Shared Understanding, Informed Participation, and Social Creativity
—
Objectives for the Next Generation of Collaborative Systems

Gerhard Fischer
Center for LifeLong Learning & Design (L^3D)
Department of Computer Science and Institute of Cognitive Science
CB 430
University of Colorado
Boulder, CO, 80309

Abstract. Complex design problems require more knowledge than any single person possesses because 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 these stakeholders can lead to new insights, new ideas, and new artifacts. New media that allow owners of problems to contribute to framing and resolving complex design problems can extend the power of the individual human mind.

Our research is grounded in the basic belief that new media should not merely deliver predigested information to individuals, but rather provide the opportunity and resources for social debate and discussion. Based on our past work, I will identify objectives for the next generation of collaborative systems. I will illustrate them with examples of systems that shift attention away from the computer as the focal point, towards improving our understanding of the human, social, and cultural system that creates the context for use.

1. Introduction

The Limitation of the Unaided, Individual Human Mind. The power of the unaided, individual mind is highly overrated—without external aids, memory, thought, and reasoning are all limited [28]. As illustrated in Figure 1, the basic capabilities of the unaided, individual human mind have changed little over time. For the design of cognitive artifacts, it is important to know these basic capabilities; some of them, such as memories (working memory, long-term memory) and processors (perceptual processors, cognitive processor, and motor processor) and their basic characteristics are described in [10].

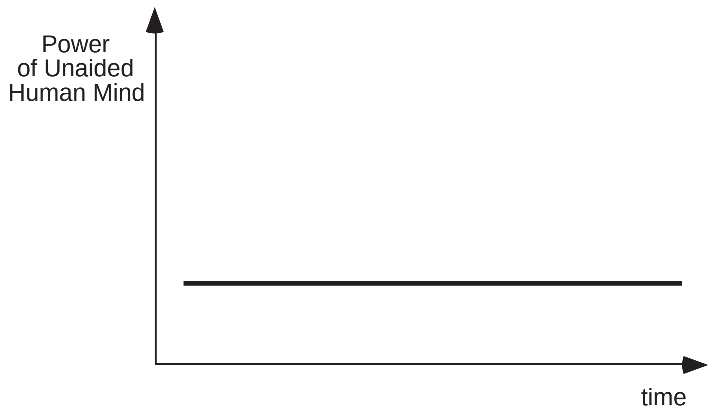

Figure 1: The power of the unaided individual human

The Tension between Human and Computational Power. In sharp contrast to the negligible change of the basic capabilities of the unaided, individual human mind, computational and communication technologies have changed dramatically. *Moore's law* (illustrated qualitatively in Figure 2) is the principle that computer capacity doubles every eighteen months. The principle, operative since the dawn of the computer age, shows no sign of abating and its implications have provided unique possibilities to create new cognitive artifacts. *Metcalfe's law* is the observation that networks (whether of people or computers and other communication technologies) dramatically increase in value with each additional user or node (both laws and their implications are further discussed in [12]). While software technologies clearly did not see the same rapid development as hardware, at least basic software components (such as compilers, networking protocols) have greatly improved the power of computational environments. One of the basic misunderstandings has been that while these technologies are necessary, they are not sufficient to allow humans to think previously unthinkable thoughts, to let them work more creatively and efficiently, to learn and understand more, and to collaborate more [23].

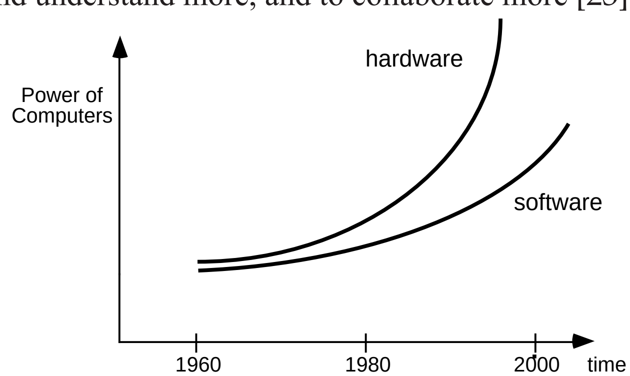

Figure 2: Computing power increases at an exponential rate

2. The Next Generation of Collaborative Systems

The Collective Human Mind. The basic foundation for social interaction is that people think, work, and learn in conjunction or partnership with others and with the help of culturally-provided tools and artifacts. For a conceptual framework (or theory) of social interaction to be interesting, to inspire, to guide, and to inform the development of new media supporting social interaction, it should contain some specifications how social interaction can be improved or altered in some significant way. A focus on social interaction has shifted our *internalist* view (seeing the mind as information processor by assuming that the mind's operations are describable independent of their relationship to the external world) to a *distributed cognition* view [22].

Exploiting Social Interaction. Talented people require approximately a decade to reach top professional proficiency [37]. Much of our intelligence and creativity results from the collective memory of *communities of practice* [24] and of the artifacts and technology surrounding them. Though creative individuals are often thought of working in isolation, the role of interaction and collaboration with other individuals is critical. Creative activity grows out of the relationship between an individual and the world of his or her work, and out of the ties between an individual and other human beings. The basic cognitive capacities (see Figure 1) are then differentially organized and elaborated into complex systems of higher psychological functions, depending on the actual activities in which people engage, and on the historical and cultural circumstances in which people live [34].

Figure 3 illustrates the major fundamental human inventions and creations that have increased the power of the unaided, individual human mind. The big questions to be asked today are: (1) will computational and communication media have an equally important impact on humans as reading and writing and the printing press had in the past; and (2) will we be able to achieve another qualitative increase (indicated by the dashed line in Figure 3) by the development of new media and new technologies that exploit the possibilities of the *collective* human mind through social interaction?

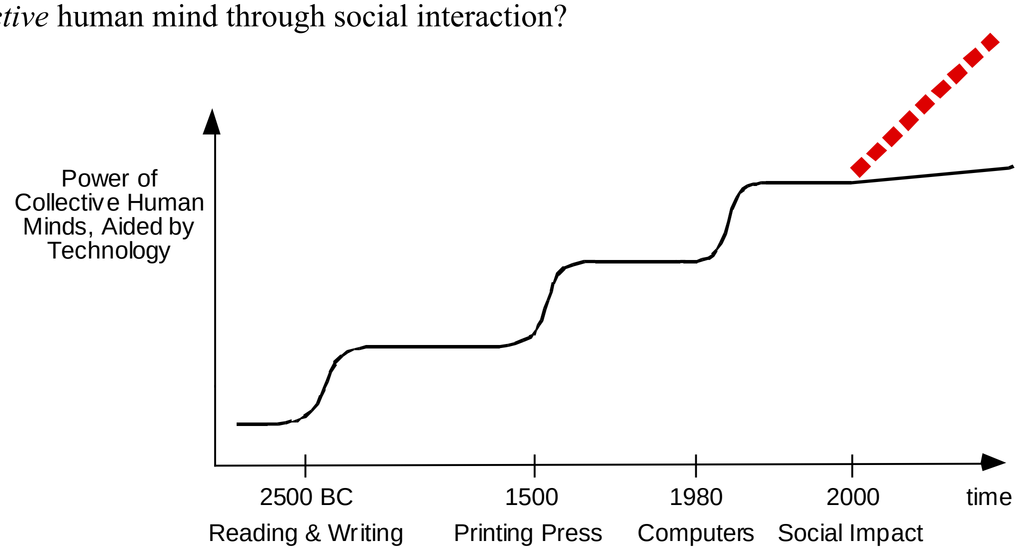

Figure 3: The Power of the Collective, Aided Human Mind

Shared Understanding. Distributed cognition [28] emphasizes that the heart of intelligent human performance is not the individual human mind but groups of minds in interaction with each other and minds in interactions with tools and artifacts. It is important to understand the fundamental difference between distributed cognition as it operates for the aided individual human mind and as it operates for groups of minds. Distributed cognition between the individual human mind and artifacts (such as memory systems) often functions well, because the required knowledge that an individual needs is distributed between her/his head and the world (for example: an address book, a folder system of e-mail messages, a file system). But in the case of interaction among a group of minds the problem arises that a "group has no head" [4]—therefore externalizations [8] are critically more important for social interaction. Externalizations (1) create a record of our mental efforts, one that is "outside us" rather than vaguely in memory, and (2) they represent situations which can talk back to us, be critiqued, and be negotiated.

Informed Participation. One of the major roles of new media is not to deliver predigested information to individuals, but to provide the opportunity and resources for social debate and discussion. For most design problems the knowledge to understand, frame, and solve these problems does not exist, but is constructed and evolved during the process of solving them. From this perspective, access to existing information and knowledge (often seen as the major advance of new media) is a very limiting concept. Many social and technological innovations are limited to provide primarily better access, rather than supporting *informed participation* [1,7] by allowing learners to incrementally acquire ownership in problems and contribute actively to their solution.

Design problems [37], being ill-defined and unique, require informed participation by all stakeholders. Openness and complexity in design arises from the need to synthesize different perspectives of a problem, the management of large amounts of information relevant to a design task, and understanding the design decisions that have determined the long-term evolution of a designed artifact. The social interaction among stakeholders in design can be characterized by a *"symmetry of ignorance"* [35] or an *"asymmetry of knowledge"* [26]. In designing artifacts, designers rely on the expertise of others [19] by referring to textbooks, standards, legal constraints, and previous design efforts. Project complexity forces large and heterogeneous groups to work together on projects over long periods of time. Designers generally have a limited awareness and understanding of how the work of other designers within the project—or in similar projects—is relevant to their own part of the design task [6]. The large and growing discrepancy between the amount of relevant knowledge and the amount any one designer can possibly remember imposes a limit on progress in design. Overcoming this limit is a central challenge for developers of systems that support collaborative design.

One such challenge is to integrate the various perspectives emerging from the symmetry of ignorance among articulate stakeholders. By supporting the process of reflection within a shared context defined by the task at hand, opportunities can emerge from enhancing the creation of shared understanding. This process melds the information that is collaboratively constructed into the problem-solving context, informing the process as well as the stakeholders and allowing them to participate from a more enriched and meaningful perspective [7].

Informed participation is impossible in communities in which most of their members regard themselves as consumers. Consumers must be allowed to evolve into power-users, co-developers, and designers who use artifacts and at the same time modify and extend them. A strict separation between these two groups is undesirable and unproductive.

Individuals acting as designers must acquire a *new mindset*—they are no longer passive receivers of knowledge, but instead are active researchers, constructors, and communicators of knowledge. Knowledge is no longer handed down from above, but instead is constructed collaboratively in the contexts of work. Empowering individuals with convivial tools is grounded in the fundamental belief that humans (albeit not all of them, not at all times, not in all contexts) want to be and act as designers [15].

Social Creativity. As argued before, the power of the unaided, individual mind is highly overrated—"the Renaissance scholar does not exist anymore." Much of our intelligence and creativity results from exploiting the symmetry of ignorance as a source of power. Although creative individuals are often thought of as working in isolation, the role of interaction and collaboration with other individuals is critical [14]. Creative activity grows out of the relationship between an individual and the world of his or her work, and out of the ties between an individual and other human beings.

To make social creativity a reality, we need new forms of knowledge creation, integration, and dissemination. The first step toward social creativity is the externalization of individual's knowledge. Externalization, the creation of external representations [8], plays the following essential roles in social creativity:

- it causes us to move from vague mental conceptualizations of an idea to a more concrete representation of it. Externalization requires the expression of ideas in an explicit form, and in this process, as well as the end result, may reveal ideas and assumptions that beforehand were only tacit [31];
- it provides a means for stakeholders to interact with, react to, negotiate around, and build upon ideas. Such a "conversation with the materials" of the design problem [36] is a crucial mode of design that can inspire new and creative ideas;
- it can focus discussions upon relevant aspects of the framing and understanding of the problem being studied, providing a concrete grounding upon which to create a common language of understanding that allows stakeholders to communicate and synthesize creative ideas.

A principal challenge for social creativity is to capture a significant portion of the knowledge generated by work done within a community. Experiences with organizational memories and collaborative work have exposed two barriers to capturing information: (1) individuals must perceive a direct benefit in contributing to organizational memory that is large enough to outweigh the effort [21]; and (2) the effort required to contribute to organizational memory must be minimal so it will not interfere with getting the real work done [11].

Social creativity is supported by *human-computer and human-human collaboration* which have been central goals for many disciplines including HCI, CSCW, and CSCL. Collaboration in this context is defined as "a process in which two or more agents work together to achieve shared goals" [39]. Some fundamental issues (such as shared goals, shared context, control, (co)-adaptation, (co)-evolution, and learning) can be derived from this definition. Human-computer collaboration can be approached from two different perspectives: an emulation approach and a complementing approach. The *emulation approach* is based on the metaphor that to improve human-computer collaboration is to endow computers with "human-like abilities." The *complementing approach* is based on the fact that computers are not human and that human-centered design should exploit the asymmetry of human and computer by developing new interaction and collaboration possibilities [38]. Historically, the major emphasis, especially in Artificial Intelligence, was based on the emulating approach. Based on its limited success, the interest has shifted more and more to the complementing approach [5] whose possibilities we have explored and exploited to serve social creativity.

Figure 4: The Envisionment and Discovery Collaboratory (EDC)

3. Examples of Systems in Support of Social Interaction

3.1. The Envisionment and Discovery Collaboratory

The Envisionment and Discovery Collaboratory (EDC) (http://www.cs.colorado.edu-/~l3d/systems/EDC/) [2] is a domain-oriented design environment under development to support social interaction by creating shared understanding among various stakeholders, contextualizing information to the task at hand, and creating externalizations in collaborative design activities. The EDC framework is applicable to different domains, but 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 [36]. The symmetry of ignorance is a defining characteristic of such collaborative design activities: stakeholders are aware that while 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 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 driving another touch-sensitive (vertical) surface shown in the center of Figure 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 simulation 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 [3].

Historically, 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 and the cultural embedding for learning and design within the context of communities of learners. Crucial processes relevant for social interaction that are supported by the EDC are its ability to:

- deal with a set of possible worlds effectively (i.e., support exploration of design alternatives) to account for the fact that design is an argumentative process in which the goal is not to prove a point but instead to create an environment for a design dialog [13];
- incorporate an emerging design in a set of external memory structures [8], and record the design process and the design rationale [17];
- generate low-cost, modifiable models that assist stakeholders in creating shared understanding by engaging in a "conversation with the materials" [36];
- use simulations to engage in "what-if" games and to replace anticipation of the consequences of our assumptions by analysis [33];
- introduce the notion of a common language of design by integrating physical objects with virtual objects [3].

The EDC is a contribution toward a new generation of collaborative systems. It shifts the emphasis away from the computer screen as the focal point and creates an *immersive* environment in which stakeholders can incrementally create shared understanding through collaborative design.

3.2. Dynamic Information Spaces Supporting Social Creativity

There is a growing interest in dynamic information spaces. From early conceptions of hypertext [9] to current excitement regarding the World Wide Web and open source developments [29], computers have the potential to capture and manipulate dynamic information spaces.

DynaSites [30] is an environment for creating and evolving collections of Web-based information spaces that are open-ended and grow through the contributions of users thereby supporting social creativity. For example, within L^3D, we have used DynaSites to develop a shared, evolvable glossary of concepts (http://Seed.cs.colorado.edu/-dynagloss.home.fcgi). The basic idea is that concepts are not fixed entities, but evolve over time, especially in work groups characterized by a symmetry of ignorance between the participating stakeholders. Terms definitions in the glossary are automatically linked to their uses in other Dynasites, helping users to locate different uses of the terms across a large information space, and understand the term as it is used in the specific discussions.

Another application of DynaSites in support of social creativity is a Virtual Library system for collecting and sharing links to World-Wide Web sites developed in collaboration with a high school. Figure 5 illustrates the library, which is built on top of the

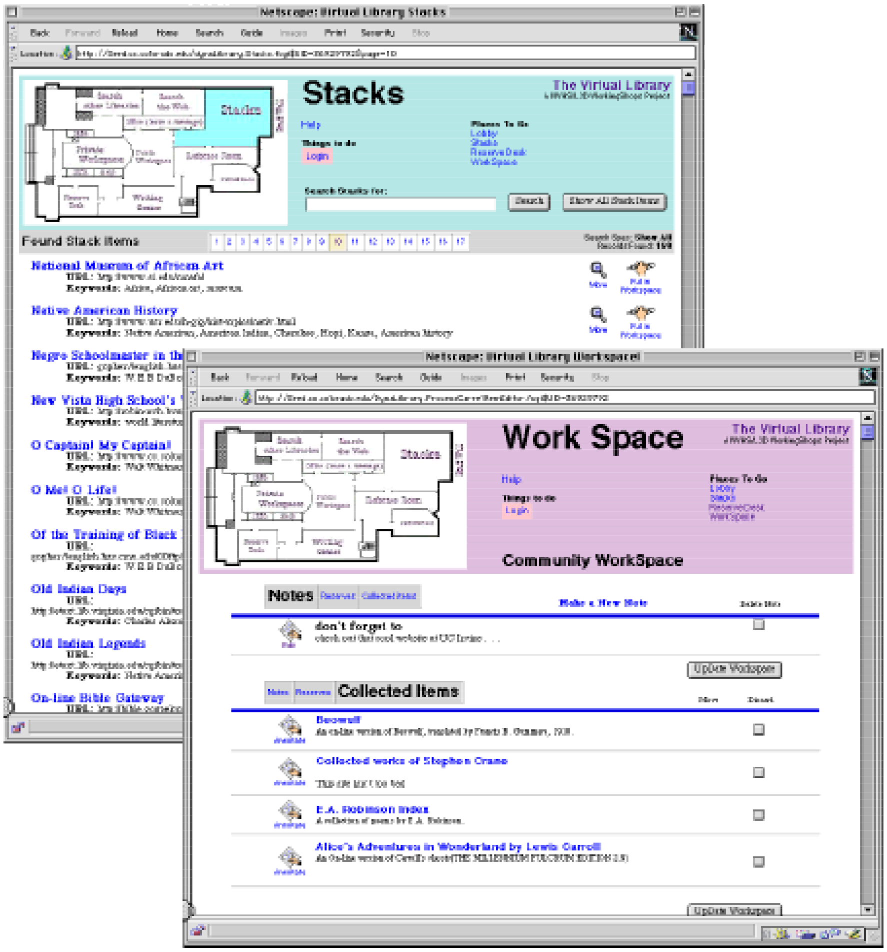

Figure 5:The Dynasites Virtual Library

DynaSites substrate, in action. The Virtual Library provides *Workspaces* for making notes and collecting and annotating website addresses that can be grouped into *Reserves*. An instructor, for example, might create a reserve for an American Literature assignment containing sites about famous American authors. The DynaSites Virtual Library can be found at http://robin.bvsd.k12.co.us/virtlib/.

4. Implications

Open Systems. If systems are to effectively support collaborative design, they must be *open* and not closed—allowing users to modify the information contents as well and functionality as they use the system to solve problems. To address real-world problems that are ill-defined, systems must cope with problem contexts that change over time. In addition to the fluid nature of the problems themselves, the very process of collaboration among stakeholders further increases the ever-changing problem context. Because the issues that arise in these problems will depend on the background, motivation, and agendas of the participants, the problem will take different forms, depending on the collaborators. *Closed systems*, in which the essential functionality is fixed when the system is designed, are inadequate for coping with dynamic problem contexts. Creating a system with constrained functionality requires making assumptions about use that cannot be fully anticipated when the system is designed, because many of the issues come out only when a system is used.

Open systems provide opportunities for significant changes to the system at all levels of complexity, thereby making enhancement and evolution of the system "first-class design activities." By creating the opportunities to shape the systems, the owners of the problems can be involved in the formulation and evolution of those problems through the system. The challenge for these open systems is to provide opportunities for extension and modification that are appropriate for the people who need to make changes. This is based on the following principles:

- *Software systems must evolve; they cannot be completely designed prior to use*. System developers cannot anticipate and design for every possible situation. Although it may not be possible to design "complete" systems, this does not mean that *all* aspects of a system must be constructed through user-directed evolution. In such a system, users would be unlikely to wish to spend considerable effort constructing even the simplest situations. Instead, designers must provide a *seed* for the system. The seed has an initial core functionality that can be readily applied to some situations and facilitates the construction of new situations. The seed must be designed to *evolve* over time, allowing users to make incremental changes to the core functionality when necessary. Eventually, designers and users may *re-seed* the system by incorporating pieces that were created during the system's evolution into the core of subsequent systems [16].
- *Systems must evolve at the hands of the users*. Giving the *owners* of problems the ability to change systems as they explore their problem leverages the insight into problems that uniquely belongs to those experiencing the problems. Many systems have explored the notion of end-user programming [27], often focusing on providing mechanisms for nonprogrammers to change systems. Our focus is on end-user modification, where programming is just one form of modification necessary to evolve systems. The ability to specify goals and structure information are examples of other important modification tasks. Furthermore, the notion of "end user" need not be limited to someone who is not a programmer. Instead, it is important to provide different avenues for modification that are appropriate for different kinds of stakeholders.
- *Systems must be designed for evolution*. Extending an application in an initially closed design may be difficult because of the assumptions implicit in a system designed without extension in mind [20]. A closed system with some extension capabilities will likely restrict what can and can't change. Designing a system for evolution from the ground up, however, can provide a context in which change is expected and can take place. But because it is not known in advance what way a system will evolve, even the underlying assumptions behind an evolvable system may be suspect. Therefore, it is important to design with an understanding of the nature of potential extensions, for some changes will always be more difficult than others.
- *Evolution of systems must take place in a distributed manner*. Systems must acknowledge the fact that users will be distributed both in space and in time. Distributed systems provide a framework for evolution in which all participants have the chance to contribute in a manner appropriate to their ability. The success of

distributed open systems (as measured by their creation and continual growth by communities of users who are not obliged to extend the systems) is a testament to the efficacy of the distributed approach [32].

New Conceptualizations of the World-Wide Web (WWW). Many people will argue that the most important new technology in support collaborative systems is the WWW. In analogy to the argument made with the exponential growth of computational power (see Figure 2) the WWW is a necessary medium for new forms of social interaction, but not a sufficient one. For example, the WWW in its current form does not support evolutionary design.

Figure 6 describes three different models of the WWW. Most WWW-based use engages the WWW as a broadcast medium (Model M1) in which content is predetermined at design time and placed on static WWW pages. Most popular general-purpose WWW tools provide support for the easy generation of this static content. As a broadcast medium, the WWW serves as a distribution channel and provides few opportunities for designers to interact with the information because the content was not originally designed to be interactive. Responding to the need for feedback from consumers, many WWW sites are evolving into forms that augment content with some communication channels. *Broadcast with feedback* (Model M2) provides links from consumer to producer such as allowing learners to provide feedback and ask questions by filling out forms. Although users can react to information provided by the author, this presentation model provides little support for evolution.

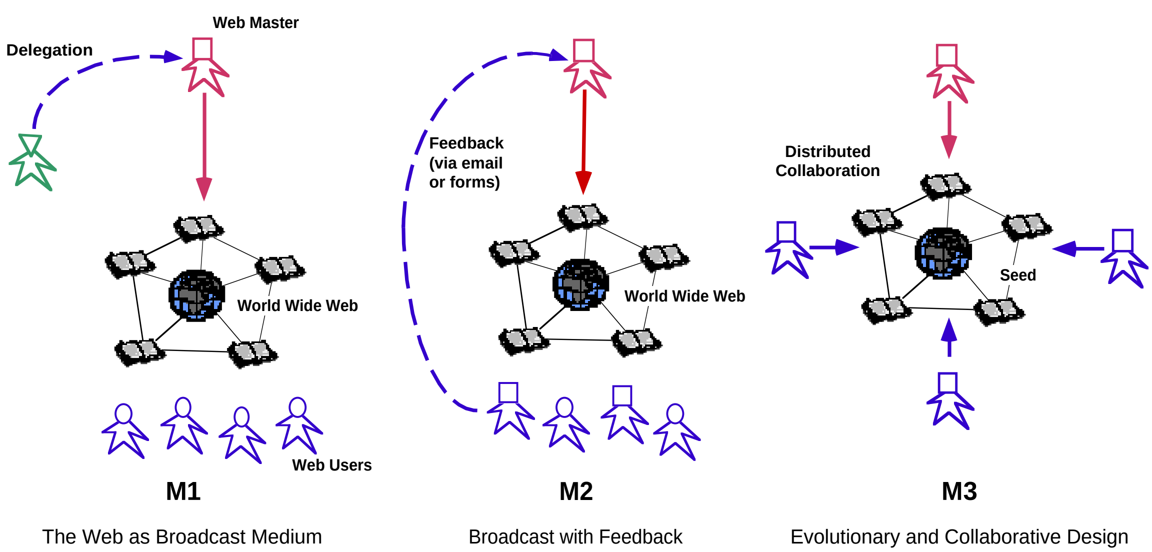

Figure 6: Making the World Wide Web a Medium for Collaborative, Evolutionary Design

To support collaborative design, users need to be able to use the WWW to collaborate on projects by *actively* contributing and by learning from all contributors (Model M3). 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. When a wide variety of individuals collaborate in a cooperative forum, the unique skills of the members all become valuable resources in making the WWW resources useful in the current context. The DynaSites system briefly described above is an attempt to support the M3 model.

Organizational Learning and Organizational Memories. Shared understanding, informed participation and social creativity are supported by organizational learning and organizational memories. *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 task (in the long term) [18]. A central component of organizational learning is a repository for storing knowledge in an organizational memory. However, the mere presence of an organizational memory system does not ensure that an organization will learn. Organizational learning happens only when the contents of organizational memory are utilized effectively in the service of doing work. Efficient support for organizational learning raises many unresolved issues: how can we create a working and learning culture, in which individuals are willing and encouraged to share; how do we effectively collect individual knowledge and make it easily accessible to the entire organization?

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. 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 not be 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. Systems that support organizational learning and organizational memories will be useful for professionals working on complex tasks in large team environments. An example of an organizational memory is GIMMe, the Group Interactive Memory Manager [25], which captures group email, automatically categorizes it, and then provides context-sensitive search capabilities.

For sustained organizational learning, three seemingly disparate goals must be served simultaneously. 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.

Decentralized Constructed Information Repositories. The M3 model is a useful framework for understanding the processes inherent in the development of *open systems* [16]. For example, the development of open-source software systems such as the Linux operation system [32] provides an interesting example that reliable, useful, and usable complex systems can be built in a decentralized "Bazaar style" by many rather than in a centralized, "Cathedral style" by a few. The Linux development model treats users as designers [15].

Open systems are examples of first steps illustrating the power of collaborative design based on community participation. In addition to Linux there are other interesting examples:

- *Gamelan* (http://www.gamelan.com), a community repositories of Java-related information;

- the *Educational Object Economy* (http://www.eoe.org/) a collection of Java objects (mostly completed applets) designed specifically for education;
- the *Agentsheets Behavior Exchange* (http://www.cs.colorado.edu/~l3d-/systems/agentsheets/), an initial prototype of a system for sharing computational artifacts.

One important common feature of these systems is their support for evolution. As new knowledge becomes available, members of the community may share new developments with each other. In all three systems, the repository administrators set up an initial *seed* that structures how information is added, presented, and searched by users. The goal is to create useful information repositories in a decentralized fashion. Because all systems are envisioned as tools that evolve at the hands of a community of users, all three are prime candidates to study the challenges, strengths, and weaknesses of open systems and social interaction.

5. Conclusions

Until recently, computational environments focused on the needs of individual users. As computers are being used for more complex tasks by more people, it becomes apparent that environments supporting shared understanding, informed participation, and social creativity among communities of practice, groups, and organizations are needed. However, this perspective does not necessitate the development of environments in which the interests of the group inevitably supersede those of the individual. Individuality makes a difference, and organizations get their strength to a large extent from the creativity and engagement of their individual member. One of the important challenges for the future is to gain a better understanding of the relationship between the individual and the social.

Acknowledgments

The author would like to thank all the members of L^3D for their numerous contributions to this research. Special thanks to Ernie Arias, Hal Eden, Eric Scharff, and Andy Gorman, who have been the major developers of the EDC, and to Jonathan Ostwald who has been the major developer of the DynaSites substrate. The research was supported by (1) the National Science Foundation, Grants REC-9631396 and IRI-9711951; (2) Software Research Associates, Tokyo, Japan; and (3) PFU, Tokyo, Japan.

6. References

[1] Arias, E. G.; Eden, H.; Fischer, G.; Gorman, A.; Scharff, E., *Beyond Access: Informed Participation and Empowerment*, In Proceedings of Proceedings of the Computer Supported Collaborative Learning (CSCL '99) Conference, Stanford, pp. 20-32.

[2] Arias, E. G.; Eden, H.; Fischer, G.; Gorman, A.; Scharff, E., *Transcending the Individual Human Mind—Creating Shared Understanding through Collaborative Design*, In *Transactions on Computer Human Interaction* 2000, *(to appear)*,

[3] Arias, E. G.; Fischer, G.; Eden, H., *Enhancing Communication, Facilitating Shared Understanding, and Creating Better Artifacts by Integrating Physical and Computational Media for Design*, In Proceedings of Proceedings of Designing Interactive Systems (DIS '97), Amsterdam, The Netherlands, pp. 1-12.

[4] Berlin, L.; Jeffries, R.; O'Day, V. L.; Paepcke, A.; Wharton, C., *Where Did You Put It? Issues in the Design and Use of a Group Memory* In *Proceedings of INTERCHI'93 Conference on Human Factors in Computing Systems*; S. Ashlund, K. Mullet, A. Henderson, E. Hollnagel and T. White, Ed.; ACM Press: New York, 1993; pp. 23-30.

[5] Bobrow, D. G., *Dimensions of Interaction*, In *AI Magazine* 1991, *12*, pp. 64-80.

[6] Bonnardel, N., *Creativity in design activities: The role of analogies in a constrained cognitive environment* In *Proceedings of Creativity & Cognition 1999*; L. Candy and E. Edmonds, Ed.; ACM Press: New York, 1999; pp. 158-165.

[7] Brown, J. S.; Duguid, P.; Haviland, S., *Toward Informed Participation: Six Scenarios in Search of Democracy in the Information Age*, In *The Aspen Institute Quarterly* 1994, *6*, pp. 49-73.

[8] Bruner, J., *The Culture of Education*; Harvard University Press: Cambridge, MA, 1996.

[9] Bush, V., *As We May Think*, In *Atlantic Monthly* 1945, *176*, pp. 101-108.

[10] Card, S. K.; Moran, T. P.; Newell, A., *The Psychology of Human-Computer Interaction*; Lawrence Erlbaum Associates, Inc.: Hillsdale, NJ, 1983.

[11] Carroll, J. M.; Rosson, M. B., *Paradox of the Active User* In *Interfacing Thought: Cognitive Aspects of Human-Computer Interaction*; J. M. Carroll, Ed.; The MIT Press: Cambridge, MA, 1987; pp. 80-111.

[12] Downes, L.; Mui, C., *Unleashing the Killer App — Digital Strategies for Market Dominance*; Havard Business School Press: Boston, MA, 1998.

[13] Ehn, P., *Work-Oriented Design of Computer Artifacts*; Almquist & Wiksell International: Stockholm, Sweden, 1988.

[14] Engelbart, D. C., *Toward Augmenting the Human Intellect and Boosting our Collective IQ*, In *Communications of the ACM* 1995, *38*, pp. 30-33.

[15] Fischer, G., *Beyond 'Couch Potatoes': From Consumers to Designers* In *1998 Asia-Pacific Computer and Human Interaction, APCHI'98*; IEEE, Ed.; IEEE Computer Society: , 1998; pp. 2-9.

[16] Fischer, G., *Seeding, Evolutionary Growth and Reseeding: Constructing, Capturing and Evolving Knowledge in Domain-Oriented Design Environments*, In *Automated Software Engineering* 1998, *5*, pp. 447-464.

[17] Fischer, G.; Lemke, A. C.; McCall, R.; Morch, A., *Making Argumentation Serve Design* In *Design Rationale: Concepts, Techniques, and Use*; T. Moran and J. Carrol, Ed.; Lawrence Erlbaum and Associates: Mahwah, NJ, 1996; pp. 267-293.

[18] Fischer, G.; Lindstaedt, S.; Ostwald, J.; Schneider, K.; Smith, J., *Informing System Design Through Organizational Learning* In *Proceedings of the Second International Conference on The Learning Sciences*; Association for the Advancement of Computing in Education (AACE): , 1996; pp. 52-59.

[19] *Intellectual Teamwork*; Galegher, P.; Kraut, R.; Egido, C., Ed.; Lawrence Erlbaum Associates, Inc.: Hillsdale, NJ, 1990, pages.

[20] Girgensohn, A., *End-User Modifiability in Knowledge-Based Design Environments* Ph.D. Dissertation Thesis, University of Colorado at Boulder, 1992 (Also available as TechReport CU-CS-595-92).

[21] Grudin, J., *Why groupware applications fail: Problems in design and evaluation*, In *Office: Technology and People* 1989, *4*, pp. 245-264.

[22] Hutchins, E., *Cognition in the Wild*; The MIT Press: Cambridge, MA, 1994.

[23] Landauer, T. K., *The Trouble with Computers*; MIT Press: Cambridge, MA, 1995.

[24] Lave, J.; Wenger, E., *Situated Learning: Legitimate Peripheral Participation*; Cambridge University Press: New York, 1991.

[25] Lindstaedt, S. N., *Group Memories: A Knowledge Medium for Communities of Interest* Ph.D. Dissertation Thesis, University of Colorado at Boulder, 1997 .

[26] Martin, G.; Détienne, F.; Lavigne, E., *Negotiation in collaborative assessment of design solutions: an empirical study on a concurrent engineering process,* In Proceedings of 7th PSE International Conference on Concurrent Engineering, Lyon, France, July.

[27] Nardi, B. A., *A Small Matter of Programming*; The MIT Press: Cambridge, MA, 1993.

[28] Norman, D. A., *Things That Make Us Smart*; Addison-Wesley Publishing Company: Reading, MA, 1993, 290 pages.

[29] O'Reilly, T., *Lessons from Open Source Software Development*, In *Communications of the ACM* 1999, *42*, pp. 33-37.

[30] Ostwald, J., *Dynasites*, At http://Seed.cs.colorado.edu/dynasites.documentation.fcgi$node=dynasites.doc.home, 2000.

[31] Polanyi, M., *The Tacit Dimension*; Doubleday: Garden City, NY, 1966.

[32] Raymond, E. S., *The Cathedral and the Bazaar*, At http://www.tuxedo.org/~esr/writings/, 1999.

[33] Repenning, A.; Sumner, T., *Agentsheets: A Medium for Creating Domain-Oriented Visual Programming Languages*, In *IEEE Computer, Special Issue on Visual Programming* 1995, *28*, pp. 17-25.

[34] *Perspectives on Socially Shared Cognition*; Resnick, L. B.; Levine, J. M.; Teasley, S. D., Ed.; American Psychological Association: Washington, D.C., 1991, pages.

[35] Rittel, H., *Second-Generation Design Methods* In *Developments in Design Methodology*; N. Cross, Ed.; John Wiley & Sons: New York, 1984; pp. 317-327.

[36] Schön, D. A., *The Reflective Practitioner: How Professionals Think in Action*; Basic Books: New York, 1983.

[37] Simon, H. A., *The Sciences of the Artificial;* Third ed.; The MIT Press: Cambridge, MA, 1996.

[38] Suchman, L. A., *Plans and Situated Actions*; Cambridge University Press: Cambridge, UK, 1987.

[39] Terveen, L. G., *An Overview of Human-Computer Collaboration*, In *Knowledge-Based Systems Journal, Special Issue on Human-Computer Collaboration* 1995, *8*, pp. 67-81.