# EVOLUTION OF COMPLEX SYSTEMS BY SUPPORTING COLLABORATING COMMUNITIES OF PRACTICE

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**Abstract**. There is empirical evidence from almost all disciplines that complex systems need to evolve. The driving forces behind their evolution is their use by communities of practice in real-world problem solving as well as a changing world, specifically changes in technologies. The seeding, evolutionary growth, and reseeding model is a process description of how this happens. By integrating working and learning in communities of practice, we have created organizational memories that include mechanisms to capture and represent task specifications, work artifacts, and group communications. These memories facilitate organizational learning by supporting the evolution, reorganization, and sustainability of information repositories by providing mechanisms for access and delivery of knowledge relevant to current tasks. To support this approach with World Wide Web technology, the Web has to be more than a broadcast medium; it has to support collaborative design. Examples, such as domain-oriented design environments, distributed economy of educational objects, and courses offered in (distant) learning situations are used to illustrate the approach.

## 1. Introduction

Learning is a new form of labor [Zuboff, 1988], and working is often (and needs to be) a collaborative effort among colleagues and peers. In the emerging knowledge society [Drucker, 1994], an educated person will be someone who is willing to consider learning as a lifelong process. More and more knowledge, especially advanced knowledge, is acquired well past the age of formal schooling, and in many situations through educational processes that do not center on the traditional school [Gardner, 1993; Illich, 1971]. Seen in this context, working, learning, and collaboration become intimately intertwined rather than being three different and distinct activities.

Powerful and flexible computer technology can help provide individuals, groups, and organizations with the tools they need to support their self-directed learning and evolve their information repositories. Advances in networking create opportunities for communication among members of widely distributed communities. However, it is incorrect to assume that technological advances will, by virtue of their very existence, improve the quality of learning. New technologies and media must be more than add-ons to existing practices. Technology alone does not provide insight into the needs of learners working on real-world problems. Instead, new directions must be grounded in theories of learning and design. New learning theories and technologies must together serve as catalysts for fundamentally rethinking what learning, working, and collaborating can and should be in the next century (for a more in-depth analysis of this argumentation see: http://www.cs.colorado.edu/ ~l3d/ presentations/gf-wlf/).

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 [Fischer, 1994; Fischer et al., 1996], a model of work that is open-ended and long-term in nature, and incorporates personalized and collaborative aspects. 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 [Bruner, 1996]. It is impossible for design processes to account for every aspect that might affect the designed artifact. Design must therefore be treated as an evolutionary process in which designers reflect on previous designs and continue to learn new things as the process unfolds [Schön, 1983].

## 2. A Process Model Supporting the Evolution of Complex Systems

Most intelligent systems (including systems in support of learning such as Intelligent Tutoring Systems, Expert Systems, and simulation environments such as Simcity) have been developed as *closed* systems in the past. The basic assumption was that during design time, a domain could be modeled completely by bringing *domain experts* (teacher, content experts, designers) and *environment developers* (instructional designers, multimedia designers, and knowledge engineers) together into a setting where the environment developers would acquire the relevant knowledge from the domain experts and encode it into the system. This approach fails for the following reasons: (1) much knowledge is tacit and only surfaces in specific problem situations; and (2) the world changes, and any system modeling this world must change accordingly. In our research, we have developed a process model to address these problems [Fischer et al., 1994]. It postulates three major phases.

First, a **seed** will be created through a participatory design process between environment developers and domain experts. It will evolve in response to its use in new activities (e.g., design projects, information repositories, courses; see section 5) because requirements fluctuate, change is ubiquitous, and design knowledge is tacit. Therefore, mechanisms for evolution must be built into these initial conceptualizations. Postulating the objective of a seed (rather then a complete artifact) sets our approach apart from other approaches and emphasizes evolution [Basalla, 1988] as the central design concept.

Second, **evolutionary growth** takes place as 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 (i.e., supporting active, articulate learners to express themselves in the media) a necessity rather than a luxury. If seeds make evolution difficult, individuals will be seriously constrained when changes become necessary. For example, world-wide communities that use with the WWW as a collaborative tool can participate in an evolutionary process only if the Web becomes an information environment for collaboration and sharing rather than one for information dissemination (see Figure 1 in section 5).

Third, **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.

## 3. Communities of Practice

A *community of practice* is a group of people who share a set of activities and who interact to achieve shared objectives and to maintain their community [Lave & Wenger, 1991]. Unlike an organization, which has well-defined bureaucratic structures, a community of practice is often an informal network of people who share expertise and practical advice. We have worked with a wide variety of communities of practice, such as multimedia designers, kitchen designers, and teachers as lifelong learners (for details visit the website of our center at: http://www.cs.colorado.edu/~l3d/).

The daily practice of a community not only produces the community's work products, it also reproduces the preconditions for the future of the community. New members learn community practices as they engage in them actively, not necessarily through didactic instruction [Schön, 1983]. As the community of practice produces learning, it reproduces its own future. Because much of what needs to be passed on is never articulated explicitly, education takes place through apprenticeship relationships and training of reflective practitioners [Brown & Duguid, 1992]. This learning can be facilitated by a group memory that includes evolving artifacts of communal practice [Fischer et al., 1996].

The social context of a community of practice provides motivation to pass knowledge from old-timers to newcomers as everyone tries to increase their participation. It ties working and learning together into a single framework [Fischer, 1995]. Computational environments for communities of practice must support sustainability by allowing members to extend, update, and restructure organizational memories continuously. Sustainability of organizational memory means keeping it tuned to the changing needs of individuals because organizational learning takes place in parallel with the lifelong learning of community members.

## 4. Organizational Memories and Organizational Learning

*Organizational memories* are information systems that are used to record knowledge for the purpose of making this knowledge useful to individuals and projects throughout the community of practice and into the future [Ackerman, 1994] (for documentation of a symposium about organizational memories entitled "Computational Support for Continually Evolving Organizational Knowledge Bases" see: http://www.cs.colorado.edu /~ostwald /symposium/). Ideally, an organizational memory allows individuals within the community to benefit from the experiences and insights of others, by *actively* informing work practices at the point when the information is actually needed. That is, an organizational memory should be not simply a passive repository of information, but an interactive medium within which collaborative work can actually be conducted and through which communication about the work can take place and be situated (for prototypes of organizational memories constructed in our research center—e.g., GIMME, a group memory system and Dynasite, supporting the collaborative creation and evolution of artifacts—see http://www.cs.colorado.edu /~l3d/).

*Organizational learning* focuses on recording knowledge gained through experience (in the short term), and actively making that knowledge available to others when it is relevant to their particular tasks (in the long term) [Fischer et al., 1996]. A central component of organizational learning is an organizational memory. However, the mere presence of an organizational memory system does not ensure that an organization will learn. In today's world, information is not a scarce commodity [Drucker, 1994]; the problem is not just to accumulate information, but to deliver the *"right"* knowledge at the *"right"* time to the *"right"* person in the "*right*" way [Fischer et al., 1993].

For sustained organizational learning, three seemingly disparate goals must be served simultaneously. An organizational memory must (1) be extended and updated as it is used to support work practices; (2) be continually reorganized to integrate new information and new concerns; and (3) serve work by making stored information relevant to the new task at hand. Organizational learning is a continuous cycle in which organizational memory plays a pivotal role: individual projects serve organizational memory by adding new forms of knowledge that are produced in the course of doing work, such as artifacts, practices, rationale, and communication.

Through everyday work, a community of practice generates knowledge that may be critical in its future. The community's practices are generally tacit, not written down or expressed in words [Polanyi, 1966]. Often, the only time that the knowledge exists in explicit form is when it is being actively reflected upon and used to do work. By capturing this knowledge as it arises and storing it in repositories of organizational memory, a community can preserve information that is otherwise lost. Organizational memories must be "living" information repositories [Terveen et al., 1995] that are sustained and managed by the people who use them in their work. A principal challenge for organizational learning is to capture a *significant portion* of the knowledge generated by work done within a community. Experience with organizational memories and collaborative work has exposed two barriers to capturing information: (1) individuals must perceive a large enough direct benefit in contributing to organizational memory to outweigh the effort [Grudin, 1994] and (2) the effort required to contribute to organizational memory must be minimal so it will not interfere with getting the real work done.

## 5. Examples of Evolvable Systems

**Domain-oriented design environments** [Fischer, 1994; Fischer, 1995] 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, telephone voice messaging systems, local area network design, lunar habitat design, and interactive simulation games using the World-Wide Web as a research medium (these efforts are documented in: http://www.cs.colorado.edu/~l3d/Research/).

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 described in section 2) to support users in a specific domain. They provide specific functionality for manipulating, exploring, and communicating about domain entities, and they include the following components: (1) a specification component allowing the specification of design constraints and goals; (2) critiquing mechanisms capturing the accumulated "wisdom" of a design community; (3) organizational and artifact memories containing design rationale and argumentation; (4) domain-specific components allowing designers to create artifacts; (5) case libraries allowing the incremental accumulation and reuse of artifacts; and (6) simulations mechanisms supporting users in their understanding of the behavior of a component or a complete artifact. All of these components are not static entities in domain-oriented design environments. As users interact with the environment, they create and compose new artifacts that themselves become part of the system.

**Educational Economy of Objects.** More than 25 years ago, Illich [Illich, 1971] introduced the concept of *learning webs*. Illich envisioned a world in which the mass distribution capabilities of the now available technology could be used to facilitate new access to information and new ways for people to work, learn, and collaborate. Envisioning all people as capable of being both teachers and learners, depending on the circumstances, Illich envisioned an economy that encouraged people to become active teachers and producers of educational knowledge.

Examples supporting economies of knowledge for specific communities of practice based on community participation are now forming in the software design community. Due to the contributions of developers around the world, the Java programming community has used community repositories of knowledge to produce technical advances in an extremely short period of time. *Gamelan* (http://www.gamelan.com) is one of the first and largest of the community repositories of knowledge. The primary users of Gamelan are Java developers looking for information about what other people are doing with Java.

The *Educational Object Economy* (http://trp.research.apple.com/EdEconomy) provides some of the educational support that is lacking in more global systems such as Gamelan. The Object Economy is currently realized as a collection of Java objects (mostly completed applets) designed specifically for education. The target users of the economy are teachers wishing to use new interactive technology and developers interested in producing educational software. However, repositories of code resources are only part of the support that educators need for producing learning environments. The goal of this ongoing research effort is to allow designers and creators of educational resources to benefit from support for self-directed learning as much as the end-users of educational knowledge do.

**Courses as Seeds.** The courses-as-seeds idea provides a direction for exploration in many areas of lifelong learning in which communities of practice engage collaboratively in the incremental construction of knowledge [Scardamalia & Bereiter, 1994] in the context of a course. It provides a model for learning in a knowledge society that is built upon distributed cognition, articulate learners, peer-to-peer learning, and incremental enhancement of information spaces by a community of practice.

"Courses as seeds" can be contrasted against *"courses as finished products"* (the model currently practiced by most institutions), which exhibits the following characteristics:

- a course is offered in a (distance) learning environment and learners answer problems given to them in the course by the instructor;
- the course is given over a period of years, more or less in the same form;
- the learners are recipients of knowledge (the assumption is that the teacher/instructional designer has all the relevant knowledge);
- from time to time the teacher/instructional designer will incorporate new ideas into the course so the course doesn't become outdated; and
- this model is adequate for courses in which the learners are getting into a new field and therefore might have little to contribute.

In contrast, the *"courses as seeds"* model is built upon the following characteristics:

- a course is considered as a seed, and it is offered to a community of practice that is interested in learning new material; many of the course participants are knowledgeable people in their own working environments;
- the learners are not just passive recipients of knowledge, but active contributors; and
- at the end of the course, the content of the course will be greatly enriched through a semester or year-long interaction of knowledgeable people, and important and relevant addition will be incorporated into the course before it is taught the next time.

The *values added* by the "courses as seeds" approach include:

- it is a model for learning in a knowledge society that is built upon articulated learners forming and engaging in a community of practice;
- it is important for students to gain experience in such processes;
- such an approach is a necessity for many domains and aspects of lifelong learning where communities of practice engage in the incremental construction of knowledge facilitated by a teacher; and
- it exploits unique aspects of computational and communication media.

Although our approach shares objectives with other approaches such as CSILE [Scardamalia & Bereiter, 1994] by "reframing class discourse to support knowledge building in ways extensible to out-of-school knowledge advancing enterprises," it transcends CSILE in several ways: (1) new knowledge includes a greater variety of conceptual structures (e.g., simulations, critiquing rules, partial designs); (2) retrieval is more broadly supported (e.g., using artifacts as queries [Fischer et al., 1993]); and (3) learners deepen their knowledge in a field of working expertise rather than focusing primarily on academic contents.

## 6. Requirements for Making This Approach Work

Numerous theoretical, conceptual, and social challenges, as well as innovative system-building efforts are required to make the "evolution of complex systems by supporting collaborating communities of practice" a reality. Two of them are mentioned briefly here.

**New Conceptualization of the World Wide Web.** The Web provides a good example of how technology alone does not provide support that guarantees an effective learning tool.

Without a fundamental reconceptualization, the Web simply provides a convenient mechanism for delivering content. Figure 1 presents three models that illustrates different types of Web usage.

Traditional Web-based use ( including instructional uses) engages the Web as a Broadcast Medium (Figure 1, Model $M_1$). In this model, instructional content is predetermined and placed on static Web pages. Most popular general-purpose Web tools provide support for the easy generation of this static content. In $M_1$, the Web serves as a distribution channel and provides few opportunities for learners to interact with the information because the content was not originally designed to be interactive. Responding to the need for feedback from consumers, many Web sites are evolving into forms that augment content with some communication channels. This mechanism of *broadcast with feedback* ($M_2$) expands the original model by providing some link from consumer to producer such as allowing learners to provide feedback and ask questions by filling out forms. Although learners can react to information provided by the author, this presentation model provides little connection between the students' reactions and a change in content.

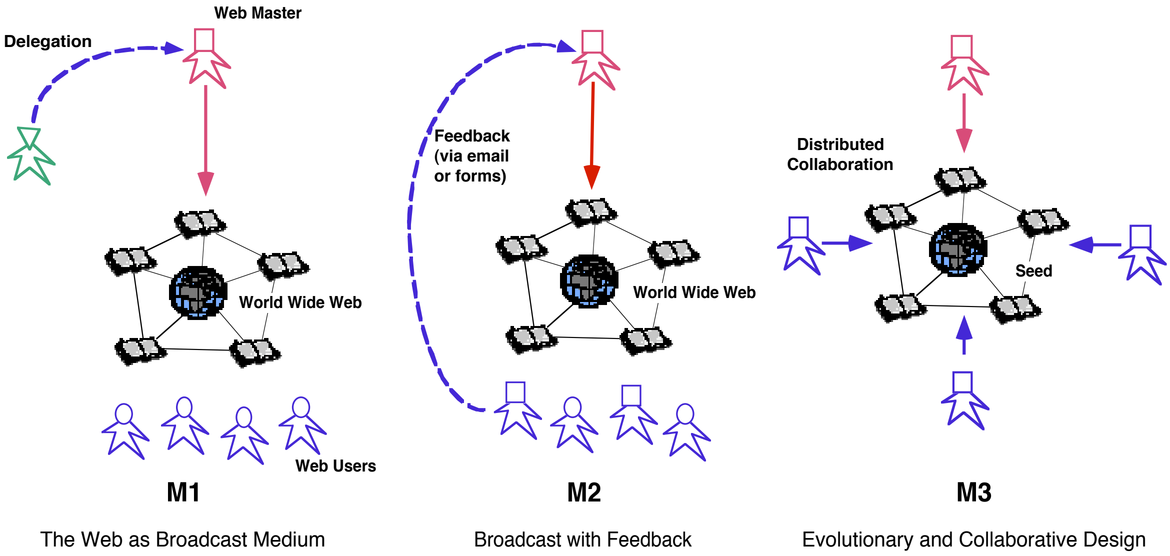


*Figure 1: Making the World Wide Web a Medium for Collaborative, Evolutionary Design*

An essential requirement for collaboration and evolution is demonstrated by the $M_3$ model for the Web. In $M_3$, users can use the Web to collaborate on projects by *actively* contributing and by learning from all contributors. The evolution of content and ideas is now the responsibility of the participating community of practice, focusing on the distributed generation of content and the reflection upon it. An $M_3$-type model is needed to support the seeding, evolutionary growth, reseeding model described in section 2. When a wide variety of individuals collaborate in a cooperative forum, the unique skills of the members all become valuable resources in making the Web resources useful in the current context. The $M_3$ model poses a number of technical challenges, including the ability (1) to add to an information space without going through an intermediary, (2) to modify the structure of the information space, and (3) to modify at least some of the existing information.

**Teachers as Lifelong Learners and Students as Teachers.** Most of current classroom and distance teaching and learning is based on a model of teaching in which an all-knowing teacher explicitly tells or shows unknowing learners something they know nothing about and in which some curriculum dictates that the learners should know this material. A focus on lifelong learning where self-directed learning plays a critical role and the learning of new material is often driven by the work to be accomplished, the problems and the questions do not originate only with the teacher but also with the learner. In today's world, where renaissance scholars no longer exist, all of us (including teachers) need to be learners in most situations. In learning communities of the past, the role distinction between teachers and learners was tied to *persons*, in today's world it has become an attribute of a *context*.

Based on mutual competency and limitations of one's own knowledge, teachers should not think of themselves as truth tellers and oracles, but as error detectors, coaches, and facilitators who (1) extend the intelligence of the students by helping them reduce the mistakes in their knowledge and skills, and (2) feel comfortable in front of students to "be caught" not knowing something. What could be one of the most important learning experiences of a student—to see the teacher struggling with understanding something—is too often avoided, because teachers do not feel comfortable in the roles of learners.

Grounded in the belief and reality that "learning is more than being taught," education is not the same thing as schooling, and there are numerous arguments that a substantial fraction of our learning and our education takes place outside of schools and universities [Bruner, 1996; Gardner, 1991; Illich, 1971]. Human beings learn a great deal from being in the world, from books, from their peers, and from learning communities (whether physically and temporally present or virtual). And real learners are not just passive consumers—they are active contributors—thereby making the evolution of complex information spaces a necessity rather than a luxury.

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