it shows the interactions between a designer and a critiquing mechanism embedded in a DODE (Figs. 1 and 2 illustrate this in the context of a specific DODE for kitchen design). Bold lines represent process flows, and thin lines represent information flows. The design process is a series of iterations through this model.

Critiquing is ubiquitous. It is, for example, at the heart of the scientific method. Popper (Popper, 1965) theorized that science advances through a cycle of conjectures and refutations. Scientists formulate hypotheses and put forth these conjectures for scrutiny and refutation by the scientific community. Besides contributing

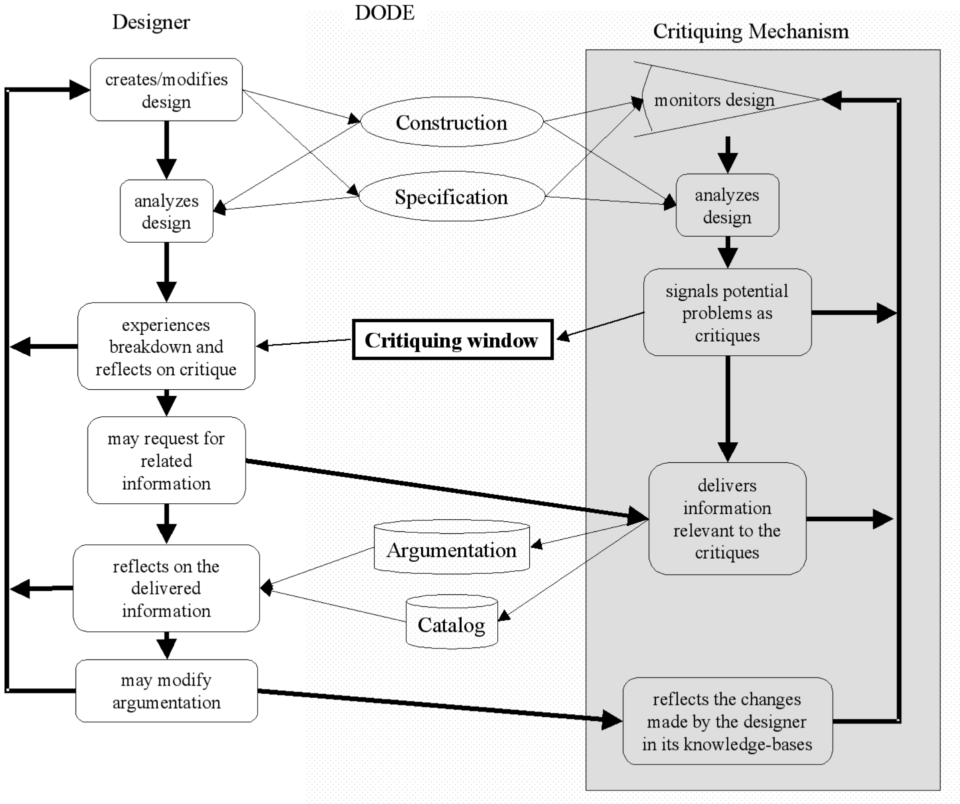

Fig. 3. Model of critiquing process in a DODE.

to the growth of knowledge, this critiquing cycle of conjectures and refutations is essential for creating a shared understanding within the scientific community and providing a stable base for future growth in scientific knowledge.

Critics play an important role in making designers aware of breakdown situations. Petroski (Petroski, 1985) noted the importance of failure in the growth of engineering knowledge. The activity of critiquing plays an important role in engineering, science, and design in general. It produces many benefits, including the growth of knowledge, error elimination, and the promotion of mutual understanding by all participants. Through the critiquing process, designers gain a better understanding of the design problem by hearing the different points of view of other design participants.

Critiquing systems support workers in increasing the quality of an artifact by signaling breakdowns, and they exploit breakdown situations as opportunities for learning on demand. Critics support users working on their *own* activities. They provide information only when it is relevant. They allow users to do what they want and interrupt only when users' plans, actions, or products are considered significantly inferior. They are applicable to tasks in which users have some basic competence because users must be able to generate a plan, action, or product by themselves. They are most useful when no unique best solution exists in a domain and trade-offs have to be carefully balanced.

5.3. *The envisionment and discovery collaboratory*

The Envisionment and Discovery Collaboratory (Arias *et al.*, 2000) is a second-generation framework for domain-oriented design environments specifically supporting *learning communities* (beyond the DODEs discussed in Sec. 5.1, which are focused on individual learners). The EDC framework supports lifelong learning by creating shared understanding among various stakeholders, contextualizing information to the task at hand, and creating objects-to-think-with in collaborative design activities. It is applicable to different domains; our initial effort has focused on the domains of urban planning and decision making, specifically in transportation planning and community development. Creating shared understanding requires a culture in which stakeholders see themselves as reflective practitioners rather than all-knowing experts (Schön, 1983). Collaborative design taking place in such a culture can be characterized by an "asymmetry of knowledge," or a "symmetry of ignorance" (Rittel, 1984): stakeholders are aware that even though they each possess relevant knowledge, none of them has all the relevant knowledge.

Figure 4 shows the current realization of the EDC environment. Individuals using the EDC convene around a computationally enhanced table, shown in the

Fig. 4. The EDC environment.

center of the figure. This table serves as the Action space for the EDC. Currently realized as a touch-sensitive surface, the Action Space allows users to manipulate the computational simulation projected on the surface by interacting with the physical objects placed on the table. The table is flanked by a second computer, which drives another touch-sensitive surface (shown horizontally in Fig. 4). This computational whiteboard serves as the EDC's Reflection space. In the figure, neighbors are filling out a Web-based transportation survey that is associated with the model being constructed. The Reflection and Action spaces are connected by communication between the two computers using the Web as a medium. The entire physical space, through the immersion of people *within* the representations of the problem-solving task, creates an integrated human/computer system grounded in the physical world.

As argued before, much development of technology for learning and design builds on or is constrained by the "single user/single computer" interaction model. The EDC emphasizes the creation of shared interaction, social structures, and cultural embedding for learning within the context of communities of learners. It is being developed as a learning and design support medium wherein three-dimensional physical objects interact dynamically with virtual ones over an integrated sensory/display work surface as the computational game board. Based on 10 years of experience in building physical simulation games, we have observed that powerful collaborative learning and shared decision making can be supported by shared interaction and integration with computational models. Together, these form a collaborative environment that builds on both distributed and face-to-face collaborations in classrooms or public sites.

Crucial processes relevant for lifelong learning and supported by the EDC are:

- dealing with a set of possible worlds effectively (i.e. exploring design alternatives) to account for the design is an argumentative process, where we do not prove a point but we create an environment for a design dialog (Simon, 1996);
- using the symmetry of ignorance (i.e. that all involved stakeholders can contribute actively) as a source of power for mutual learning by providing all stakeholders with means to express their ideas and their concerns (Rittel, 1984);
- incorporating an emerging design in a set of external memory structures, and recording the design process and the design rationale (Fischer *et al.*, 1996);
- creating low-cost modifiable models, which help us to create shared understanding, have a conversation with the materials (Schön, 1983), and replace anticipation (of the consequences of our assumptions) by analysis;
- using the domain orientation to bring tasks to the forefront and support human problem-domain communication (Fischer, 1994);
- increasing the "back-talk" of the artifacts with critics (Fischer *et al.*, 1998); and
- using simulations to engage in "what-if" games.

The EDC is a contribution to the creation of a new generation of *collaborative* domain-oriented design environments. It shifts the emphasis away from the computer screen as the focal point and creates an immersive environment in which stakeholders can incrementally create a shared understanding through collaborative design. It is an environment that is not restricted to the delivery of predigested information to individuals, but instead provides opportunities and resources for design activities embedded in social debates and discussions in which all stakeholders can actively contribute rather than assume passive consumer roles (Fischer, 2002).

The EDC will prepare the next generation of knowledge workers for lifelong learning and innovation in a world in which the traditional boundaries between formal educational institutions and the world at large will dissolve. By reaching out, industries and communities of ideas, skills, and technology can experience a natural exchange of knowledge. In this reciprocal relationship, graduates of our programs migrate to various places of work to continue their learning. Workers and community members benefit from learning how to participate in and shape the future of their workplaces and their communities through informed collaboration.

The EDC has allowed exploration of individual and social creativity through interaction and participation across a variety of different dimensions:

- **Individual interaction with computational artifacts *versus* shared interaction, supporting interaction with others through the computational artifacts as a shared medium.** Many approaches to computational support for collaborative activities have focused on the network as the shared medium and the individuals' interactions through that medium via their individual computational devices. The EDC attempts to extend this model to explore how shared interaction with the computational models within the same physical space (Olson & Olson, 2001) can provide ways to tap into elements of social interaction that occur naturally in such shared spaces.
- **Individual agendas *versus* creation of shared focus.** One aspect that often confronts attempts to create common ground is that the perspectives that participants bring to the meeting often are closely tied with (sometimes implicit) agendas. Often the format of the interaction acts to reinforce these agendas rather than moderate among them. Experiments with physical models as a means of focusing discussion around the shared problem have demonstrated that a common focus helped to create a better appreciation of other perspectives. The EDC builds upon this model for interaction and includes support for dynamic computational models as part of the interaction as well as for dynamic linkages to information relevant to the task at hand (Fischer *et al.*, 1996).
- **Expert tools *versus* providing access to design for people with different perspectives and from various backgrounds.** A critical element in the design of the EDC is the support for participation by individuals whose valuable perspectives are related to their embedded experiences (e.g., neighborhood residents) rather than on any domain expertise. The overall design of the EDC, targeted toward these participants, employs the use of physical objects to create an inviting and natural interaction with the simulation, and recognizes that parallel interaction capability is essential to support this natural interaction (Eden, 2002). The

development of active critics (Fischer *et al.*, 1998) and virtual stakeholders (Arias *et al.*, 1997) supports informed participation.

- **Dependence on model monopolies *versus* creating boundary objects.** One danger of any model (computational or otherwise) is that it may embody certain assumptions and perspectives that, if not questioned, can lead to an imbalance of influence within the process. These forms of *model monopoly* (Turkle & Papert, 1991) need to be balanced by having open representations of the models that allow for deeper understanding, experimentation, and possibly refutation. The goal is to permit a migration toward shared representations that are useful across contexts as boundary objects (Bowker & Star, 2000). The EDC design goals are to provide an open environment and design process that will allow these models to be developed and extended.
- **Reliance on high-tech scribes *versus* supporting meta-design.** Creating models within the EDC requires a considerable amount of programming effort. This represents a high degree of reliance upon high-tech scribes, distancing the real designers from the medium of expression. Environments (even domain-oriented ones) that are open and easily modifiable and extensible are still elusive. While we continue to work on support for end-user development (Fischer *et al.*, 2004a) we are also looking at ways to harness existing tool use, integrate with existing practice, develop models (such as open source systems (Raymond & Young, 2001)), and empower local developers (Nardi, 1993).

5.4. *Caretta — Integrating personal and shared spaces*

Caretta is a system for supporting face-to-face collaboration by integrating personal and shared spaces (Sugimoto *et al.*, 2004). This system is used to support users in urban planning tasks, which are categorized as open-ended social problems. In urban planning tasks, all the stakeholders want to devise their "best" ideas and need to discuss and negotiate with each other to create mutually agreeable design plans. In actual group work situations, individual reflections and group discussions often happen in parallel: Some participants individually try to come up with their own ideas, and other participants collectively evaluate existing plans. Therefore, collaborative urban planning tasks are spiral and entwined processes that require the smooth integration of individual and group activities; outcomes gained through individual activities drive group activities and those gained through group activities trigger further individual activities. Existing computational media, however, do not fully support users' individual and group activities at the same time because design trade-offs between them have been pointed out (Gutwin & Greenberg, 1998).

The design of Caretta derived from our previous experiences with computer-supported collaborative learning (CSCL) research projects (Sugimoto, 2005). We have so far developed systems for supporting collaborative learning by enhancing interactions among learners through physical shared workspaces (Sugimoto *et al.*, 2005). The evaluations of these systems with elementary school children or undergraduate students have clarified the following problems: In collaborative learning situations, some learners who were the leaders in their groups seized the leadership and the other learners often followed without discussion or consideration of the arguments. Therefore, some learners did not fully participate in their own learning (Sugimoto *et al.*, 2003).

We have often recognized that one of the underlying philosophies of CSCL, that is, "to respect differences among people, and take advantage of them as opportunities for mutual learning" does not always happen in a real learning situation. One of the reasons why ideal collaborative learning through learners' active participation does not always take place seems related to Asian (especially Japanese) culture. For example, in classrooms in Japanese schools (from elementary schools to universities), learners sit down quietly and almost always listen to what the teacher says. In many cases, learners are passive recipients of information and do not speak about their own opinions spontaneously without being asked to do so by the teacher. Actually, many learners hesitate to represent their individual ideas, and therefore active discussions that would recognize differences among them and construct shared understanding do not take place.

Caretta is designed to overcome the shortcomings of existing systems and to support passive learners in becoming active learners. It provides users with personal spaces for individual reflections, a shared space for group discussions, and intuitive transition methods between these spaces. In Caretta, a multiple-input sensing board, appropriately called the SensingBoard (Sugimoto *et al.*, 2002), is used for the shared space, and personal digital assistants (PDAs) are used for individual personal spaces, as shown in Fig. 5. Users of Caretta can discuss and negotiate with each other in the shared space by manipulating physical objects, each of which is enhanced by a radio frequency (RF) tag for rapid object recognition. An augmented reality technology for overlaying virtual graphics onto the shared space through a liquid crystal display (LCD) projector creates an immersive collaborative environment that enhances interactions and mutual awareness among the users.

The personal spaces of Caretta work for individual users' reflections because they can freely examine their ideas without being disturbed by other users. Providing each user with a personal space enhances the diversity of individual users' activities: Based on their knowledge and experiences, users can externalize and elaborate their own ideas. A user who has a design idea, but is not confident of it and does not want to represent it yet on the public workspace, can first examine it privately on his or her PDA. Providing users with the shared space allows them to share physical boundary objects and enhances interactions and negotiations with other users. By providing users with intuitive transition methods between the personal and shared spaces, Caretta allows users to easily copy the current situation from the shared space (e.g. a design plan shared and discussed by a group of users) to the individual users' personal spaces, and, conversely, to display design plans devised by individual users on their PDAs onto the shared space. Therefore, Caretta can

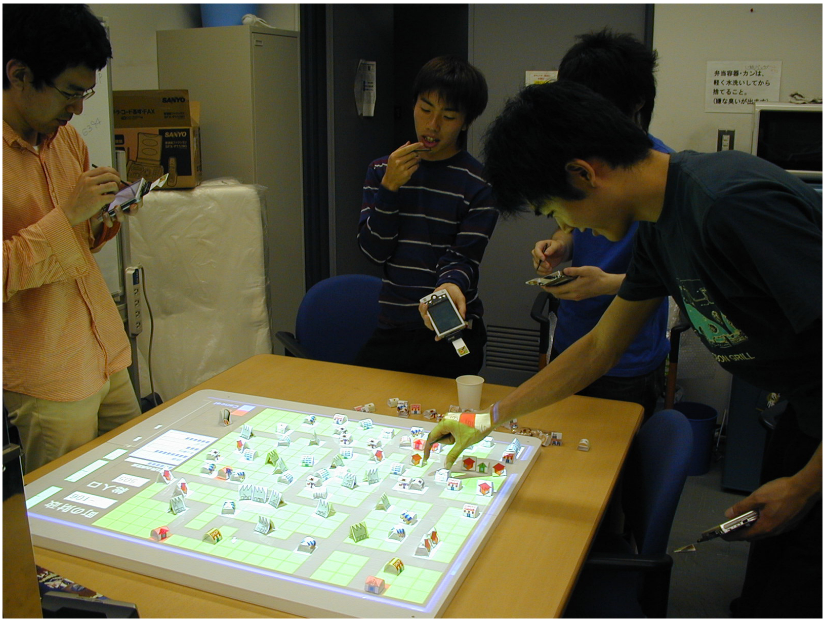

Fig. 5. Caretta in use.

support users in seamlessly conducting their tasks on both spaces, and enhance collaborative problem-solving processes through the users' active participation.

User studies of Caretta (Fig. 5) have demonstrated the following specific situations:

- A user working on his personal space was not disturbed by the others and could concentrate on his individual reflection. In this case, however, users did not always conduct their individual activities separately: They were loosely coupled because they worked to find a suitable design plan for the same town from individually different viewpoints. This enhances the diversity of design plans devised by individual users, and raises the possibility of finding creative solutions.
- A user who hesitated to represent his own idea on the shared workspace visible to all users tested the idea privately on his personal space, which was not visible to other users. When he became confident about his idea through simulations on his personal space, he proposed the idea by representing it on the shared workspace. Caretta thus supported this user in overcoming his mental barrier to participating in collaborative learning situations by allowing him to interchangeably use the personal and shared workspaces.
- A user who devised a design plan on his personal space immediately made his design plan appear on the shared space. The plan was shared and reviewed by all users and became a trigger for activating group discussions. It was then modified by and augmented with other plans devised by users on their own personal spaces, and finally accepted by the users as their group plan. Some users actually copied

a plan discussed on the shared space onto their personal spaces, individually examined it, and again proposed the modified plan on the shared space. By reviewing design plans proposed by others, users did not have to examine similar plans repeatedly.

In general, the user studies showed that Caretta supported the following collaborative design processes:

- By allowing users to simultaneously manipulate sharable boundary objects on the shared space, Caretta enhanced interactions among users and raised the level of their engagement and awareness.
- By using the intuitive transition methods, users working on their own personal spaces could easily return to the shared space, and vice versa.
- By allowing users to review others' results in the shared space, Caretta effectively worked to support not only individuals but also social creative planning processes.

The Caretta user studies thus have demonstrated that there is an "and" and not a "versus" relationship between individual and social activities in collaborative design/learning processes. In Caretta, individual and social activities are mutually augmented: users' individual work on their personal space is augmented by their group work on the shared space, and vice versa. The integration of personal and shared space was effective for making passive learners active and inducing vigorous interactions among the users.

Caretta has the following potential for enhancing lifelong learning and supporting learning communities:

- Caretta changes the learning/teaching style from an instructionist (knowledge absorption) mode to a constructionist (knowledge construction) mode by fully utilizing advanced information technologies, such as sensing and mobile technologies.
- Caretta allows people from different backgrounds and cultures to participate in learning situations because each of them is given the opportunity to devise his or her own ideas in the individual personal space and externalize them on the shared space in an intuitive manner in order to discuss these ideas with the other users. By enhancing constructive collaboration through learners' externalization and reflection (Miyake & Masukawa, 2000), Caretta can support a learning community for collaborative knowledge construction.
- Collaborative design and learning with Caretta also changes the role of the teacher when it is used in school education. As students individually and collaboratively find and solve their problems through externalization and reflection processes, the teacher's role becomes that of a facilitator or coach.

6. Challenges for the Future

The following challenges are based on the themes and issues raised and discussed in this paper and are derived from our basic objective of supporting self-directed learners and learning communities with sociotechnical environments. These challenges provide a conceptual framework to further explore *the research and practice in technology-enhanced learning — the fundamental objective of the RPTEL journal.*

Goal: Understand the Magnitude of the Change
The current thinking in society does not address the potential magnitude of the change caused by information and communication technologies. We believe that the potential changes based on digital media are of a magnitude similar to society moving from an oral to a literary society or the printing press eliminating the scribes and giving everyone the opportunity to become literate.
Challenge: Understand the long-term societal impacts of self-directed and lifelong learning. Self-directed and lifelong learning needs to be more than a label or the adoption of surface practices. Reinvent our educational institutions and our work environments to make learning a part of life.

Goal: Support Distributed Intelligence in Learning Communities
The individual human mind is limited — therefore in real life (i.e. outside of schools) people rely heavily on information and knowledge distributed among groups of people and various artifacts.
Challenge: Deemphasize rote learning and closed-book exams. Support social environments enriched by embedded computational media that emphasize collaborative learning and communication skills.

Goal: Explore Different Learning Paradigms
In lifelong and self-directed learning, people encounter the need for learning coming from a large variety of backgrounds and being engaged in a great variety of different tasks.
Challenge: Provide multiple educational forms and opportunities rather than trying to design the "one best" educational and computational environment. Teacher-driven approaches (such as intelligent tutoring systems) will be limited in their support of self-directed learning.

Goal: Reconceptualize the Role of Teachers and Learners
In the past, the roles of teacher and learner were associated with impersonal encounters. In the learning environments of the future (characterized by a "symmetry of ignorance" among the participating stakeholders), these roles will change dynamically, dependent on the issues and questions under investigation. Questions arising from self-directed learning activities (as opposed to presentations by the teacher) will indicate the limitations of the teachers' knowledge.
Challenge: Change the role of the teacher from an oracle to a coach, mentor, and facilitator, and support peer-to-peer learning. Teachers need to be comfortable interacting with learners in situations in which they do not know everything. There is ample evidence that a constructionist approach toward education in which students can engage in self-directed, authentic learning activities requires substantially more teacher resources than the standard classroom lecture of today's university.

Goal: Educate Learners to Become Lifelong Learners
Educational institutions need to prepare learners and workers for a world that relies on interdependent, distributed, nonhierarchical information flow and rapidly shifting authority based on complementary knowledge. Lifelong learning is more than "adult education"; it covers and unifies all phases: intuitive learner (home), scholastic learner (school and university), and skilled domain worker (workplace). It is a misleading assumption that humans at a certain age will be able to throw the "big switch" and become self-directed learners after they have not experienced or practiced this mode of learning during the first 30 or 40 years of their lives.
Challenge: Close the gap between school and workplace learning by allowing learners in all phases to engage in activities requiring collaboration, creativity, problem framing, and distributed cognition. Integrate learning into working and playing instead of conceptualizing it as a separate activity.

Goal: Support New Interdisciplinary, Cross-Cultural Collaborations
Realistic problems are framed and solved by groups, communities, and organizations rather than individuals. The participants come from different "cultures" (e.g. different professions, different countries, different objectives) and must have the willingness, the experience, the environment, and the tools to be able to learn from each other.
Challenge: The role of a community of learners with different backgrounds needs to be explored and explicitly incorporated into our conceptual frameworks and computational media. Develop environments supporting mutual learning and mutual understanding.

Goal: Balance Economics and the Quality of Education Education needs to be Cost-effective
The inherent conflict between economics and education needs to be resolved; for example, teachers' time and attention are scarce resources, but educationally meaningful interactions require more of teachers' time and attention. Whereas new media offer the possibility of reducing the cost of education, an equally important goal is to improve the quality of education ("*If you think education is expensive, try ignorance!*").
Challenge: Explore the scalability of educationally desirable innovations (for example, the Nobel Prize winner as a private coach does not scale). Design and develop computational media to support learners in their own doing. Create new role distributions between human teachers and computational media. Although there is no evidence that all the tasks of a teacher can be "handed over" to a computer, new media allow us to rethink the role of the teacher.

Goal: Move beyond Standard Curricula and Simple Notions of Efficiency
Some researchers (e.g. Hirsch, 1996) adhere to the claim that the level of learners' achievement through self-directed learning is not clear, compared to that through learning based on traditional instructionist approaches, because in self-directed

learning, learning goals are usually not predefined but need to be discovered by the learners themselves. Therefore, in terms of efficiency, instructionist approaches are postulated to be more effective than self-directed learning approaches because all learners in a classroom will simultaneously learn the same knowledge.

Challenge: In a rapidly changing society, a strategy to let all people know or learn the same (but restricted) knowledge has severe limitations. Rather, by allowing people to have different fields and levels of knowledge, the potential growth and sustainability of our society must be raised, requiring self-directed learning and learning communities to transcend the information given and explore diverse knowledge more deeply (Mayer, 2004).

Goal: Avoid Reinventing the Wheel

Self-directed learning should not underestimate the knowledge of the past. Let learners stand on the shoulders of the giants who preceded them!

Challenge: Self-directed learning (as well as any other approach toward learning and teaching) should complement other approaches. Instructionist approaches are suited to making the knowledge of the past available under the guidance of an experienced teacher.

Goal: Support Collaborative Knowledge Construction

Whereas we face too much information in the abstract, in most specific problem situations, we do not have enough knowledge.

Challenge: Learning cannot be restricted to finding knowledge that is "out there." If nobody in a group knows the answer, we have to create new knowledge. Create environments that stimulate innovation and creativity by exploiting breakdowns, symmetry of ignorance, experimentation, and external objects serving as objects-to-think-with and objects-to-talk-about.

Goal: Identify "Basic" Skills

A lifelong learner cannot learn any arbitrary skill on demand — prerequisites normally limit what a person can and cannot learn. This raises an important question: What "basic skills" are required in a world in which occupational knowledge and skills become obsolete in years rather than decades?

Challenge: The "old" basic skills (such as reading, writing, and mathematics), once acquired, were relevant for the rest of a human life; modern "basic skills" (tied to rapidly changing technologies and media) change over time. Education cannot be reduced to mere skill acquisition and information processing, but needs to prepare students to become self-directed and lifelong learners by creating passion and deep understanding about their existence as human beings in the future knowledge society.

Goal: Develop New Assessment Strategies

Self-directed learning makes assessment strategies — in which everyone is measured with the same yardstick and in which human capabilities are reduced to a number — infeasible. New approaches, however, should not avoid the assessment challenge; it is legitimate to ask for evidence that the "new" approaches are working.

Challenge: Assessment strategies developed for instructionist learning are not suitable for self-directed learning. The development of new assessment strategies that address the needs of self-directed learning is an important research problem. For further development of theories and systems on self-directed learning, analyses on positive and negative examples should be conducted.

Goal: Take Motivation Seriously

If we want people to be lifelong learners, we must make sure they enjoy it. *Motivation* is central to learning.

Challenge: The beginnings of a motivational theory urgently need to be developed further. One of the benefits of integrating working and learning is the potential increase in motivation. Motivation to learn new things is critically influenced by optimal flow, a continual feeling of challenge, the right tools for the job, and a focus on the task.

Goal: Design and Develop Innovative Media in Support of Lifelong, Self-Directed Learning

Noncomputational media (such as books and films) cannot, in principle, analyze and critique the work of learners and contextualize new information, advice, and help to their work.

Challenge: Although computational media provide us with the possibility to learn efficiently (for example, by using the Internet we can easily find necessary information in classrooms or workplaces without visiting a library), it is not sufficient. The interpretive power of computational media is needed to support people in their own activities. To make self-directed learning economically feasible, new kinds of media and technology are needed that are able to analyze and critique a student's work. This objective is more tractable for self-directed learners because their engagement is more articulate, and therefore sociotechnical environments have more information available for helping, providing hints, and developing a student model.

Goal: Educate New Kinds of Professionals

Education must prepare humans for a world in which learning is an integral part of their lives. Industrial-age models of education are inadequate in preparing students to compete in the knowledge-based workplace.

Challenge: Create educational settings for young researchers and students (at a formative stage in their careers) in which they can learn how to learn, are able to engage in personally meaningful activities, exploit the power of media, and collaborate with others in interdisciplinary and cross-cultural settings.

Goal: Change Mindsets and Organizations

There is no evidence from the past that technology by itself has changed education, learning, and teaching in any fundamental way, especially technologies used in the "gift wrapping" mode.

Challenge: Develop new mindsets and attitudes among (1) individuals (e.g.: learners, teachers, researchers, and policy makers); and (2) organizations (e.g. nurturing a collaborative work environment, being willing to undergo culture changes).

7. Conclusion

One of the most important objectives of the use of technology to enhance learning is to transcend "gift-wrapping" and "techno-determinism" by fundamentally rethinking learning, whether in schools, in universities, in workplaces, or in life. We have to understand the coevolutionary processes between fundamental human activities and their relationships and interdependencies with new media. We need progress and a deeper understanding of new theories, innovative systems, practices, and assessment. We have to create new intellectual spaces, new physical spaces, new organizational forms, and new reward structures to make lifelong learning an important part of human life. We need individuals, groups, and organizations to personally engage in and experience these new forms. In effect, we need risk takers who use their creativity and imagination to explore alternative ways of learning.

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