Center for
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Wisdom is not a product of schooling
but the lifelong attempt to acquire it.
- Albert Einstein

Making Learning a Part of Life
—
Beyond the "Gift Wrapping" Approach of Technology

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Abstract

The previous notions of a divided lifetime — education followed by work — are no longer tenable. Learning can no longer be dichotomized, spatially and temporally, into a place and time to acquire knowledge (school) and a place and time to apply knowledge (the workplace). Professional activity has become so knowledge-intensive and fluid in content that learning has become an integral and inseparable part of “adult” work activities. Professional work can no longer simply proceed from a fixed educational background; rather, education must be smoothly incorporated as part of work activities fostering growth and exploration. Similarly, children require educational tools and environments whose primary aim is to help cultivate the desire to learn and create, and not to simply communicate subject matter divorced from meaningful and personalized activity.

Lifelong learning is a continuous engagement in acquiring and applying knowledge and skills in the context of authentic, self-directed problems. The research in lifelong learning in our Center for “Lifelong Learning and Design (L3D)" at CU Boulder is grounded in descriptive and prescriptive goals such as: (1) 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); (2) learning should be embedded in the pursuit of intrinsically rewarding activities; (3) learning-on-demand needs to be supported because change is inevitable, complete coverage is impossible, and obsolescence is unavoidable; (4) organizational and collaborative learning must be supported because the individual human mind is limited; and (5) skills and processes that support learning as a lifetime habit must be developed.

We claim that most current uses of technology to support life-long learning are restricted to a “gift wrapping” approach: they are used as an add-on to existing practices rather than 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, etc., are not changed by technology itself. This is true whether we use computer-based training, intelligent tutoring systems, multimedia presentations, or the WWW. We are engaged in developing computational environments to support “new” frameworks for lifelong learning such as: integration of working and learning, learning on demand, authentic problems, self-directed learning, information contextualized to the task at hand, (intrinsic) motivation, collaborative learning, and organizational learning.

1. Introduction

There is general agreement as we approach the next century and next millennium that our society is changing into a knowledge and information society. We will face new opportunities and new challenges in all dimensions of our lives. But the future is not out there to be "discovered": It has to be invented and designed. Our research agenda is focusing on "making learning a part of life," and the implications this has on how—under the influence of new media, new social structures, and new objectives for a quality of life—human beings will think, create, work, learn, and collaborate in the future.

2. Learning: Current Theories

Current trends in educational theory make the following fundamental assumptions about *learning* (arguments supporting this view can be found in the books by [Csikszentmihalyi 1990a; Norman 1993; Resnick 1989]:

- Learning is a process of **knowledge construction**, not of knowledge recording or absorption.
- Learning is **knowledge-dependent**; people use their existing knowledge to construct new knowledge.
- Learning is highly **tuned to the situation** in which it takes place.
- Learning needs to account for **distributed cognition** requiring knowledge in the head to combined with knowledge in the world.
- Learning is affected as much by **motivational issues** as by cognitive issues.

3. Lifelong Learning

Lifelong Learning: A Ubiquitous Goal. Lifelong learning has emerged as one of the major challenges for the worldwide knowledge society of the future. A variety of recent events support this claim: (1) 1996 is the "European Year of Lifelong Learning" [Otala 1993], (2) UNESCO has included "Lifetime Education" as one of the key issues in its planning, and (3) the G7 group of countries has named "Lifelong Learning" as a main strategy in the fight against unemployment. Despite this great interest, there are few encompassing efforts to tackle the problem in a coherent way. Lifelong learning cannot be investigated in isolation by looking just at one small part of it, such as K-12 education, university education or worker re-education.

Learning as a New Form of Labor. The previous notions of a divided lifetime—education followed by work—are no longer tenable. Learning can no longer be dichotomized, spatially and temporally, into a place and time to *acquire* knowledge (school) and a place and time to *apply* knowledge (the workplace). Professional activity has become so knowledge-intensive and fluid in content that learning has become an integral and inseparable part of "adult" work activities. Professional work can no longer simply proceed from a fixed educational background; rather, education must be smoothly incorporated as part of work activities fostering growth and exploration. Similarly, children require educational tools and environments whose primary aim is to help cultivate the desire to learn and create, and not to simply communicate subject matter divorced from meaningful and personalized activity.

Lifelong learning is a continuous engagement in acquiring and applying knowledge and skills in the context of authentic, self-directed problems. L^{3}D's theoretical framework for lifelong learning is grounded in descriptive and prescriptive goals such as: (1) 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); (2) learning should be embedded in the pursuit of intrinsically rewarding activities; (3) learning-on-demand needs to be supported because change is inevitable, complete coverage is impossible, and obsolescence is unavoidable; (4) organizational and collaborative learning must be supported because the individual human mind is limited; and (5) skills and processes that support learning as a lifetime habit must be developed.

4. Lifelong Learning and Design

Lifelong learning integrates and mutually enriches the cultures of work and education. Central to this vision in our own research is the notion of design activity, a model of work that is open-ended and long-term in nature, incorporates personalized and collaborative aspects, and combines technical and aesthetic elements. Design is an argumentative process, involving ongoing negotiations and trade-offs; it is also a collaborative process making increasing use of new social structures brought about by the advent of computer networks and "virtual communities." The communality that crucially binds these and other design activities together is that they are centered around the production of a new, publicly accessible artifact. Engineers and architects design infrastructure and buildings, lawyers design briefs and cases, politicians design policies and programs, educators design curricula and courses, and software engineers design computer programs. It is impossible for design processes to account for every aspect that might affect the designed artifact. Therefore design must be treated as an evolutionary process in which designers continue to learn new things as the process unfolds. The relationship between learning and design provides the impetus for the work done at the L^{3}D Center. Because design is an essential aspect of all problem-solving activity, and since designers are constantly learning and communicating with each other, the research done at the L^{3}D Center seeks to ground educational theory within the domain of technology that supports design and communication.

5. Beyond the "Gift Wrapping" Approach of Educational Reform—Rethinking, Reinventing, and Reengineering Education

A deeper understanding and more effective support for lifelong learning will contribute to the transformation that must occur in the way our society works and learns. A major finding in current business reengineering efforts is that the use of information technology had disappointing results compared to the investments made in it [Landauer 1995]. While a detailed causal analysis for this shortcoming is difficult to obtain, it is generally agreed that a major reason is that information technologies have been used to mechanize old ways of doing business—rather than fundamentally rethinking the underlying work processes and promoting new ways to create artifacts and knowledge.

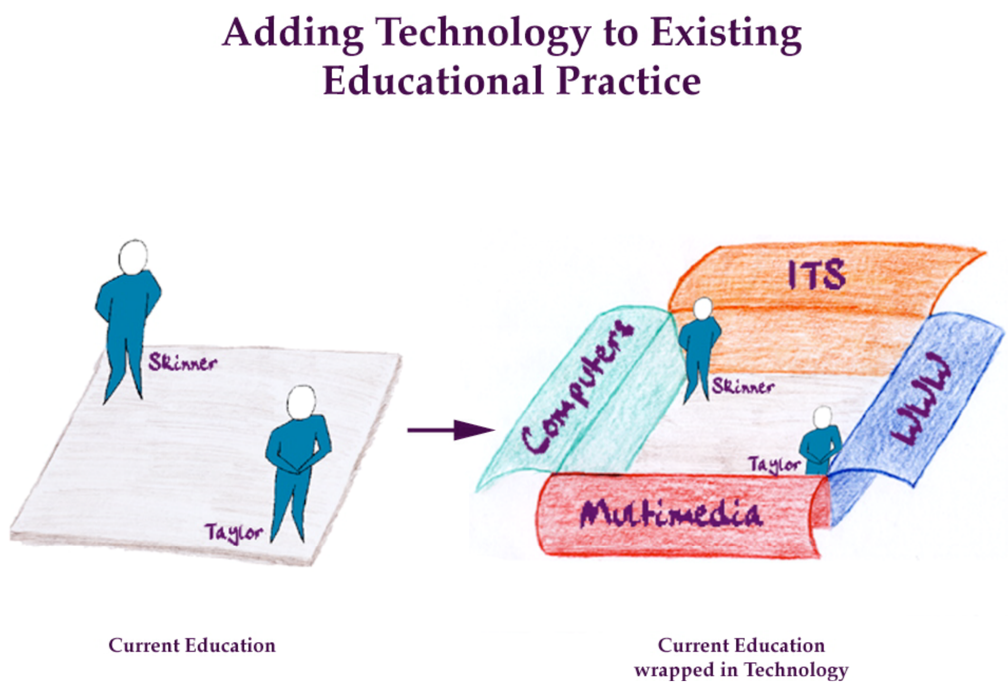


Figure 1: The "Gift Wrapping" Approach

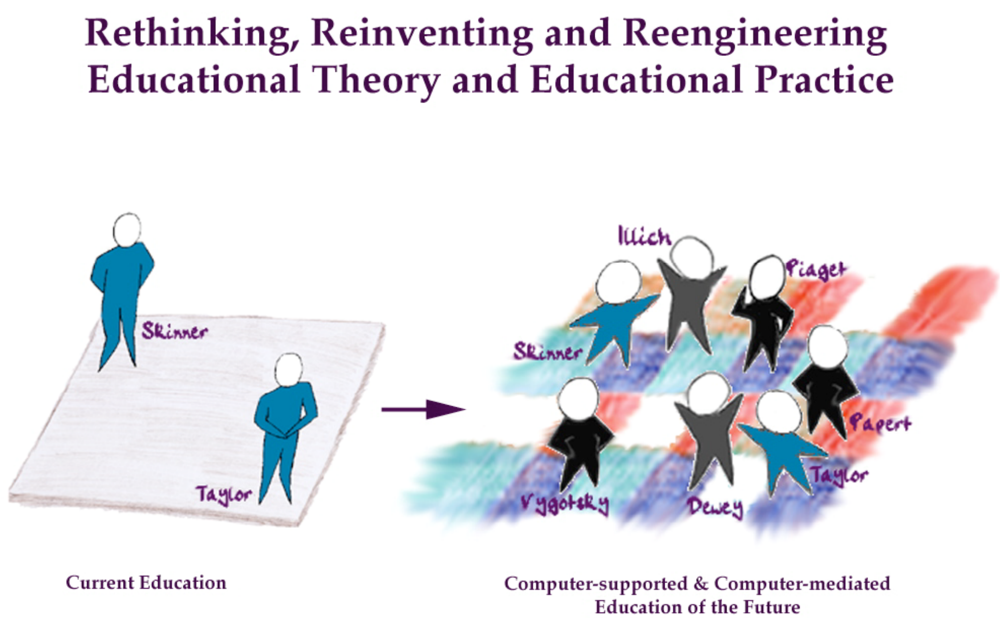


Figure 2: Rethinking and Reinventing Education

We claim that a similar argument can be made for current uses of technology in education: it is used as an add-on to existing practices rather than a catalyst for fundamentally rethinking what education should be about in the next century. For example, the "innovation" of making transparencies available on the World-Wide Web (WWW) rather than distributing copies of them in a class takes advantage of the WWW as an electronic information medium. This may change the economics of teaching and learning, but it contributes little to introducing new epistemologies. "Old" frameworks, such as instructionism, fixed curriculum, memorization, decontextualized learning, etc., are not changed by technology itself. This is true whether we use computer-based training, intelligent tutoring systems, multimedia presentations, or the WWW.

We need computational environments to support "new" frameworks for education such as lifelong learning, integration of working and learning, learning on demand, authentic problems, self-directed learning, information contextualized to the task at hand, (intrinsic) motivation, collaborative learning, and organizational learning. Figure 1 illustrates the "gift-wrapping "approach in which technology is merely wrapped around old frameworks for education. Figure 2 indicates what is needed instead: a richer conceptual framework, leading not just to the addition of technology but to the weaving of technology into learning and working.

Figure 3 tabulates the major changes required. It shows strong similarities between the behaviorist learning theory of B.F. Skinner and the models of industrial work of F.W. Taylor, and contrasts these with the lifelong approach to learning.

Skinner/Taylor		L3D
there is a "scientific," best way to learn and to work (programmed instruction, computer-assisted instruction, production lines, waterfall models)	→	real problems are ill-defined and wicked; design is argumentative, characterized by a symmetry of ignorance among stakeholders
separation of thinking, doing, and learning	→	integration of thinking, doing, and learning
task domains can be completely understood	→	understanding is partial; coverage is impossible
objective ways to decompose problems into standardizable actions	→	subjective, situated personal interests; need for iterative explorations
all relevant knowledge can be explicitly articulated	→	much knowledge is tacit and relies on tacit skills
teacher / manager as oracle	→	teacher / manager as facilitator or coach
operational environment: mass markets, simple products and processes, slow change, certainty	→	customer orientation, complex products and processes, rapid and substantial change, uncertainty and conflicts

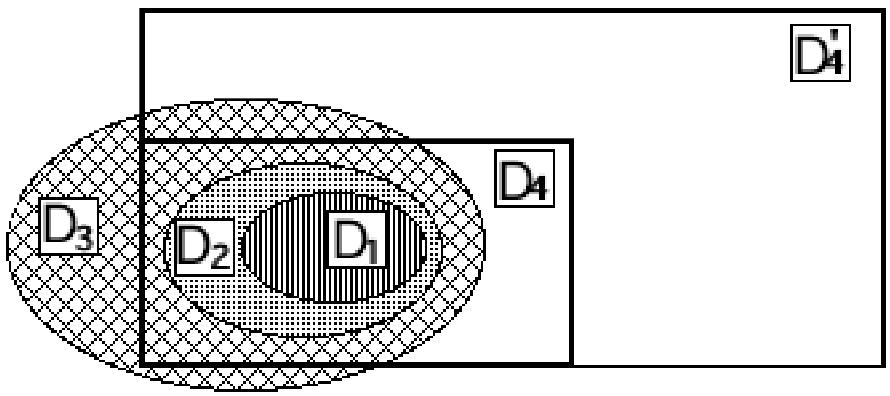
Figure 3: Beyond Skinner and Taylor

6. Myths and Misconceptions

The current debate about the ability of computation and communication to fundamentally change education are (in our opinion) based on a number of fundamental myths and misconceptions. The most prevalent ones are:

- *Computers by themselves will change education*—There is no empirical evidence for this assumption based on the last 30 years of using computers to change education (such as computer-assisted instruction, computer-based training, or intelligent tutoring systems). Technology is no "Deus ex machina" taking care of education. As mentioned before, making slides available over the World-Wide Web rather than giving paper copies to students can be valuable, but will not change education. Instructionist approaches are not changed by the fact that information is disseminated by an intelligent tutoring system.

- *Information is a scarce resource* —"Dumping" even more decontextualized information on people is not a step forward in a world where most of us already suffer from too much information. Instead, technology should provide ways to "say the 'right' thing at the 'right' time in the 'right' way." In our research, we have explored problems associated with high-functionality applications (such as operating systems, word processors, spreadsheets, etc.). Our empirical findings (which are universally true for all systems) are illustrated in Figure 4[Fischer 1993a]. These systems provide challenging problems for a research agenda for "Learning and Intelligent Systems," because if future "progress" is achieved only by extending D_4 to D_4', there will be no benefits for users. Instead of increasing the tool mastery burden of users even more, we need new concepts such as learning-on-demand, information delivery, and task-based unfolding, so users can incrementally explore and master such systems according to their needs.



The rectangle (D_4) represents the actual information space of a system and the ovals represent users' knowledge about the system's information space. D_1 represents concepts well known and easily employed by the users. D_2 contains concepts known vaguely and used only occasionally, often requiring passive help systems. D_3 represents concepts users *believe* to exist in the system, some of which lie outside the actual information space. In the case of increased functionality (as illustrated by D_4'), the area D_4-D_3 (representing the functionality users are not even aware of) increases to D_4'-D_3 , not that of the ovals.

Figure 4: Levels of Users' Knowledge About a System's Information Spaces

- *"Ease of use" is the greatest challenge or 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 people should and will be able to do everything without a substantial learning effort, we should design 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.

- *The content, value, and quality of information and knowledge is improved just because it is offered in multi-media or over the WWW*—Media itself does not turn irrelevant or erroneous information into more relevant information (as indicated by Figure 5). We must create innovative technologies (such as simulations, visualizations, critiquing, etc.) to let people "experience" knowledge in new ways.

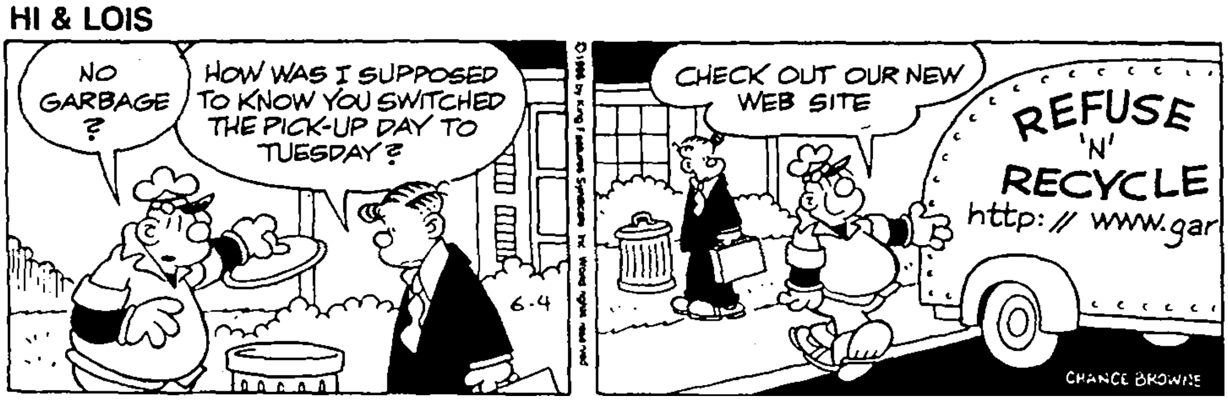


Figure 5: The Existence of Information Alone is Not Good Enough

- *The "Nobel Prize winner" myth: Every school child will have access to a Nobel Prize winner*—This was one of the selling points for the information superhighway. While this argument is true (or will be true soon) at the level of technical connectivity, it is doubtful that Nobel Prize winners will look forward to getting a few thousand e-mail messages a day.

- *The single or most important objective of computational media is 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.

7. Requirements for Systems Supporting Lifelong Learning

To operationalize and instantiate the preceding theoretical framework we have articulated six hypotheses which frame the design and development of the computational artifacts in our proposed research.

• ***Hypothesis 1: User-directed and supportive.*** **In any computational system supporting lifelong learning, the choice of tasks and goals (including the learning opportunities offered) must be under the control of the user/learner and support contextualized to the user's task must be provided.**

Implication for System Building. Creating a system that supports user-directed tasks within a chosen domain implies that such an environment covers an extensive range of potential projects. Such a system needs to provide rich additional structures, i.e., all the components of our domain-oriented design environments (DODEs) [Fischer 1994a]: domain-specific construction tools, catalogs (or on-line libraries) of examples, and so forth.

Potential Challenges or Pitfalls. Any DODE that is rich enough to support realistic projects is likely to present significant complexity to the user. A major challenge in designing such environments is to allow users to encounter the complexity of the system gradually. Mechanisms such as self-disclosure [DiGiano, Eisenberg 1995a], in which a system allows users to perform simple tasks by direct means while simultaneously suggesting other (ultimately more powerful) ways of accomplishing the same tasks, offer promise in meeting this challenge.

• ***Hypothesis 2: Contextualized presentation.*** **A system supporting lifelong learning, when it presents information to the user must do so in a way that is maximally relevant to the user's chosen project or task.**

Implication for System Building. A DODE is not merely a tool for design but is more like a knowledgeable assistant [Collins, Brown, Newman 1989]—sharing, when possible, system knowledge relevant to a particular design task. It should not only provide more information, but say the "right" thing at the "right" time in the "right" way [Nakakoji, Fischer 1995].

Potential Challenges or Pitfalls. The feasibility of a knowledgeable assistant crucially depends on how users can communicate their intentions and task descriptions to the system—and whether they can do so in a way that does not itself require inordinate expertise. Systems that support the articulation of partial task specifications (such as Janus [Fischer, Nakakoji 1991], and ProNet [Sullivan 1994]) suggest means to address this challenge.

• *Hypothesis 3: Breakdowns as opportunities for learning.* A system supporting lifelong learning will be sufficiently open-ended and complex so that users will encounter breakdowns. The system must provide means for allowing users to understand, extricate themselves from, and learn from breakdowns—turning them into opportunities rather than failures.

Implications for System-Building. As any professional designer knows, breakdowns [Dede 1995; Fischer 1994b; Popper 1965]—although at times costly and painful—also offer unique opportunities for reflection and learning [Petroski 1985]. This is also expressed by Norman: "The way we learn is by trying something, doing it and getting stuck. In order to learn, we really have to be stuck, and when we're stuck we are ready for the critical piece of information. The same piece of information that made no impact at a lecture makes a dramatic impact when we're ready for it." [Norman 1993] This insight provided the rationale for exploring learning on demand [Fischer 1991]. Critiquing systems [Fischer et al. 1991] offer advice and information to the user precisely at the problematic moment and by supporting reflection-in-action [Schön 1983], allow users to explore the argumentation and design rationale associated with their actions. Our future design environments will be equipped not only with catalogs of exemplary or illustrative work (as suggested by Hypothesis 2), but also with catalogs of illustrative failures.

Potential Challenges or Pitfalls. In many design domains, the notion of "breakdown" is imbued with so much context and "common sense knowledge" that it precludes easy identification by a computational system. New and creative mechanisms are required to allow the user and system to engage in a form of "dialogue" centering on understanding those breakdowns that neither the user or system is able to identify independently.

• *Hypothesis 4: End-user modification and programmability.* A system supporting lifelong learning must provide means for significant modification, extension, and evolution by users.

Implications for System-Building. Design environments deal with complex and open-ended domains in which long-term users build extensive catalogs of personalized creative work. In contrast, non-programmable systems—systems in which the user is compelled to make choices by selection among fixed sets of alternatives (e.g., via menus or dialog boxes)—are rarely capable of providing users with the means for achieving their work; users' tasks eventually outstrip the capabilities provided by such systems. As a result, DODEs need means by which users can extend the functionality of their applications, building progressively more complex vocabularies and "languages of design." We [Eisenberg, Fischer 1994; Fischer 1993b] have only scratched the surface of what would be possible if end users could freely program their own applications [Nardi 1993]. DODEs will be equipped with an end-user programming language (such as Visual AgenTalk). This, in turn, implies certain desiderata for that language: interactivity, learnability, and expressiveness within the domain of the application.

Potential Challenges or Pitfalls. We are currently exploring several approaches to end-user empowerment including: creating more powerful substrates, enriching existing languages with domain specific elements [Eisenberg 1995], designing new domain specific languages [Repenning, Sumner 1995], and developing self-disclosure mechanisms [DiGiano, Eisenberg 1995b] within

DODEs. Each of these solutions presents its own characteristic advantages and disadvantages as we apply them to end-user modification and programming.

• ***Hypothesis 5: Supporting a range of expertise.*** **Systems supporting lifelong learning will be employed over long periods of time by their users; hence, these systems must be able to accommodate users at progressively different levels of expertise.**

Implications for System-Building. The notion of "expertise" is twofold, implying both expertise in the particular domain and expertise in the use of the system itself. For a DODE to support wide levels of expertise among its users, it must permit beginners to start with a learnable but expandable set of "building blocks" for design [Fischer, Lemke 1988; Soloway, Guzdial, Hay 1994]. To the extent that a design environment can represent to itself the level of the user's expertise, background knowledge and interests, it can tailor interaction and learning material to the appropriate level.

Potential Challenges or Pitfalls. Within design environments, modeling the user's expertise is especially delicate because these domains and the artifacts developed in them are not amenable to simple evaluations. The primary opportunity in developing ideas of making DODEs adaptive and adaptable [Fischer 1993b] and in supporting task and user modeling is to exploit the domain orientation and the integration of the different components of these systems.

• ***Hypothesis 6: Promoting collaboration.*** **Systems supporting lifelong learning must include means for collaboration between users.**

Implications for System-Building. Designers do their work within a "community of practice" [Arias 1995; Brown, Duguid 1991; Lave 1988], in which collaboration may take many forms: large-scale projects may involve close ongoing collaboration among numerous designers, whereas smaller-scale projects may be better viewed as a matter of individual work followed by collective evaluation and critiquing [Rittel 1984]. Design environments must be structured to permit productive and flexible collaboration among users. The World Wide Web offers promising new means for providing such collaboration [Brown et al. 1993; Bruckman, Resnick 1995; Scardamalia, Bereiter 1991] as in our Remote Explorium project [Ambach, Perrone, Repenning 1995].

Potential Challenges or Pitfalls. Problems designing and maintaining collaborative environments include: the difficulty of allowing multiple users to keep track of distinct versions of projects and recording the rationale for the decisions of multiple users. The development of Visual AgenTalk and other Web-based mechanisms within our group for sharing self-contained "pieces" of end-user programs offer new avenues for facilitating group design.

8. Applying our Theory to SimCity

We will illustrate our theoretical framework by applying it to a commercial software package, SimCity 2000, by Maxis, Incorporated. We have selected SimCity because it is one of the outstanding educational games available (as rated by educators [Miranker, Elliott 1995]). It allows players to understand the possibilities and limits of simulation and the concepts of indirect causality by immersing them in a complex construction environment. It is *evocative*—players of the game are immediately engaged to the extent that they soon try to model cities and city planning issues that have direct, personal relevance. Doing this, they quickly run up against the limitations of the game environment. By analyzing SimCity, we wanted to understand how our envisioned environments could support this kind of enjoyable, engaged, self-directed learning experience while, instead of playing a game, users perform real, personally meaningful design tasks.

H1: User-directed and supportive. SimCity allows users to build a city within the framework, object sets, and constraints provided. The construction mechanisms are quite rich and include support mechanisms such as, reactions based on the simulation model, visual, budgetary, and "newspaper" feedback. Despite its features, SimCity fails when applied to "real" city-planning problems (such as the Boulder HOP design, a real problem for the city of Boulder that is explained in our scenario below) because, with the exception of the SimCity Urban Renewal Kit (SCURK)—an add-on module to increase user control—it is a closed system. Players must interact with a fixed set of objects at a particular level of detail that does not necessarily provide the capabilities that allow them to construct models they are truly interested in. The system offers no explanations, and causal relationships among simulation objects are hidden.

H2: Contextualized presentation. In SimCity, the "task at hand" is the construction situation; there is no way for users to specify high-level goals such as limited growth, or a preference for mass transportation. The game includes pre-modeled city scenarios, however, there is no support for task-based indexing to enable users to identify those most relevant to current tasks or interests. For instance, public transportation affects the success or decline of a city in many ways [Dargahi 1991]. This information is hidden from a user who might find it helpful in a planning context.

H3: Breakdowns as opportunities for learning. Breakdowns are likely in SimCity, but the support for reflection is insufficient. Breakdowns are presented to the user in scenario form, as disasters, or simply diminishing population and dwindling city revenues. When something is going wrong, there are no explanations of what simulation mechanisms are causing problems. Possible solutions must be provided and implemented by the user with little support to explore the worth or applicability of each one to a particular situation. Therefore contextualized learning is limited.

H4: End-user modification and programmability. SimCity provides users with a very broad but fixed functionality. A user cannot explicitly examine the system model to see how the developers of SimCity have framed certain fundamental issues nor can they make modifications that extend the functionality of the system. For instance, if the crime rate is too high, we can (with substantial effort) infer which of the many components in the game that affect it, such as zoning, education, ordinances, property values, population density, police stations, and the level of police funding. Users cannot develop and introduce innovative ways to prevent crime, by the addition of social services, for example. SCURK allows existing graphical depictions to be edited and new cities to be constructed outside of the simulation. One can change the look of most objects but not object *behavior*. Therefore, SCURK would not help to model the Boulder HOP. The simulation is a "black box," and users are only permitted to paint the box.

H5: Supporting a range of expertise. Depending on their level of expertise, users can turn disasters off, vary the amount of money they have available at the start, and adjust the speed of the simulation. The explanations given and the tools offered are not adapted to the perspectives, goals, needs, and background knowledge of users with varying degrees of skills within the domain.

H6: Promoting collaboration. There is a multi-user version of the SimCity game that provides similar functionality to the single-user version, except that mayoral decisions can be made by a committee that votes on them. It does not include support for a community of users, including the ability to share reasoning and argumentation or the ability to share simulation components.

The above critique of SimCity illustrates how our theoretical framework can be used to assess computational environments supporting lifelong learning and the integration of working and learning. Because of the weaknesses we have identified in SimCity, it is unlikely to be used to model real problems. We have confirmed this in discussions with members of organizations such as the Boulder City Council, the Transportation Committee, and the Boulder County Healthy Communities Initiative.

Domain-Oriented Design Environments (DODEs). Over the last 8 years, we have created and evolved DODEs [Fischer 1994a] as a new class of computational environments [Winograd 1995] to overcome the limitations and to address the challenges identified by out analysis of SimCity. We have developed process models supporting the creation and evolution of DODEs [Eisenberg, Fischer 1994; Fischer et al. 1994] and a component architecture including construction, specification, and argumentation components, catalogs serving as case-based libraries for the representation of domain knowledge [Willams 1992], and critiquing and simulation components [Fischer et al. 1991] to help users to identify breakdowns [Fischer 1994b] and integrate reflection and action [Norman 1993; Schön 1983].

9. The Seeding, Evolutionary Growth and Reseeding (SER) Model — Information Spaces Developed and Evolved by Distributed Constructionism

Most intelligent systems (including systems in support of learning such as Intelligent Tutoring Systems and Expert Systems) of the past have been developed as “closed” systems. The basic assumption was that during design time, a domain could be modeled completely by bringing domain experts (designers) and environment developers (knowledge engineers) together and the knowledge engineers would acquire the relevant knowledge from the domain experts and encode it into the system. This approach fails for the following reasons: (1) as argued before, much knowledge is tacit and only surfaces in specific problem situations; and (2) the world changes, and intelligent systems modeling this world must change accordingly. In our research, we have developed a process model to address these problems (see Figure 6). It postulates three major phases:

A **seed** will be created through a participatory design process between environment developers and domain designers. It will evolve in response to its use in new design projects because requirements fluctuate, change is ubiquitous, and design knowledge is tacit. Postulating the objective of a seed (rather then a complete domain model or a complete knowledge base) sets this approach apart from other approaches in intelligent systems development and emphasizes evolution as the central design concept.

Evolutionary growth takes place as workers and learners use the seeded environment to undertake specific projects. During these design efforts, new requirements may surface, new components may come into existence, and additional design knowledge not contained in the seed may be articulated. During the evolutionary growth phase, the environment developers are not present, making end-user modification a necessity rather than a luxury. World-wide communities of practice can participate in this process, named distributed constructionism [Resnick 1996] if the WWW becomes an information environment for collaboration and sharing rather than one for information dissemination.

Reseeding, a deliberate effort of revision and coordination of information and functionality, brings the environment developers back to collaborate with domain designers to organize, formalize, and generalize knowledge added during the evolutionary growth phases. Organizational concerns play a crucial role in this phase. For example, decisions have to be made as to which of the extensions created in the context of specific design projects should be incorporated in future versions of the generic design environment. Drastic and large-scale evolutionary changes occur during the reseeding phase.

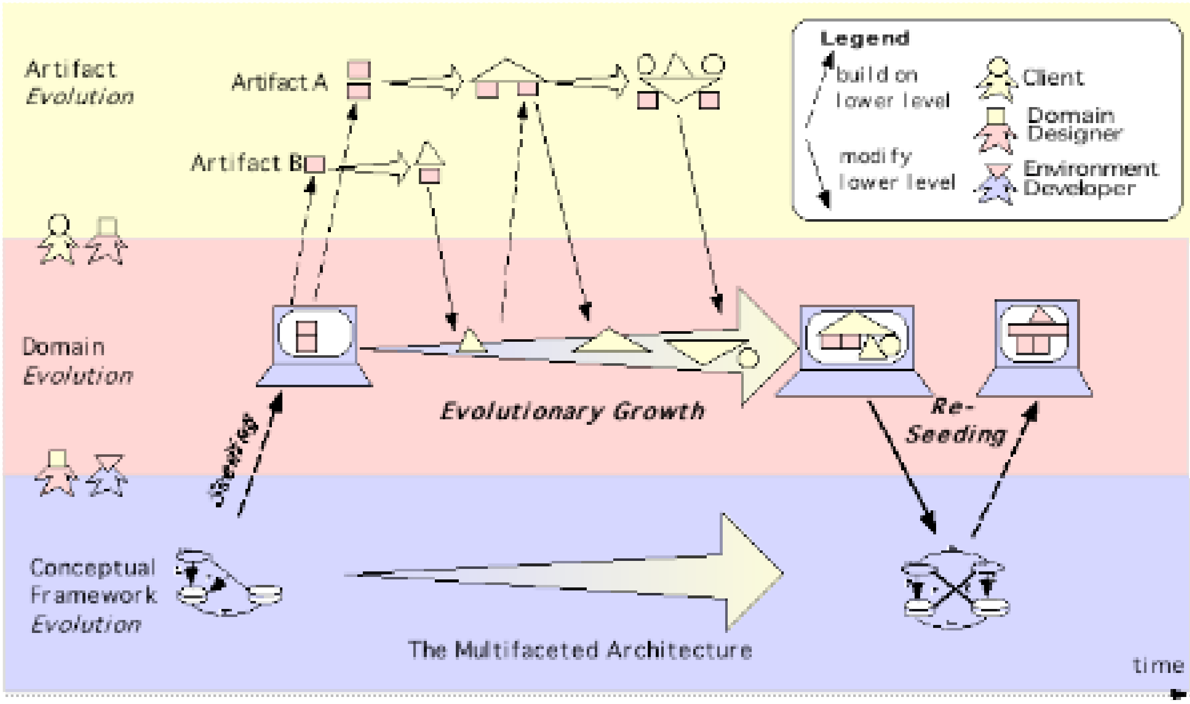


Figure 6: The SER Model: A process model for the development and evolution of domain-oriented intelligent systems

10. Building Interdisciplinary Investigation of Lifelong Learning

Building successful interdisciplinary investigations is not a small task in a world in which specialization necessarily increases and the days of the universally educated "Renaissance Scholars" belong to the past. C.P. Snow, in his famous book "The Two Cultures" [1959], identified the difficulty of "literary intellectuals" and "natural scientists" communicating successfully with each other. He claimed to have found a profound mutual suspicion and incomprehension, which had damaging consequences for the prospects of applying technology to the alleviation of the world's problems. Many more different cultures exist today, e.g., novices versus skilled workers, software developers versus software users, industry people versus academics, and committed technophiles versus determined technophobes.

Experiences. At CU Boulder we have tried for the last ten years to build bridges among different cultures (the most relevant ones will be briefly mentioned):

1. The Institute of Cognitive Science at CU Boulder brings together researchers from the humanities, the social sciences, the natural sciences, and engineering, acknowledging that problems the scientific community needs to address do not always fall neatly into the structures of established departments.

2. In the context of university/industry relationships, we have tried to reinvent the purposes of such collaborations (and have explored research issues in detail in our close collaboration with NYNEX University and NYNEX Science and Technology).

3. By working with the Boulder Valley School District and with several specific schools, we have tried to understand the problems of empowering teachers to become lifelong learners and of introducing and sustaining technology in school settings.

4. Acknowledging that learning is desired and takes place outside formal institutions, we have recently started a collaboration with the Boulder County Healthy Community Initiative, a group of several hundred concerned citizens, which reflects on the future of our county.

5. In our L^{3}D Center we have brought together researchers and students from various parts of the world to understand different perspectives how people think about our world.

Our focus on lifelong learning and design has served as a forcing function to create these interdisciplinary investigations and they in return have been of critical importance to our understanding of the challenges of learning and intelligent systems.

Challenges. The building of successful interdisciplinary investigations faces the following challenges:

1. To regard the existing "symmetry of ignorance" (a concept articulated by [Rittel 1984], who argues that among all the carriers of knowledge for any real problem there is nobody who has a guarantee that her or his knowledge is superior to any other person's knowledge) as an opportunity rather than as a limitation or an undesired obstacle.

2. To overcome the boundaries of creating divisions between basic and applied research by doing basic research on *real* problems.

3. To find ways and to develop means to allow different cultures to talk to each other and to engage them as active participants in inventing the future (e.g., to liberate social scientists from their passive consumer and Cassandra role, and to make technologists aware that technological changes and innovations do not happen in isolation but in existing social networks involving people).

11. A Set of Challenges for Lifelong Learning

"Making Learning a Part of Life" creates many challenges, requiring creative new approaches and collaboration among many different stakeholders. For illustration, just a few of them will be mentioned here.

1. *The educated and informed citizen of the future: 'super-couch potato' consumers or enlightened designers*—The major innovation that many powerful interest groups push for with the information superhighway is to have a future where everyone shows her or his 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," i.e., by creating mindsets and habits that help people become empowered and willing to actively contribute to the design of their lives and communities. This goal creates specific challenges for computational artifacts, such as the support of end-user programming and authoring.

2. *The "basic skills" debate*—If the hypothesis that most job-relevant knowledge must be learned on demand is true, we have to ask ourselves: What is the role of "basic skills"? If, for example, the use of software packages dominates the use of mathematics in the workplace, shouldn't a new function of mathematics education be teaching students to use these mathematical artifacts intelligently? Another important challenge is that the "old basic skills" such as reading, writing, and arithmetic, once acquired, were relevant for the duration of a human life; modern "basic skills" (tied to rapidly changing technologies) will change over time.

3. *Can we change motivation?*—As mentioned, there is substantial empirical evidence that the chief impediments to learning are not cognitive but motivational[Csikszentmihalyi 1990b]. This raises the challenge of whether we can create learning environments in which learners work hard, not because they *have* to, but because they *want* to. We need to alter the perception that serious learning has to be unpleasant rather than personally meaningful, empowering, engaging, and even fun. In our research efforts we have developed computational environments to address these motivational issues; for example, our systems have explored making information relevant to the task at hand, providing challenges matched to current skills, creating communities (among peers, over the net), and providing access to real practitioners and experts.

4. *School-to-work transition*—If the world of working and living (a) relies on collaboration, creativity, definition, and framing of problems; (b) deals with uncertainty, change, and distributed cognition; (c) copes with symmetry of ignorance; and (d) augments and empowers humans with powerful technological tools, then the world of schools and universities needs to prepare students to function in this world. Industrial-age models of education and work (based on Skinner and Taylor, as illustrated above) are inadequate to prepare students to compete in the knowledge-based workplace. A major objective of our lifelong learning approach is to reduce the gap between school and workplace learning. Our research addresses some of the major "school-to-work" transition problems and develops answers to the following questions:

   - How can schools prepare learners and workers for a world that relies on interdependent, distributed, non-hierarchical information flow and rapidly shifting authority based on complementary knowledge?
   - What "basic skills" are required in a world in which occupational knowledge and skills become obsolete in years rather than decades?
   - How can schools (which currently rely on closed-book exams, the solving of given problems, and so forth) be changed so that learners are prepared to function in environments requiring collaboration, creativity, problem framing, and distributed cognition?
   - To what extent will lifelong learning and new approaches to learning and teaching—such as learning on demand, learning while working, relations, and the involvement of professionals in schools—prepare learners for work?

12. What's Wrong With Current Universities

We consider the self-application of our theories a critical element (and a unique opportunity) in the assessment of our research efforts. Universities as institutions need to be in the middle of rethinking the future of working and learning—applying their findings not only to other institutions, but to themselves. Using the previously developed framework causes us to critically examine our own work as university faculty members in the following ways:

- Understanding learning as active knowledge construction rather than passive knowledge absorption questions the dominance of lectures.
- Allowing learners to engage in authentic, self-directed learning activities is at odds with micro-managed curricula.
- Acknowledging that problem solving in the real world includes problem framing calls into question the practice of asking students to solve mostly given problems.

- Recognizing that most interesting problems in the real world do not have right or wrong answers, but instead must be solved by satisfying objectives that are most important for that situation.
- Acknowledging that the individual human mind is limited and that outside of schools people rely heavily on information and knowledge distributed among groups of people and various artifacts (distributed cognition) questions the value of closed-book exams, and requires a much greater emphasis on collaborative learning and communication skills.

13. Conclusions

Research in lifelong learning, especially if we want to move beyond the "gift wrapping" approach of technology, will have fundamental long-term societal impacts. It will force us to reinvent how we think, work, learn, create, and collaborate. It will change

1. institutions, e.g.,
   - 1.1. universities (as argued above) [Noam 1995]
   - 1.2. companies will have to become learning organizations [Senge 1990]
2. individuals, e.g.,
   - 2.1. who will have a desire to become independent of high-tech scribes in personally meaningful and important activities
   - 2.2. who would like to contribute to their (computer-enriched) reality rather than merely interacting with it
3. mindsets, e.g.
   - 3.1. teachers should see themselves not as truth-tellers and oracles, but as coaches, facilitators, learners, and mentors engaging with learners
   - 3.2. breakdowns [Fischer 1994b] and symmetry of ignorance [Rittel 1984] need to be understood as opportunities
4. connections and collaborations, e.g.,
   - 4.1. connecting in new ways (e.g., distributed communities of practice and interest) will go along with disconnecting in old ways (being physically together, increased specialization)
   - 4.2. organizational learning supported by organizational memories will complement individual learning [Fischer et al. 1996].

This research will provide us with opportunities to explore fundamentally new possibilities and limitations of computational media as they complement existing media. It will force us to think about new concepts such as sustainable communities of practice. It will pose the question of how large complex information spaces can be evolved over long periods of time, not by their professional designers but by their affected users. It will enrich the notion of distributed cognition, allowing us to draw different lines between what humans should do and what machines should do.

One may argue that our current thinking does not address the potential magnitude of the change. Have we arrived at a point where the change is of a similar magnitude to the time when our society moved from an oral to a literary society (and Socrates and Plato were arguing about the trade-offs associated with this change) or when Gutenberg's printing press eliminated the scribes and gave everyone the opportunity to become literate? The fact that societies have often overestimated change in the short run and underestimated it in the long run suggests that we should make every effort to understand the long-term societal impacts of learning and intelligent systems.

As argued at the beginning, the future of how we live, think, create, work, learn, and collaborate is not out there to be *"discovered"*— it has to be *invented and designed*. Computational and communication media (firmly grounded in a deep understanding of theories and prescriptive goals) will be a critical force in shaping this future.

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