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Knowledge Communication in Design Communities

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Abstract: Design is a rich domain in which to investigate barriers and biases in computer-supported communication because it involves many different modes of communication in social-technical contexts.

This chapter briefly describes different design approaches. It analyzes the biases and barriers of two different types of design communities: *communities of practice* and *communities of interest*. To address the communication challenges between diverse design communities, *boundary objects* are needed to establish common ground and shared understanding in the context of complex design tasks.

We explore the unique possibilities that *computational media* have to support our conceptual framework. Our work is based on the fundamental belief that there is no media-independent communication and interaction—that tools, materials, and social arrangements are always involved in some way in these activities. The possibilities and the practice of design are functions of the media with which we design. We present examples of such environments from our work.

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Introduction

Design is a rich setting in which to study computer-mediated communication. Large and complex design projects cannot be accomplished by any single person, and they often cut across different established disciplines, requiring expertise in a wide range of areas (Ernesto G. Arias, Eden, Fischer, Gorman, & Scharff, 2000). Software design projects, for example, involve designers, programmers, human-computer interaction specialists, marketing people, and user participants. Design projects are *unique* (Rittel & Webber, 1984), and therefore each design project requires learning and produces new knowledge in the form of understanding as well as artifacts. Complexity in design arises from the need to synthesize stakeholders' 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. Successful projects must overcome many barriers to communication and shared understanding.

Media change the nature of learning and communication in design. Ideally, new media will improve both individual and collaborative design by augmenting the cognitive abilities of designers and allowing them to transcend some of the barriers that have limited knowledge creation and sharing in design.

This chapter characterizes design as a human activity and discusses knowledge communication in several design contexts, including individual as well as collaborative design. It focuses on design communities as key loci of collaborative design, and their respective biases and barriers for knowledge communication. Specifically, this chapter analyzes *communities of practice* (CoPs) and *communities of interest* (CoIs); the latter addressing the challenges of collaborative design involving stakeholders from different practices and backgrounds by promoting constructive interactions among multiple knowledge systems (Fischer, 2001). Our approach to coordinating the various perspectives of different communities for a shared design task relies on boundary objects to mediate knowledge communication. We present several major system developments that employ boundary objects in support of knowledge communication within design communities. The chapter concludes by discussing how some of the barriers and biases in computer-mediated communication, specifically in the context of design, can be overcome by new media that support design communities.

Design and Design Communities

Design

Design is a ubiquitous activity that is practiced in everyday life as well as in the workplace by professionals (Cross, 1984; Donald A. Schön, 1983; Simon, 1996). It is not restricted to any specific discipline, such as art or architecture, but instead is a broad human activity that pursues the question of *"how things ought to be"*, as compared to the natural sciences, which study *"how things are"* (Simon, 1996). It is a fundamental activity within all professions: architects and urban planners design buildings and towns, lawyers design briefs and cases, politicians design policies and programs, educators design curricula and courses, writers design novels and technical documentation, psychologists design experiments, and software engineers design computer programs.

Designers solve problems. But apart from problems in school, most *problems in real life are encountered, not given.* For these problems, understanding the problem *is* the problem. Real-life problems must be *framed*, a process in which the important objects are determined and desired outcomes are defined.

Many problem-solving methodologies assume that problems can be clearly framed a priori, before any attempt at a solution is made. Design problems are typically, however, "ill-defined", or "wicked", creating the following dilemma: (1) one cannot understand the problem without information about it; (2) one cannot gather information meaningfully unless the problem is understood; and (3) one cannot understand the problem without having a concept of the solution in mind. In real life, as opposed to the classroom, problems are moving targets requiring an *integration of problem framing and problem solving*, such that the work in progress suggests ways to proceed and the development of a solution causes the framing of the task to grow and change.

Emphasizing the integration of problem framing and problem solving casts design as a search *for* a problem space rather than just *within* a problem space. It brings into question all design methodologies that are founded on a separation of analysis and synthesis. Furthermore, it emphasizes the importance of problem owners (those for whom an artifact is designed) as stakeholders in the design process because they have the authority and the knowledge to reframe the problem as the problem space becomes better understood.

Our research in design integrates the task of problem framing with that of problem solving by stressing the importance of externalizations that enable designers to represent both tasks. In this sense, externalizing ideas is not a matter of emptying out the mind but of actively reconstructing it, forming new associations, and expressing concepts in external representations while lessening the cognitive load required for remembering them: *"Externalization produces a record of our mental efforts, one that is 'outside us' rather than vaguely 'in memory'. ... It relieves us in some measure from the always difficult task of 'thinking about our own thoughts' while often accomplishing the same end. It embodies our thoughts and intentions in a form more accessible to reflective efforts."* ((Bruner, 1996), p. 23)

Designers engage in a cyclic process of action (the creation or modification of an externalization) and reflection (Donald A. Schön, 1983). Action is governed by nonreflective thought processes and proceeds until it breaks down. A breakdown occurs when the designer realizes that an action has resulted in unanticipated consequences. Designers engage in a conversation with their materials by listening to the "back-talk of the situation".

In collaborative design, Schön's metaphor of "conversation with the situation" takes on new meaning. The design situation now includes other designers as well as external representations, and conversation occurs between designers as well as between designers and design representations. The external design situation serves as context for communication between designers as well as between individual designers and the design situation.

A common notion about interpersonal communication is that knowledge is transmitted from one person to another. This assumption seems to hold in unproblematic communication, such as that between people who share a common background. But when we think of the difficulties in communication between people with different backgrounds, or in communicating a complex or vague idea, it is evident that "*the phenomenon of communication depends on not what is transmitted, but on what happens to the person who receives it. And this is a very different matter than transmitting information*" (Maturana & Varela, 1987).

Differentiating Design Approaches

Design processes involve stakeholders (often coming from different disciplines) who create artifacts. For many design activities, one can distinguish between *design time* (when the artifact is being designed) and *use time* (when the artifact is being used). At design time, a major challenge is to imagine how users will experience artifacts, whereas at use time the users are actually experiencing the artifacts.In *professionally dominated design*, professional designers (such as architects, software developers, urban planners, and teachers) engage in design methodologies founded on the belief that they understand the users' needs. At design time, they create artifacts with which users "have to live" at use time. In professionally dominated design, the "experts" see the creation of artifacts as their primary tasks (e.g., architects build buildings, software developers create software systems, urban planners design cities, and teachers develop courses); and understanding and communicating with other stakeholders are seen as secondary tasks representing extra work and thereby taking resources away from the primary task (Rambow & Bromme, 2000).

Participatory design approaches (Fischer & Ostwald, 2002a; Schuler & Namioka, 1993) seek to involve users more deeply in the process as co-designers by empowering them to propose and generate design alternatives themselves. Participatory design supports diverse ways of thinking, planning, and acting, thus making work, technologies, and social institutions more responsive to human needs. It requires the social inclusion and active participation of the users. It is a response to the theoretical argument that design problems are ill-defined and wicked and therefore cannot be delegated to experts. Instead, all stakeholders who are *owners of problems* must have a voice in the design process and they must participate in the framing of the problem.

Communication processes between designers and clients in participatory design face two barriers: (1) clients may not know exactly what they want; and (2) stakeholders lack a common language that allows them to educate each other, propose new visions, understand and critique these proposals, and come to a shared understanding of how things should be.

Developers are often biased toward working in their own language and formalisms, which is a barrier for users, who are forced to express their knowledge in the developer's vocabulary. Communication breakdowns occur when developers and users do not have a shared context. The challenge for communication is to establish a shared context that allows for communication and the accumulation of shared understanding.

Despite the best efforts at design time, designed artifacts need to be evolvable at use time to fit new needs, account for changing tasks, and incorporate new technologies. However, design approaches (whether done for users, by users, or with users) have traditionally focused primarily on activities and processes taking place at design time and have given little emphasis and provided few mechanisms to support systems as *living* entities that can be evolved by their users (see Table 1).

Meta-design approaches (Fischer & Scharff, 2000; Giaccardi, 2003) characterize objectives, techniques, and processes for creating new media and environments that allow the owners of problems to act as *designers* (Fischer, 2002). A fundamental objective of meta-design is to create socio-technical environments that empower users to engage in creating knowledge rather than being restricted to the consumption of existing knowledge.

Meta-design extends the traditional notion of system design beyond the original development of a system to include an ongoing process in which stakeholders become *co-designers*—not only at design time, but throughout the whole existence of the system (Morch, 1997). A necessary, although not sufficient, condition for users to become co-designers is that software systems include advanced features that permit users to create complex customizations and extensions. Rather than presenting users with closed systems, meta-design approaches provide them with opportunities, tools, and social reward structures to extend the system to fit their needs. Meta-design shares some important objectives with user-centered and participatory design, but it *transcends* these objectives in several important dimensions and it changes the processes by which systems and content are designed. Meta-design shifts control over the design process from designers to users and empowers users to create and contribute their own visions and objectives at use time as well as at design time. Meta-design is a useful perspective for projects for which 'designing the design process' is a first-class activity, meaning that creating the technical and social conditions for broad participation in design activities (in both design time and use time) is as important as creating the artifact itself (Wright, Marlino, & Sumner, 2002).

Table 1 summarizes the role of the user in professionally dominated, participatory, and meta-design approaches. Only meta-design views the users as active participants and designers throughout the lifecycle of a designed artifact.

Table 1: The Role of Users in Different Design Approaches

Design Approach	*Design Time*	*Use Time*
Professionally-dominated design	Users have no voice	Users have to live with artifacts designed by others
Participatory design	Users are active participants; systems are designed as complete systems artifacts	Users are consumers of artifacts designed with their input, but artifacts cannot be evolved to serve unforeseen needs
Meta-design	Users are active participants; systems are designed as seeds; design is focused on design for participation, as well as use	Users can act as designers and evolve the artifact to fit new needs

Dimensions of Computer-Mediated Communication in Design

Computer-mediated communication (specifically in complex design activities) can be differentiated along the following dimensions:

- *spatial* (across distance), requiring networks (B. Nardi & Whittaker, 2002; Olson & Olson, 2001);
- *temporal* (across time), requiring support for asynchronous, indirect, long-term communication (Fischer et al., 1992; Mørch & Mehandjiev, 2000);
- *technological* (between persons and artifacts), requiring knowledge-based, domain-oriented systems (Fischer, 1994; Terveen, 1995); and
- *social* (across different communities of practice), requiring support for common ground and shared understanding (Fischer, 2001; Resnick, Levine, & Teasley, 1991).

Many research efforts in computer-mediated communication have focused on collaborative activities across time and space, in which media support is not a luxury but a necessity.

Spatial Dimension*.* Even though communication technology enables profoundly new forms of collaborative work, Olson and Olson (Olson & Olson, 2001) have found that closely coupled work can still be difficult to support at a distance. In addition, critical stages of collaborative work, such as establishing mutual trust, appear to require some level of face-to-face interaction. Brown and Duguid (John Seely Brown & Duguid, 2000) present a similar argument: *"Digital technologies are adept at maintaining communities already formed. They are less good at making them"* (p. 226)*."* In contrast, distributed teams of collaborators are able to carry out effective work, and indeed evolve totally new ways of working that have a great impact on their activities (Olson & Olson, 2001). Open source software communities provide an example of successful collaboration on a large scale mediated by computational media (Raymond & Young, 2001; Scharff, 2002).

Temporal Dimension*.* Design processes often take place over many years, with initial design followed by extended periods of evolution and redesign. In this sense, design artifacts (including systems that support design tasks, such as reuse environments (Ye & Fischer, 2002)) are not designed once and for all, but instead they evolve over long periods of time. For example, most computer networks are enhanced and updated, rather than redesigned completely from scratch, when a new device or technology emerges.

Much of the work in ongoing design projects is done as redesign and evolution, and the people doing this work are often not members of the original design team. But to be able to do this work well, or sometimes at all, requires "collaboration" with the original designers of the artifact. A special case of this collaboration is *reflexive computer-supported cooperative work (CSCW)* supporting the same individual user, who can be considered as two different persona at points of time that are far apart (Thimbleby, Anderson, & Witten, 1990). In ongoing projects, long-term collaboration is crucial for success yet difficult to achieve. This difficulty is due in large part to individual designers' ignorance of how the decisions they make interact with decisions made by other designers. A large part of this, in turn, consists of simply not knowing what has been decided and why.

Long-term collaboration requires that present-day designers be aware of the rationale (Moran & Carroll, 1996) behind decisions that shaped the artifact, and aware of information about possible alternatives that were considered but not implemented. This requires that the rationale behind decisions be recorded in the first place. Closed systems thus present a barrier to rationale capture by not providing opportunities for designers to add rationale for their decisions. As argued before, designers are *biased* toward doing design but not toward putting extra effort into documentation. This creates an additional rationale-capture barrier for long-term design.

Another barrier raised by long-term design projects is the ability to modify a system's functionality. During the lifecycle of a ongoing design project, the environment in which the artifact functions may change in ways that were not anticipated by the original designers. If the system cannot be adapted to it's changing environment at use time, it will cease to be useful. One way to view this need for adaptation is to think of the lifecycle of a system as an ongoing design process, sometimes called *design-in-use* to emphasize that design of a system happens alongside use (Henderson & Kyng, 1991).

Technological Dimension. Design can be described as a reflective conversation between designers and the designs they create. Designers use materials to construct design situations, and then listen to the "back-talk of the situation" they have created (Donald A. Schön, 1983). Unlike passive design materials, such as pen and paper, computational design materials are able to interpret the work of designers and actively talk back to designers. For example, critiquing mechanisms embedded in domain-oriented design environments can alert designers when they violate design principles and then deliver relevant information to help designers understand how to improve their designs.

Social Dimension. Design communities are increasingly characterized by a *division of labor*, comprising individuals who have unique experiences, varying interests, and different perspectives about problems, and who use different knowledge systems in their work. *Shared understanding* (Resnick et al., 1991) supporting collaborative learning and working requires the active construction of a knowledge system in which the meanings of concepts and objects can be debated and resolved. In heterogeneous design communities, such as those that form around large and complex design problems, the construction of shared understanding requires an interaction and synthesis of several separate knowledge systems. Our own research efforts have focused on supporting communication across two conceptual dimensions: (1) the expertise gap between experts and novices within a particular practice; and (2) the conceptual gap between stakeholders from different practices. In the following section, we analyze these dimensions of communication in the context of design communities.

Design Communities

Design communities are social structures that enable groups of people to share knowledge and resources in support of collaborative design. Different communities grow around different types of design practice. Each design community is unique, but for the purposes of this discussion, we identify two stereotypical kinds of design community—the community of practice (CoP) and the community of interest (CoI)—and discuss their respective barriers and biases for knowledge creation and sharing in collaborative design.

Communities of Practice

CoPs (Wenger, 1998) consist of practitioners who work as a community in a certain domain undertaking similar work. For example, copier repair personnel who work primarily in the field but meet regularly to share “war stories” about how to solve the problems they encountered in their work make up a CoP (Orr, 1996). Learning within a CoP takes the form of *legitimate peripheral participation* (LPP) (Lave & Wenger, 1991), which is a type of apprenticeship model in which newcomers enter the community from the periphery and move toward the center as they become more and more knowledgeable (depicted in Figure 1).

Sustained engagement and collaboration lead to boundaries that are based on shared histories of learning and that create discontinuities between participants and nonparticipants. Highly developed knowledge systems (including conceptual frameworks, technical systems, and human organizations) are biased toward efficient communication *within* the community at the expense of acting as barriers to communication with outsiders: boundaries that are empowering to the insider are often barriers to outsiders and newcomers to the group.

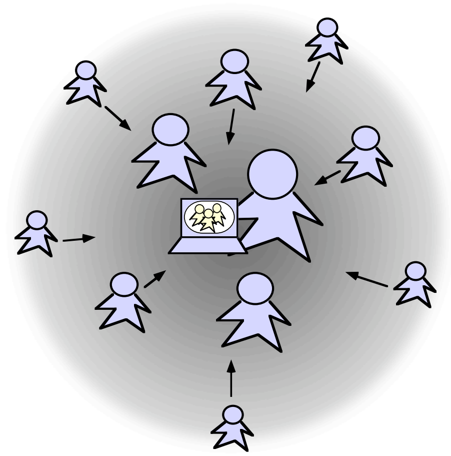

Figure 1. Learning in CoPs

At the center are knowledgeable members and knowledge systems. Members enter the community from the periphery and move toward the center over time through participating in the community.

A community of practice has many possible paths and many roles (identities) within it (e.g., leader, scribe, power-user, visionary, and so forth) (Ye & Kishida, 2003). Over time, most members move toward the center, and their knowledge becomes part of the foundation of the community's shared background.

Communities of Interest

"Innovations come from outside the city wall."

CoIs bring together stakeholders from different CoPs and are defined by their collective concern with the resolution of a particular problem. CoIs can be thought of as "communities of communities" (John S. Brown & Duguid, 1991) or a community of representatives of communities. Examples of CoIs are: (1) a team interested in software development that includes software designers, users, marketing specialists, psychologists, and programmers, or (2) a group of citizens and experts interested in urban planning, especially with regard to implementing new transportation systems, as illustrated later in this chapter by the Envisionment and Discovery Collaboratory (EDC).

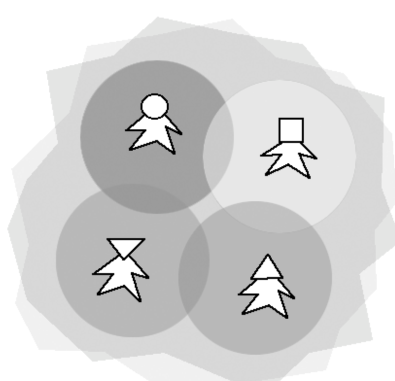

Figure 2: CoIs — Bringing Different CoPs Together

CoIs bring together stakeholders from different CoPs (represented by the different colored circles). The ragged edge of the bounding shape depicts that the boundaries of the problem and the community are not well established, particularly at the beginning of a project.

Stakeholders within CoIs are considered as *informed participants* (J.S. Brown, Duguid, & Haviland, 1994) who are neither experts nor novices, but rather both: they are experts when they communicate their knowledge to others, and they are novices when they learn from others who are experts in areas outside their own knowledge.

As a model for working and learning in CoIs, *informed participation* (Fischer & Ostwald, 2002b) is based on the claim that for many (design) problems, the knowledge to understand, frame, and solve these problems does not already exist, but must be collaboratively constructed and evolved during the problem-solving process. Informed participation requires information, but mere access to information is not enough. The participants must go beyond the information that exists to solve their problems. For informed participation, the primary role of media is not to deliver predigested information to individuals, but to provide the opportunity and resources for social debate and discussion. In this sense, improving access to existing information (often seen as the major advance of new media) is a limiting aspiration. A more profound challenge is to allow stakeholders to incrementally acquire ownership in problems and contribute actively to their solutions (Florida, 2002).

Communication among stakeholders is difficult because they come from different CoPs, and therefore use different languages, different conceptual knowledge systems, and perhaps even different notational systems. In his book, "*The Two Cultures*" (Snow, 1993), C. P. Snow describes these difficulties through an analysis of the interaction between literary intellectuals and natural scientists, who (as he had observed) had almost ceased to communicate at all. He writes, *"there exists a profound mutual suspicion and incomprehension, which in turn has damaging consequences for the prospects of applying technology to the alleviation of the world's problems"* and *"there seems to be no place where the cultures can meet."*

The fundamental barrier facing CoIs is that knowledge distribution is based on an *asymmetry of ignorance (or knowledge)* (Rittel, 1984), in which each stakeholder possesses some, but not all, relevant knowledge, and the knowledge of one participant complements the ignorance of another. This barrier must be overcome by building a shared understanding of the task at hand, which often does not exist at the beginning, but is evolved incrementally and collaboratively and emerges in people's minds and in external artifacts. Members of CoIs must learn to communicate with and learn from others (Engeström, 2001) who have different perspectives and perhaps a different vocabulary for describing their ideas. In other words, this symmetry of ignorance must be exploited.

Comparing CoPs and CoIs

Learning through informed participation within CoIs is more complex and multifaceted than *legitimate peripheral participation* (Lave & Wenger, 1991) in CoPs, which assume a single knowledge system. Learning in CoPs can be characterized as "learning when the answer is known", whereas learning in CoIs is often a consequence of the fact that the answer is not known (e.g., to a complex, unique design problem). CoIs have multiple centers of knowledge, with each member considered to be knowledgeable in a particular aspect of the problem and perhaps not so knowledgeable in others. In informed participation, the roles of "expert" or "novice" shift from person to person, depending on the current focus of attention.

Table 2 characterizes and differentiates CoPs and CoIs along a number of dimensions. The point of comparing and contrasting CoPs and CoIs is not to pigeonhole groups into either category, but rather to identify patterns of practice and helpful technologies. People can participate in more than one community, or one community can exhibit attributes of both a CoI and a CoP. Our *Center for LifeLong Learning and Design (L^3D)* is an example: It has many characteristics of a CoP (having developed its own stories, terminology, and artifacts), but by actively engaging with people from outside our community (e.g., other colleges on campus, people from industry, international visitors, and so forth), it also has many characteristics of a CoI. Design communities do not have to be strictly either CoPs or CoIs, but they can integrate aspects of both forms of communities. The community type may shift over time, according to events outside the community, the objectives of its members, and the structure of the membership.

Table 2: Differentiating CoPs and CoIs

Dimensions	*CoPs*	*CoIs*
Nature of problems	Different tasks in the same domain	Common task across multiple domains
Knowledge development	Refinement of one knowledge system; new ideas coming from within the practice	Synthesis and mutual learning through the integration of multiple knowledge systems
Major objectives	Codified knowledge, domain coverage	Shared understanding, making all voices heard
Weaknesses	Group-think	Lack of a shared understanding
Strengths	Shared ontologies	Social creativity; diversity; making all voices heard
People	Beginners and experts; apprentices and masters	Stakeholders (owners of problems) from different domains
Learning	Legitimate peripheral participation	Informed participation

Both forms of design communities exhibit barriers and biases. *CoPs* are biased toward communicating with the same people and taking advantage of a shared background. The existence of an accepted, well-established center (of expertise) and a clear path of learning toward this center allows the differentiation of members into novices, intermediates, and experts (see Figure 1). It makes these attributes viable concepts associated with people and provides the foundation for legitimate peripheral participation as a workable learning strategy. The barriers imposed by CoPs are that *group-think* can suppress exposure to, and acceptance of, outside ideas; the more someone is at home in a CoP, the more that person forgets the strange and contingent nature of its categories from the outside.

A bias of *CoIs* is their potential for *creativity* because different backgrounds and different perspectives can lead to new insights (Bennis & Biederman, 1997; Campbell, 1969). CoIs have great potential to be more innovative and more transforming than a single CoP if they can exploit the *asymmetry of ignorance* (Rittel, 1984) as a source of collective creativity. A fundamental barrier for CoIs might be that the participants failed to create common ground and shared understanding. This barrier is particularly challenging because CoIs often are more temporary than CoPs: They come together in the context of a specific project and dissolve after the project has ended.

CoPs are the focus of disciplines such as CSCW: They provide support for work cultures with a shared practice (Wenger, 1998). The lack of a shared practice in CoIs requires them to draw together diverse cultural perspectives. Computer-mediated knowledge communication in CoPs is different from that in CoIs. CoIs pose a number of new challenges, but the payoff is promising because they can support pluralistic societies that can cope with complexity, contradictions, and a willingness to allow for differences in opinions.

Boundary Objects

Boundary objects (Bowker & Star, 2000; Star, 1989; Wenger, 1998) are externalizations of ideas that are used to communicate and facilitate shared understandings across spatial, temporal, conceptual, or technological gaps. In design communities, boundary objects help to establish a shared context for communication by providing referential anchoring (Clark & Brennan, 1991). Boundary objects can be pointed to and named, helping stakeholders make sure they are talking about the same thing. Grounding communication with external representations helps to identify breakdowns and serves as a resource for repairing them.

In CoPs, boundary objects represent the domain concepts and ontologies that both define and reflect the shared practice. They might take the form of documents, terminology, stories, rules, and unspoken norms. For example, the boundary objects in our community of researchers includes research papers, dissertations, and a conceptual framework that encompasses the individuals and work done within the community.

In CoIs, boundary objects support communication across the boundaries of different knowledge systems, helping people from different backgrounds and perspectives to communicate and to build common ground (see Figure 3).

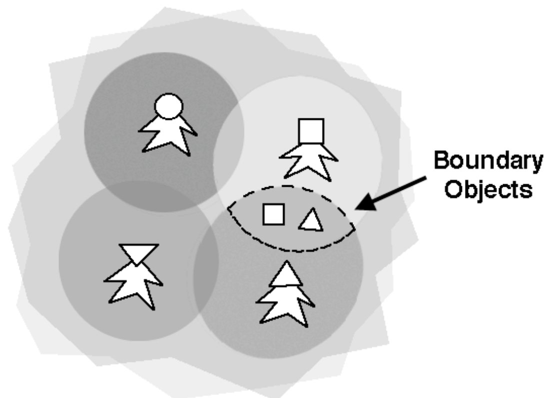

Figure 3: Boundary Objects as Bridges between CoPs

> Boundary objects should be meaningful within the conceptual knowledge systems of at least two communities of practice. The meaning need not be the same—in fact, the differences in meaning are what lead to the creation of new knowledge.

Boundary objects allow different knowledge systems to communicate by providing a shared reference that is meaningful within both systems. Computational support for CoIs must therefore enable mutual learning through the creation, discussion, and refinement of boundary objects that allow the knowledge systems of different CoPs to interact. In this sense, the interaction between multiple knowledge systems is a means to turn the *asymmetry of ignorance* (Rittel, 1984) into a resource for learning and *social creativity* (Fischer, 2000).

Boundaries are the locus of the production of new knowledge. They are where the unexpected can be expected, where innovative and unorthodox solutions are found, where serendipity is likely, and where old ideas find new life. The diversity of CoIs may cause difficulties, but it also may provide unique opportunities for knowledge creation and sharing (Ernesto G. Arias et al., 2000).

Importantly, boundary objects should be conceptualized as evolving artifacts that *become* understandable and meaningful as they are used, discussed, and refined (Ostwald, 1996). For this reason, boundary objects should be conceptualized as reminders that trigger knowledge, or as conversation pieces that ground shared understanding, rather than as containers of knowledge. The *interaction* around a boundary object is what creates and communicates knowledge, not the object itself.

Humans serving as knowledge brokers can play important roles to bridge boundaries that exist across or within communities. For example, within design communities that develop around complex software systems, members who are interested and inclined to learn about the technologies may develop into *power-users* (also known as “local developers” and “gardeners” (B. A. Nardi, 1993)) who are able to make modifications and customizations. By making needed changes to a system on behalf of the community, or by teaching others how to do so, power-users help others to transcend the boundary that exists between using a system as it is and modifying it.

Media in Support of Knowledge Communication

There is no media-independent communication and interaction: tools, materials, and social arrangements always mediate activity. The possibilities and the practice of design are functions of the media with which we design. We explore here the unique possibilities that *computational media* can have on design. Cognition is shared not only among minds, but also among minds and the structured media within which minds interact (Resnick et al., 1991; Salomon, 1993). In this section, we briefly differentiate among various kinds of media and then provide examples of the socio-technical environments that we have developed to support design in different design communities.

Rich and Lean Media

> "You cannot use smoke signals to do philosophy. Its form excludes the content".
> ((Postman, 1985), p. 7)

Our research is grounded in the basic belief that computer-mediated communication is not the opposite of face-to-face communication, but that face-to-face communication can be effectively supported with computational media. We distinguish between rich media and lean media (see Figure 4). Rich media exploit all communication channels (face-to-face interactions being a prime example). They are highly interactive and highly malleable, and provide rich knowledge structures (including boundary objects), but they are often very costly to realize. We are in search of defining *media ecologies* (B. Nardi & Whittaker, 2002) that support matching appropriate and effective media to specific tasks. Although cost-effective solutions are important, our primary interest is in maximizing the creativity of all stakeholders in design.

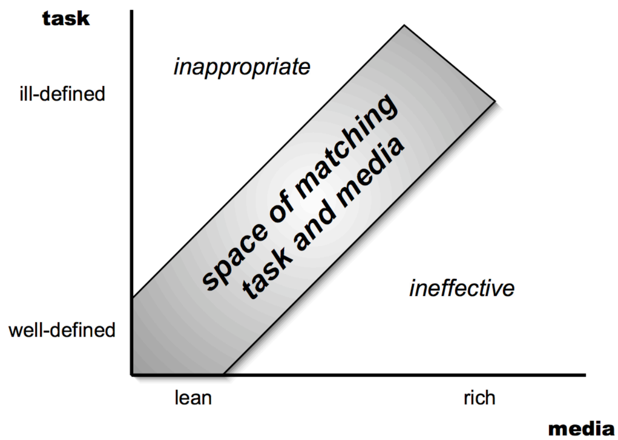

Figure 4: Matching Media to Tasks

Our basic assumption is that complex tasks (such as creating an initial understanding of a new public transportation system in urban planning) require rich media, whereas for well-specified tasks (such as finding out how far different people are willing to walk to a bus stop or how long they are willing to wait for a bus), lean media are sufficient. *Inappropriate* uses of media occur when lean media are used to address complex tasks, and *ineffective* uses occur when rich media are used to deal with well-specified problems (see Figure 4).

In the course of solving complex design problems, *different phases* occur (see Figure 5):

- *what:* deciding what the problem is by framing it;
- *how:* determining how the problem can and should be decomposed;
- *subtasks:* doing the work on the subtasks from decomposing the original problem;
- *restructuring:* restructuring the pieces and reassembling them into a whole; and
- *reframing:* taking stake, evaluating an initial solution, and reframing the problem.

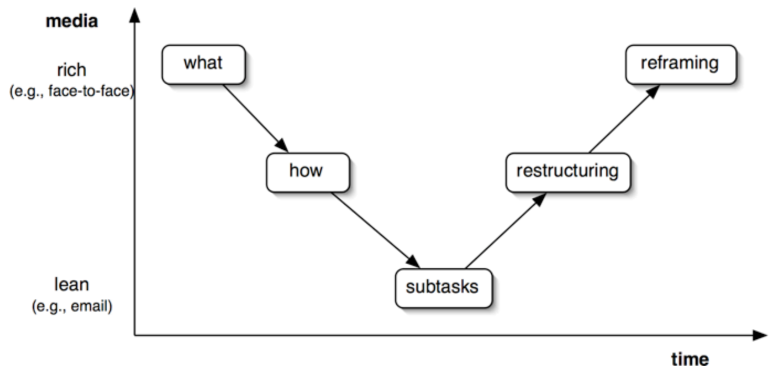

Figure 5: Covering a Wide-Spectrum of Activities with Media Integration

Computer-mediated interaction and collaboration should use many different kinds of media to fit the specific tasks to be achieved.

Rich media (such as face-to-face collaborations) enable us to leverage our native modes of communication. This is particularly important at the boundaries of domain knowledge, where problems are ill-defined, only partially understood, and difficult, if not impossible, to express explicitly. In such situations, the full range of communication capabilities and facilities is required to aid different people's natural abilities to construct shared understanding through detection and repair of communication breakdowns. Once problems are more fully understood, they can be more meaningfully expressed by using lean media because they can be explicitly described. The creation and evolution of boundary objects requires rich media, but once the evolution is over, these objects can be represented and referred to by using leaner media.

Solving complex design problems requires that stakeholders engage in all of these activities. Therefore integrated socio-technical environments (as described in the following sections) should offer a variety of media to support the whole spectrum of different activities. They should support CoPs and CoIs by allowing them to think previously *unthinkable thoughts*, to do previously *undoable actions*, and to explore previously *unfeasible questions*.

Computer-Mediated Communication in CoPs

Domain-oriented design environments (DODEs) (Fischer, 1994) are a class of integrated systems that support design in a particular domain by a CoP. They explicitly represent the domain-specific knowledge structures developed by the CoP, including abstractions, domain models, tools, design methodologies, and so forth; they embody the CoPs intellectual history; and they have theories and basic assumptions built into them. Moreover, users accept the built-in theories and assumptions when when they use these tools. DODEs support CoPs by providing cognitive economy to a particular professional community, but they are of little or no use outside of this community.

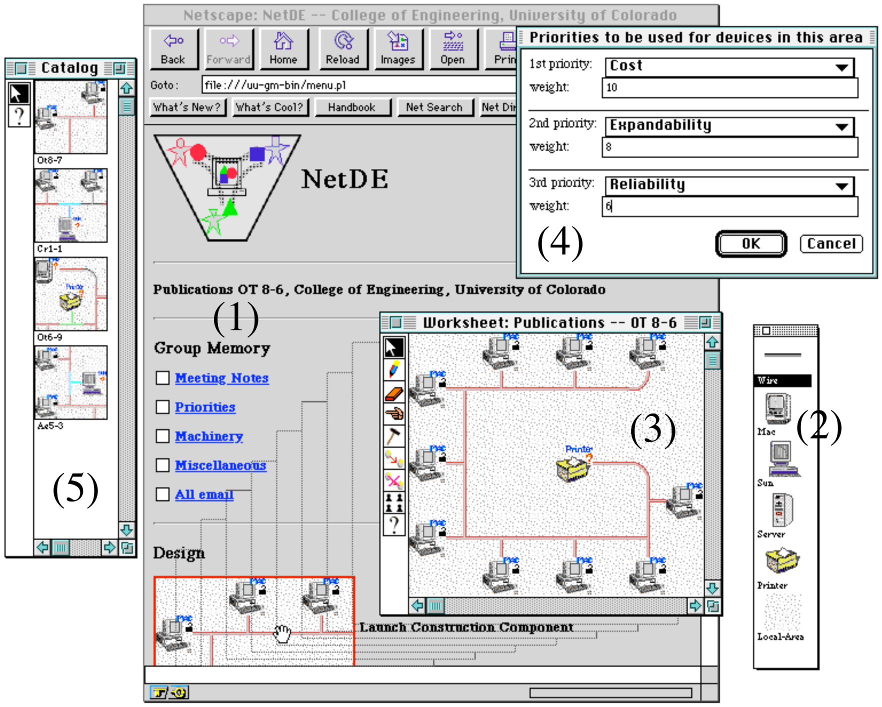

Figure 6: A DODE for Computer Network Design

Figure 6 shows a screen image of a DODE supporting a CoP of computer network designers who create local area networks in the *construction space* (see Pane 2) by using a *palette of components* (see Pane 3). A *specification component* (see Pane 4) allows the designers to articulate high-level intentions for their projects, such as ranking of priorities, that are not explicit in the worksheet.

The DODE contains a *group memory* (see Pane 1) (Lindstaedt, 1998) that holds information collected from previous projects, email communication archives, and other textual information. The *catalog* (see Pane 5) contains example networks that can be used to see how a similar problem was solved, to understand the evolution of the particular network being designed, or as a starting point for a new design, thereby supporting case-based reasoning approaches (Kolodner, 1993).

DODEs help users to be reflective practitioners (Donald A. Schön, 1983) by providing support for "reflection-in-action." The action space (i.e., construction workspace) is linked with the reflection space (i.e., group memory and catalog) through critics, which are codified domain knowledge in the form of design rules. *Embedded critics* (Fischer, Nakakoji, Ostwald, Stahl, & Sumner, 1998) enable DODEs to (1) increase the "back-talk" of a design situation by monitoring the actions of users as they work and informing them about breakdowns; (2) increase the user's understanding of problems to be solved; (3) point out the need for information that might have been overlooked; and (4) locate relevant information in very large information spaces. Embedded critics use partial constructions and partial specifications as implicit queries over information spaces. This enables the system to automatically find relevant information, rather than requiring the user to explicitly search for it.

A primary focus of DODEs was to support the *technological dimension* of computer-mediated communication by bridging the communication gap between a computational environment and an individual user, who may be a domain expert but not typically a computer expert. Domain-oriented objects, embedded critics, and rich information spaces allow users to communicate with the design situation and the problem domain, rather than with the computer per se, thereby supporting *human problem-domain interaction* in addition to human-computer interaction.

In this sense, the interactive objects and mechanisms provided by DODEs are boundary objects that mediate communication between the user and the domain-oriented knowledge contained in the system. DODEs support meta-design by providing end-user modifiable components (Girgensohn, 1992) that enable these boundary objects to be changed and modified at use time. The result of this approach is that the boundary objects can evolve and acquire new meanings as users discover new design rules, or new applicability conditions for existing rules, in the course of solving design problems.

DODEs support the *temporal dimension* of computer-mediated communication by enabling users to communicate indirectly through artifacts and group memories. This indirect channel of communication has several advantages within CoPs, including the fact that interactions can be captured and associated with the artifacts to which they refer. We found (Reeves, 1993), however,that this was not a sufficiently rich channel to support the kind of communication and learning required by CoIs, especially in the early stages of framing a problem (see Figure 5).

Computer-Mediated Communication in CoIs

Communication in CoIs requires boundary objects to address the unique challenges of allowing people from different CoPs to establish common ground and mutual understanding. This section describes two different contexts in which boundary objects are used to mediate conceptual gaps among stakeholders in CoIs. The first context is informed participation in support of collaborative decision making. The second context is informed participation in software development.

Collaborative Decision Making: The Envisionment and Discovery Collaboratory

The Envisionment and Discovery Collaboratory (EDC) (Ernesto G. Arias et al., 2000) attempts to maximize the richness of communication between stakeholders in face-to-face interaction, *mediated by both physical and computational objects*. The EDC supports CoIs by empowering all stakeholders to (1) engage in informed participation, (2) create shared understanding, (3) contextualize information to the task at hand, and (4) create boundary objects in collaborative design activities.

Whereas, DODEs primarily support CoPs within a specific domain, the EDC supports CoIs by providing boundary objects that all stakeholders can understand and manipulate, as well as by providing underlying computational support for trying out alternative solutions, accessing information relevant to the task at hand, and capturing information and design rationale from the design process.

The EDC approach is based on our experience in building and using physical simulation games to support decision making and critical thinking in the participatory design of physical environments (E.G. Arias, 1995). In a simulation game for urban neighborhood planning, game pieces representing structures, such as houses or commercial buildings, are placed on a game board representing the streets and lots. The game pieces and their placement on the board allow neighborhood residents to create and evaluate possibilities for changing their environment. The game pieces form a *language* for the stakeholders to use as they explore areas of conflict and consensus in planning the neighborhood. The language of the game pieces is a vehicle for interactions between players, including neighbors and design professionals.

Design games aim to integrate design and communication. The objects used to express the design situation are also the means for communication. The goal of the language is to support shared understanding and critical thinking — not to get in the way by introducing unneeded complexity. The language of the game pieces should “integrate the requirements of relevancy, flexibility, transparency, and above all, simplicity” (E.G. Arias, 1995).

The EDC extends the physical simulation game approach by integrating computational environments and (computationally enriched) external physical worlds with mechanisms capturing the larger (often unarticulated) context of what users are doing. Like DODEs, the EDC is grounded in Schön’s “reflection-in-action” problem-solving approach (Donald A. Schön, 1983).

Stakeholders using the EDC convene around a computationally enhanced table that serves as the *action space*. Currently realized as a touch-sensitive surface, the action space allows users to manipulate a computational simulation projected on the surface by interacting with the physical objects placed on the table. The simulation is an interactive model of the design problem that allows users to propose and explore alternative solutions in a complex design space. The table is flanked by another touch-sensitive (vertical) surface that serves as the *reflection space*. The reflection space displays information that is relevant to the context as defined by the simulation in the action space.

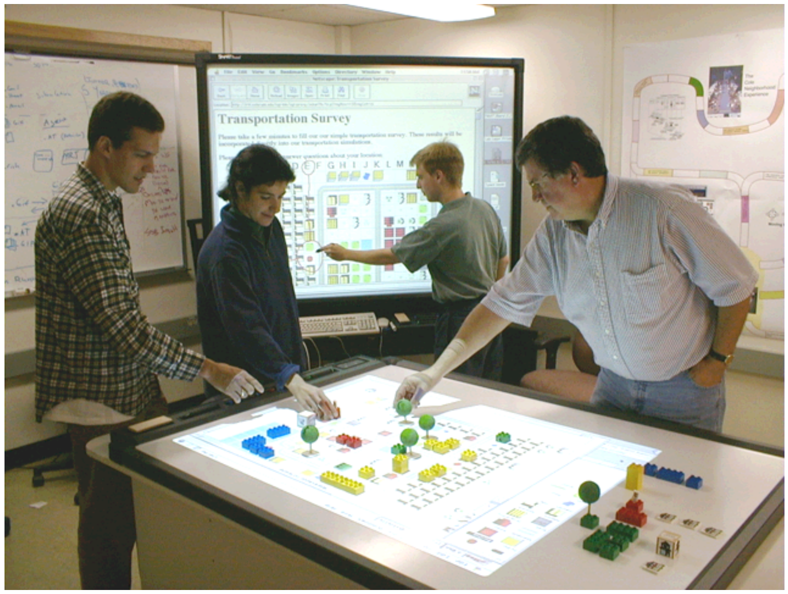

Figure 7: The Envisionment and Discovery Collaboratory

In the action space (foreground), stakeholders use physical objects to interact with an underlying computational simulation environment. In the reflection space (background), stakeholders interact with an information space, in which they access information, fill out surveys, and add new information.

The EDC framework is applicable to different domains; our initial effort has focused on the domains of urban planning and decision making, specifically transportation planning and community development. In Figure 7, neighbors are filling out a Web-based transportation survey associated with the simulation being constructed.

***Boundary Objects in the EDC*.** In the EDC, a design functions as a communication artifact around which stakeholders from different CoPs, coming together as a CoI in the context of a specific problem, can negotiate their contributions, their positions, and their alignments. Action space objects are domain-oriented — they represent objects in the problem domain in terms of both visual appearance and behavior within the simulations. These objects and their behaviors are meaningful to all stakeholders who have familiarity with the problem domain. However, the precise meanings of the objects and the implications of these meanings for design decisions for each stakeholder may not be shared initially among them. The objects serve as boundary objects by providing a common starting ground for stakeholders to identify and explore the differences in their understandings and to build new understandings that bridge the boundaries.

For example, in the domain of transportation planning, stakeholders include transportation engineers and neighborhood residents who will work together to improve the design of bus routes in their neighborhood. In the action space, they use domain objects, such as buses, bus stops, neighborhoods, and streets to explore different facets of the problem. An engineer might think of a bus stop in terms of its capacity to serve a certain size of neighborhood, whereas a resident might think of a bus-stop in terms of it's convenience to his house, or maybe in terms of it's after-dark safety. The bus stop object in the EDC is a boundary object for engineers and residents to build a shared understanding of the "bus-stop" concept in terms of the importance and implications for the particular design. This process is enhanced by the action space simulation, which helps stakeholders to explore alternatives, and the reflection space, which provides background that informs each perspective.

***Human-Computer Interaction Support for Boundary Objects in the EDC*.** In the original version of the EDC, the game board was biased toward single-user interaction due to limitations in the underlying SmartBoard technology. This bias resulted in the following barrier: parallel interactions, which were often attempted by users unfamiliar with this restriction, resulted in unpredictable effects. The single-user limitation of the SmartBoard could not simply be "programmed around" because the device accepted simultaneous presses as a normal single input occurring halfway between the two presses. This limitation for acting in parallel combined with the existence of only a single cursor led to frequent "mode" errors (for example, a user might attempt to *delete* an object when the "*add* mode" was active). The limitation imposed by a single cursor required that an explicit association be made between the physical cursor and the current virtual object of interest. In addition, users had to take an explicit action to associate a physical object with the underlying simulation by firmly pressing the object onto the touch screen rather than just placing the object at the desired location. We observed that users coming from CoPs with little experience or interest in computers per se frequently failed to make this association, which resulted in an operation other than that intended being erroneously applied to an object.

Taken together, these limitations required users to have an abstract mental model of how the SmartBoard technology works, in addition to a model of how the object being manipulated behaves. Although experienced users acquire an understanding of the SmartBoard interaction model as they worked with the system, participants who had limited exposure to the system may have experienced confusion that significantly degraded their engagement with the system. Such situations are a barrier for collaborative design because they (1) break the built-up context of a partial solution, (2) force stakeholders to focus on the interface rather than on the problem, and (3) reduce the emergence of boundary objects that all stakeholders can deal with in a natural way.

To remove these barriers in the SmartBoard technology, we are currently developing a new game board technology called the *Participate-in-the-Action Board* (PitA-Board) (Eden, 2003) that allows multiple users to interact with the virtual environment directly and simultaneously, leading to more *engaging* forms of interaction (see Figure 8). Because the interface objects will behave more like the domain objects they represent, their potential to serve as boundary objects is greatly enhanced.

Figure 8: Parallel Interactions in the PitA-Board EDC

The PitA-Board EDC eliminates barriers of the Smartboard EDC and facilitates the creation and evolution of boundary objects.

Software Development: The Evolving Artifact Project

The *Evolving Artifact (EVA)* project (Ostwald, 1996) explores the use of boundary objects in support of participatory software development. The EVA approach is based on the claim that the knowledge required to design software systems cannot be acquired simply through interviews, observations, and other types of analysis. Instead, it must be constructed in an evolutionary and participatory manner, driven by the creation and refinement of boundary objects that mediate knowledge communication between users and developers.

In the EVA approach, boundary objects serve as a bridge between stakeholders and their respective knowledge systems. The development process is driven by the creation, discussion, and refinement of boundary objects, which are collected in a single information space (EVA) that reflects the shared understanding constructed by the stakeholders.

The approach was applied to design a new system to support service representatives at a regional telephone company. The EVA project focused on knowledge communication between stakeholders from two CoPs:

- *developers*, who prefer to think and communicate in terms of programming languages and object-oriented design, and
- *service representatives*, who conceptualize their practice in terms of "screens" and "orders" and have difficulty verbalizing some of their practice and skills because this knowledge is tacit and therefore difficult to put into words.

The EVA project explored the use of several types of boundary objects for communicating design knowledge, including rich pictures, scenarios, and prototypes (Ehn, 1988). Rich pictures were created mainly to express ideas about the existing service-provisioning domain, scenarios were used primarily to express ideas of what new computational tools could change the way service representatives worked, and prototypes expressed how these changes could take place.

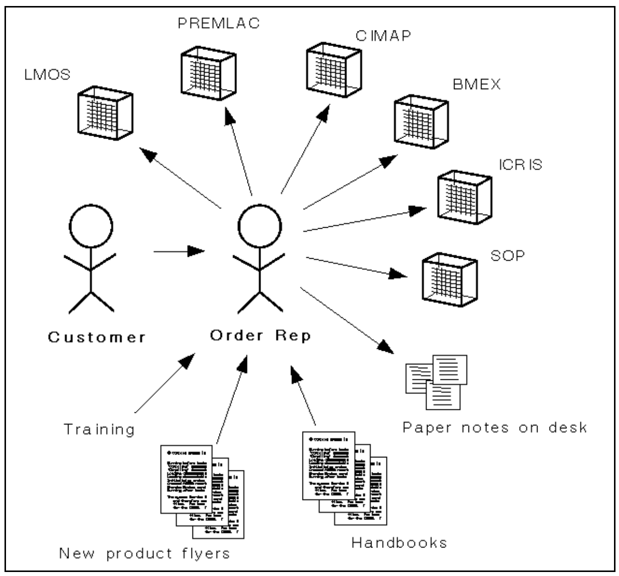

Figure 9: Rich Picture used in the EVA Project

This rich picture (from (Ostwald, 1996)) depicts the databases and paper-based documentation with which a representative must interact while simultaneously speaking with a customer by telephone. This boundary object was created by developers early in the project to learn about the various databases and their use in the representative's practice.

Rich pictures are a powerful type of boundary object that combine text and graphics (see Figure 9). Rich pictures do not have a formal syntax, but they do make use of symbols and diagrammatic conventions to represent a particular situation in a manner that is explicit and understandable by all stakeholders. Rich pictures give users the opportunity to identify important aspects of their work, and to correct missing elements and incorrect terminology. Additionally, rich pictures serve to identify well-defined aspects of the current domain, and to understand these aspects in domain practices. Rich pictures thus help stakeholders to build a shared understanding of the current domain.

Scenarios were used in the EVA project to build a shared vision of how a new system might change the practice of users. Task-based scenarios were built as an evolutionary step in the development process by using terminology and concepts made explicit in rich pictures. Because they were task-based, scenarios allowed users to think about what they would like to do with a new system, rather than to articulate system requirements in an abstract context. Scenarios proved to be a powerful type of boundary object because they combine aspects of both reflective and experiential artifacts (Norman, 1988). Scenarios are reflective in that they involve an explicit context, and experiential in that they allow users to imagine or act out an activity. The emphasis of traditional scenario approaches is to help system builders understand the user's requirements. In these approaches, scenarios help to uncover hidden implications and ambiguities in the requirements document.

In EVA, scenarios are also used to provide a context for *prototypes*, which are concrete, interactive representations that constrain what a user can do (unlike scenarios, which provide a more flexible context for improvisation). In this use, scenarios might specify *what* tasks will be performed, and the prototype determines *how* the tasks can be performed. As boundary objects, prototypes were used in a manner similar to the rich pictures: to express what developers knew and what they did not know, and to provide an opportunity for users to articulate their knowledge. When developers lacked the domain knowledge to implement a particular piece of functionality, they would implement their "best guess" at what the functionality should be, and ask the users to critique the prototype.

Prototypes that are grounded in the tradition of the domain bring the users' skill and practical knowledge to bear. Users are experts in their traditions, even though this type of knowledge may be *"literally indescribable in linguistic terms"* (Ehn, 1988). Prototypes are essential boundary objects because they let users directly experience possible new ways of working, thus going beyond scenarios in allowing users to envision the future.

Boundary objects in EVA followed an evolutionary trajectory from rich picture to scenario to prototype. The shared understanding gained from discussion and interaction with each object was used to guide the next step in the trajectory. Because all the boundary objects, as well as the conversations around them, were collected in the evolving artifact, the final product of the development process contained a history of the design process, including design rationale for the decisions made along the way. In this way, EVA bridges the temporal gap to support indirect communication between stakeholders at design time and those seeking to modify the system at use time.

The use of boundary objects in EVA can be contrasted with traditional software development approaches (based on waterfall models (Rittel, 1984)) that are based on the idea of *transformation* from one representation to another. The representations in these transformation-based approaches must be complete because ambiguities in one representation are carried over into the next one through the transformation process. In EVA, representations need not be complete. Instead, ambiguities in boundary objects are considered as opportunities for activating knowledge and creating new understandings, serving as the driving force for communication and the construction of shared understanding.

Lessons Learned

Barriers and Biases

Our research over the last decade has developed conceptual frameworks and socio-technical environments to support design and design communities. This research was driven forward by analyzing the barriers and biases inherent in specific approaches; subsequent approaches were aimed at overcoming the limitations and shortcomings of earlier approaches. Table 3 provides an overview of the biases and barriers discussed in this chapter.

Table 3: Overview of Barriers and Biases

	Biases	*Barriers*
Design Approaches		
Professionally dominated design	Focus on design time; ignores the needs of the users	Users have to deal with professionally conceived solutions
Participatory design	Focus on design time	Closed systems
Meta-design	Create context only	Difficulty in envisioning "unknown" futures"
Design Communities		
CoP	Group-think	Innovations from beyond the city walls
CoI	Divergent thinking	Creation of a shared understanding
Design Media		
DODEs	Codified domain knowledge; intelligent design support	Innovations beyond the boundaries of the domain
EDC	Face-to-face interaction mediated by tangible objects	Limited support for parallel interactions; conversation between participants is lost
EVA	Face-to-face interaction mediated by boundary objects	Enables participants to create boundary objects.
Forms of Computer-Mediation		
Spatial	Face-to-face supports maximal bandwidth	Face-to-face limits number of participants
Temporal	Communication through artifacts	Inherent difficulty of collaboration between people who do not know each other
Technological	Focus on what is technologically doable	Requires formalization
Social	Focus solely on communication	Requires shared understanding

The specific *biases and barriers* associated with boundary objects used in the EDC and in EVA are summarized in Table 4.

Textual descriptions and graphics are well suited for describing and understanding the tradition of the domain and the context in which the new system will be embedded. They are useful for activating existing domain knowledge, and for envisioning how the tradition of the domain should be changed. *Scenarios* are good for imagining the tasks that a new system might support as well as the steps necessary to accomplish tasks. They are weak, however, in allowing stakeholders to actually experience the situations they are designing. *Prototypes* are strong at allowing users to experience what work might be like using new systems, but they run the risk of being misinterpreted (Atwood et al., 1995). *Games* encourage collaborative, critical thinking and informed participation (Ernesto G. Arias et al., 2000), but the support of the EDC is required to capture the knowledge generated through the interactions. *Computational simulations* allow stakeholders to ask "what-if" questions, but unless a meta-design approach is supported, they may provide no support for specific important questions to be explored.

Table 4. A Spectrum of Barriers and Biases Associated with Different Kinds of Boundary Objects

Representations	*Biases*	*Barriers*	*Role in Collaborative Design*
Text and graphics	Expressive (i.e., lack of syntax), easily modified	Limitations of verbal descriptions; often not part of design artifact	To make knowledge explicit
Scenarios	Envisioning, focusing	Fictional, and not part of design artifact	A context for experiencing and envisioning
Prototypes	Experiential cognition	Can be misinterpreted and otherwise misused	A vehicle for expressing ideas about, and experiencing visions.
Games	Collaborative, critical thinking	Cannot capture knowledge in reusable form, lack of realism	A perspective on design as a cooperative game involving many participants and grounded by design artifacts
Computational simulations	Dynamic behaviors	Gap between simulation and real world	To observe and understand emergent behavior

CoIs: Beyond Novices and Experts

As argued before, the complexities of real problems transcend the boundaries of a CoP and require the collaboration of stakeholders from different domains. Practitioners from several domains (including architecture, engineering, management, psychotherapy, and town planning) were studied by Schön (D.A. Schön, 1987), yielding the interesting conceptual framework of the "reflective practitioner", which we have used and extended in our research (Fischer & Nakakoji, 1992) and to which we have referred on several occasions in this chapter. Rambow and Bromme (Rambow & Bromme, 2000) have analyzed Schön's work and suggest that Schön's reflective practitioner could learn by communicating with "laypersons" (e.g., clients, customers, patients, or users). They argue that the knowledge of laypersons is not merely an incomplete version of the knowledge of the expert, and therefore they should not be considered as students or apprentices, but rather as experts in their own right, albeit with a different expertise than that of professional designers.

These observations become obvious in our framework, which contrasts CoPs and CoIs. In addition, our framework clarifies the following issues:

- It introduces a symmetry between representatives of different CoPs by postulating a asymmetry of ignorance, rather than referring to one person as an "expert" and the other person as an "layperson ".
- It illustrates that legitimate peripheral participation (implying that the learner will eventually learn what the expert knows) is a concept belonging to CoPs, whereas informed participation is a better characterization for CoIs.
- It shows that a primary objective of CoPs is "learning when the answer is known" (by the expert), whereas the primary objective of CoIs is "learning when the answer is not known" (e.g., the answer to a unique design problem).
- It emphasizes that in CoIs (as they try to solve complex design problems), being a "learner/novice" or "teacher/expert" is an attribute of a context, and not of a person (e.g., some of our computer science students know considerably more about specific programming environments than we do.
- It provides evidence that the specific languages and ontologies used by stakeholders in one CoP (e.g., the diagrammatic representations used by architects, or the formal system descriptions used by computer scientists) will in many cases not serve as boundary objects for stakeholders coming from other CoPs.

Applying our Framework to Structuring Organizational Units within Universities

Our framework about computer-mediated knowledge communication and different kinds of communities is not unique to design; however, design has been an important and fruitful domain to pursue these ideas. One other application of the framework has been to structure organizational units within universities.

University colleges and departments are organizational units defining different disciplines. Throughout history, the use of disciplines and their associated development of a division of labor have proven to be powerful approaches. However, as evidenced by all the attempts to support inter- and multidisciplinary work, real problems cannot be successfully approached and solved by individual disciplines (Ernesto G. Arias et al., 2000).

Campbell (Campbell, 1969) stated that *"the present organization of content into departments is highly arbitrary, a product in large part of historical accident"* (p. 331). The key to interdisciplinary work is not in what Campbell called *"Leonardos who are competent in all sciences"* (p. 330) nor in educating a generation of "super humans" who know all relevant knowledge required for a complex design problem (Shneiderman, 2002). With information growing exponentially in all disciplines, it is impossible for any single scholar to have the time and aptitude to gain mastery in multiple disciplines; even complete mastery of one discipline is far beyond reach. A more promising and realistic interdisciplinary approach is represented by the foundations for CoIs to bring different CoPs together. Interdisciplinary researchers need not be specialists in all other relevant disciplines, but must at least be aware of the developments (research results and research methods) in other disciplines that relate to their own research interests (the *power users* identified by Nardi (B. A. Nardi, 1993) and as mentioned earlier in the discussion comparing CoPs and CoIs are good examples of such persons). Keeping up with relevant developments in other disciplines is difficult, but it can be facilitated by the right kind of socio-technical environment.

The framework developed in this chapter allows us to characterize a number of innovative new developments at our own institution, the University of Colorado at Boulder, which is bringing different communities together as learning organizations by creating the right mix of CoPs and CoIs:

- The *Alliance for Technology, Learning, and Society* (http://www.colorado.edu/ATLAS/) is building new innovative collaborations and learning opportunities among arts, humanities, science, engineering, and new media to support these collaborative efforts and express new ideas.
- The *Institute of Cognitive Science* (http://psych-www.colorado.edu/ics/), which struggled for a long time with the question of whether it should become a department (thereby emphasizing the CoP dimension, as was done by the University of California, San Diego, USA, and the University of Osnabrück, Germany), eventually decided that the CoI nature was more important and remained an institute, bringing representatives of different departments together.
- The *Discovery Learning Initiative* (http://discoverylearning.colorado.edu/) is an inquiry-based educational approach (housed in the new *Discovery Learning Center)* through which students develop their critical thinking skills, experience the passion and excitement of original research, and engage in problem solving in a collaborative, technology-enhanced environment. The approach supports CoIs by supporting integration both *vertically* (undergraduate, graduate, postgraduate, professionals) and *horizontally* (learners and teachers from all disciplines).
- The *Center for LifeLong Learning and Design (L^3D)* (http://www.cs.colorado.edu/~l3d/) is a good example that real design communities exhibit characteristics of both CoPs and CoIs. L^3D has established itself as a CoP, based on a shared history and the use of concepts and system developments as shared reference points. Based on our belief that CoPs must be allowed and must desire some latitude to shake themselves free of existing wisdom, we make every conscious effort to exploit the strengths of CoIs by embracing new ideas, new people, new collaborations, and new media. We apply our ideas and frameworks about design not only to the development of the systems we build, but also to the design of work practices and spaces that can bring social creativity alive (Fischer, 2001) .

Conclusions

Design is a ubiquitous activity. The complexity of design problems requires communities to address them. We have presented a conceptual framework based on different design approaches and we have identified different design communities. Communities of interest (CoIs) bring different communities of practice (CoPs) together to cope with the complexities of real-world design problems. CoIs provide unique opportunities to bring social creativity alive by transcending individual perspectives. To create a shared understanding and common ground between different CoPs requires boundary objects.

In the past, most computational environments focused on the needs of individual users. Our research has evolved from (1) empowering individuals to (2) supporting CoPs with domain-oriented design environments to (3) creating shared understanding among CoIs with the Envisionment and Discovery Collaboratory and the Evolving Artifact approach. In this journey, we have not abandoned earlier themes, but we have widened our focus. Moreover, by analyzing biases and barriers of earlier systems, we have learned how different computational and conceptual knowledge systems fit together and complement each other.

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