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Awareness and teamwork in computer-supported collaborations

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Abstract

A contemporary approach to describing and theorizing about joint human endeavor is to posit 'knowledge in common' as a basis for awareness and coordination. Recent analysis has identified weaknesses in this approach even as it is typically employed in relatively simple task contexts. We suggest that in realistically complex circumstances, people share activities and not merely concepts. We describe a framework for understanding joint endeavor in terms of four facets of activity awareness: common ground, communities of practice, social capital, and human development. We illustrate the sort of analysis we favor with a scenario from emergency management, and consider implications and future directions for system design and empirical methods.

Keywords: Activity awareness; Awareness; Collaboration; CSCW; Teamwork

1. Introduction

What do collaborators need to share in order to work together effectively?

This is the touchstone question for understanding the problems and possibilities for distributed work groups and remote collaboration, and for designing effective technologies and environments to support new kinds of collaborative work arrangements.

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The question unpacks into a plethora of further issues: collaborators need to be assured that their partners are 'there' in some sense. They need to know what tools and resources their counterparts can access. They need to know what relevant information their collaborators know, and what they expect, as well as their attitudes and goals. They need to know what criteria collaborators will use to evaluate joint outcomes, the moment-to-moment focus of their attention and action during the collaborative work, and how the view of the shared plan and the work actually accomplished evolves over time. These issues are often considered under the banner of 'awareness', which itself has been dissected into several types social awareness, action awareness, workspace awareness, situation awareness (for an excellent review, see Schmidt, 2002).

Collaborative awareness been approached in recent years from many disciplinary standpoints, indeed, so many that the need to integrate diverse and fragmented disciplinary perspectives has now emerged as a first-order research task. Mohammed and Dumville (2001) reconsidered work on shared mental models in light of research on information sharing, transactive memory, group learning and cognitive consensus. They observe that research on these various concepts has rarely cited or demonstrated knowledge of research on any of the other concepts. They argue that a broader, interdisciplinary consideration of shared knowledge concepts could enrich and expand theoretical and empirical research in shared mental models.

In this paper, we build upon Mohammed and Dumville's integrative survey, and suggest a complementary framework for understanding team effectiveness, and for designing technology to enhance team effectiveness. We draw on the concepts of activity awareness (Carroll et al., 2003a), common ground (Clark, 1996), communities of practice (Wenger et al., 2002), social capital (Coleman, 1988), and human development (Vygotsky, 1978). We illustrate our framework for understanding joint endeavor with a scenario from emergency management, and then discuss implications and future directions for system design and for empirical methods. Although issues of team formation, group and member maintenance, and group metamorphosis are important elements of teamwork (Arrow et al., 2000; McGrath, 1984), these topics are beyond the scope of this paper.

2. Shared mental models as knowledge in common

The theoretical concept of shared mental models was developed as a direct extension of the earlier concept of individual mental model (Carroll and Olson, 1988; Gentner and Stevens, 1983; Rouse et al., 1992). The key idea is to descriptively isolate task-relevant knowledge shared by all team members-knowledge about task relevant objects, knowledge of how to carry out domain procedures, knowledge about domain goals and constraints.

The heavy emphasis of shared mental models on knowledge common to all members is simplistic. Collaborators are rarely just interchangeable parts; more typically, people play specialized roles or attain distinct knowledge in the course of joint endeavors. Indeed, the major workflow rationale for collaboration in general and divisions of labor in particular is that the distribution of knowledge and skill across a team typically is not uniform. Moreover, the benefit to individuals engaging in collaborative work is greatly enhanced

when partners have complementary knowledge and skills, since this increases the possibility for personal development through the collaboration. Finally, as Mohammed and Dumville (2001) point out in their review of the literature on information sharing, groups frequently perseverate on knowledge common to all members, and fail to consider and pool their diverse knowledge. Thus, knowledge in common can be a risk as well as a resource for team performance.

Shared mental model descriptions tend to be psychologically and socially static. They are theorized as structures to which information can added and verified, but not refactored or transformed in the sense of developmental theory (Piaget and Inhelder, 1969; Sinnott, 1993; Vygotsky, 1978). Research has not focused on antecedent states to having a shared mental model, or on possible stage trajectories in the development of shared mental models. Similarly, the research has not considered the impacts of group discussion or other social information exchange on mental model formation and development, even though such processes must in some degree be constitutive of shared mental models. It is important to better understand how collaborators identify knowledge in common, how they use knowledge in common to coordinate activities that also involve complementary knowledge, and how shared mental models develop through the course of collaborative work activity.

Shared mental models embrace a strongly mentalistic epistemology, that is, they focus on describing representations imputed to the mind. The knowledge at issue in a shared mental model analysis is explicitly and exhaustively described in the mental model. Other theoretical frameworks, such as distributed cognition and activity theory, consider the business of cognition to be mental structures as well as the social, cultural, and physical contexts within which they are embedded (Bertelsen and Bodker, 2003; Perry, 2003). Thus, in activity theory personal states of knowledge, motives, and consciousness are understood as caused in part by an actor's social and material context (Nardi, 1996, especially chapter 4).

Mohammed and Dumville (2001) discuss the interesting example of 'transactive memory', a theory that describes how the individual memories of group members are supplemented by shared knowledge of who knows what. Thus, in a work group, all members might learn the basic functions of a machine used by all, but might divide up responsibility for advanced functions so that each member of the staff masters a unique non-overlapping set (Rosson and Carroll, in press). In such a work group, using one of the advanced functions would require knowing who in the group has mastered that function, knowing enough about the advanced functionality (that is, at a less-than-mastery level) to be able to be coached by that member, having confidence in the local expert, and seeking out that person for one-on-one coaching. Shared mental models are inadequate for describing such cases.

Mohammed and Dumville observe that the knowledge-in-common view of shared mental models may be appropriate for only certain task domains and types of groups. For example, in teams with persistent roles, the distinction between knowledge in common and complementary knowledge takes on a different significance. A high level of overlapping knowledge in such teams might be inefficient, or even counterproductive if it encouraged members to second-guess the decisions and performance of their counterparts

in other roles. In groups and task domains where performance involves judgment and evaluation, consensus in value and beliefs may be more important than shared knowledge.

In sum, while shared mental models are defined to comprise at least a partial answer to the question of what collaborators need to share in order to work together effectively, much is missing in the simple notion of knowledge in common. Following Mohammed and Dumville (2001), we conclude that shared mental models should be elaborated to include how knowledge and beliefs in common are identified and used to coordinate group activities (e.g. through consensus formation), how complementary knowledge and skills are deployed and developed in roles and other divisions of labor in team performance, and how social, cultural and physical concepts and entities are incorporated to support team cognition and performance.

3. Teamwork as activity

Mohammed and Dumville's (2001) integrative review and critique of shared mental models enhances the theoretical and empirical foundation of shared mental models, but their conclusions are based largely upon laboratory phenomena. These researchers acknowledge that 'much of the work on groups has been conducted in laboratories with undergraduate students doing tasks (e.g. murder mystery; making origami birds) that are far removed from the complex, multidimensional context typical of 'real world' military, medical, or process control teams' (pp. 101).

A more realistic teamwork setting—military training tasks—has been discussed by Mathieu et al. (2000). But general military training involves highly structured tasks with clearly delineated roles and specified communication and coordination protocols all defined a priori. Well-structured tasks can still be complex, of course, and are indeed qualitatively different from laboratory tasks that can be completed in 40 min by random groups of undergraduates. Routine military skills are of enormous practical importance. However, it is important to realize that models of such tasks are quite limited with respect to the behavior and experience of teams coping with ill-structured problems in real-world contexts of high uncertainty. Consider for example, the complexity of team performance in emergency response teams, software design projects, tactical battle management teams, managers and employees in distributed business organizations, or even a community group initiating and managing their own technology infrastructure and development.

In these two bodies of work—laboratory tasks and well-structured training tasks—the complexity, dynamics, and lack of a priori constraints of group activity have been severely underestimated. This in turn has entrained analyses founded on knowledge constructs: Mathieu et al. (2000) discuss the general concept of shared knowledge; Mohammed and Dumville (2001) offer an elaborated view that includes beliefs in common, complementary knowledge, and social, cultural and physical concepts. But the emphasis throughout is on static constructs. We propose an approach that shifts the focus from shared concepts to shared activity.

As the range and complexity of collaborative work expands, it is critical to account for the behavior of groups constituted to address open-ended work activities. Many 'normal' shared tasks cannot be precisely specified in advance; tasks and roles cannot be rigidly

structured a priori; communication and coordination protocols must be flexible in order for teams to succeed (see discussions of ill-structured problem solving and design in Carroll, 2000, chapters 2–3). As a simple example, consider a town zoning committee that is 'designing the layout of a town park'. Such an endeavor requires intricate collaboration, not just pooled effort; it involves a variety of technical knowledge and skill (urban planning, landscape architecture, civil engineering, environmental science) and a variety of stakeholder perspectives (state or federal environmental agencies, local government, neighborhood groups of affected residents, community groups with particular interests and responsibilities). The design goal is not achieved in a few minutes, or even a few hours. It is directed at a complex outcome and requires a substantial problem solving process. It incorporates goal decomposition and refactoring, nonlinear development of partially-ordered plan fragments, interleaving of planning, acting, and evaluation, and opportunistic plan revision. It involves coordinating and carrying out different types of task components, such as assigning roles, making decisions, negotiating, prioritizing, and so forth. These components must be understood and pursued in the context of the overall purpose of a shared activity, the goals and requirements for completing it, and how individual tasks fit into the group's overall plan.

The teams that undertake such work, and the individuals that comprise these teams, are often quite unlike randomly-selected college students performing contrived exercises; they are also quite unlike groups of military trainees being drilled in routine operations. Membership in such teams is constitutive of one's identity as a person, professional relationships and values, family and community roles, etc. Consequently, team members have a high degree of intrinsic commitment to group processes and outcomes; they are not affiliating and collaborating merely for course credit or because they were ordered to do so by a superior.

We use the term 'activity' to refer to substantial and coherent collective endeavors directed at meaningful objectives, which we sharply distinguish from laboratory exercises and training tasks. The term draws upon the theoretical and empirical foundations of Activity Theory (Bertelsen and Bodker, 2003; Bødker, 1991; Nardi, 1996). Activity Theory describes human behavior and experience as organized and contextualized in multiple hierarchies running from motor gestures and elementary perceptions to cultural mores and attributions. Conceiving of human endeavor in this rich framework helps to avoid the oversimplification entrained by considering laboratory exercises and training tasks as models of complex human activity in the real world.

4. Activity awareness in team performance

When groups engage in collaborative activity—in the sense of Activity Theory—members must share a wide variety of information. This points to the relevance of shared mental models and the knowledge-in-common thesis offered by Mohammed and Dumville (2001) in their survey of shared mental models research. These researchers have elaborated this general thesis: knowledge in common is used to coordinate how complementary knowledge and skills are deployed and developed in roles and other divisions of labor in team performance; knowledge in common is used to negotiate beliefs

in common in order to attain group consensus; knowledge in common is used to collectively leverage social, cultural and physical concepts and entities to support team cognition and performance. Like Mohammed and Dumville, we are investigating an integrative framework for how collaborators share and coordinate their efforts to work together effectively. To emphasize our focus on teamwork as activity, we refer to the sharing requirement as activity awareness (Carroll et al., 2003a).

With an activity perspective on teamwork, the focus shifts from relatively static and stable constructs such as shared knowledge to the more dynamic and constructive views offered by theories of interpersonal interaction and development. Our framework for understanding activity awareness integrates several such theory bases, identifying four facets of sharing and coordination that promote effective collaborative activity—common ground, community of practice, social capital, and human development. These facets can be seen as sub-processes supporting the general need for activity awareness; by analyzing the character, inter-relationships, and implications of each sub-process, we hope to better envision tools and methods for studying and enhancing shared activity.

The four facets summarized in Table 1 have a rough ordering, in the sense that interpersonal communication is a primitive function in any team, whereas the development and application of social capital or human development happens over time with effective group functioning. Common ground is shared knowledge and beliefs, mutually identified and agreed upon by members through a rich variety of linguistic signaling (Clark, 1996). Common ground allows members to communicate and cooperate easily. This construct is similar to the knowledge in common emphasized in the notion of shared mental models plus beliefs in common, as discussed by Mohammed and Dumville (2001), But common ground is not simply a static assumption about shared knowledge and beliefs; it is an ongoing communication protocol through which collaborators test and signal shared knowledge and beliefs.

A second facet of activity awareness is communities of practice (Wenger et al., 2002). Groups whose success depends on effective activity typically share goals, values, and practices. This shared praxis is frequently tacit: it is not construed of, and cannot be stated explicitly, as propositions. Rather, it is conveyed among members by mutual enactment in activity contexts. Through participating together in work activity—planning and coordinating effort, giving and receiving advice, and evaluating joint outcomes (including diagnosing breakdowns), members learn, share, and refine core goals, values, and practices. Like common ground, the shared praxis of a community of practice is related to

Table 1
Four facets of activity awareness

Facet	Description
Common ground	A communication protocol for testing and signaling shared knowledge and beliefs
Communities of practice	The tacit understanding of community-specific behaviors shared through enactment
Social capital	The creation of persistent social goods through networks of mutually beneficial or satisfying interaction
Human development	Innovative behavior or decisions entrained by open-ended, complex problem solving, and evolving skills of both members and teams

the knowledge-in-common notion of shared mental models, but the shared knowledge is deeper, more subtle, and highly community-specific. Furthermore the sharing is typically accomplished through a tacit process of enactment.

A third facet of activity awareness is social capital (Coleman, 1988). Teams that perform complex work tasks under high uncertainty inevitably experience stress. Particularly when membership is not coerced, powerful social mechanisms must support sustained participation through potentially effortful or divisive episodes. Social capital is formed when mutually satisfying interactions among members creates a persistent social good; this persistent social resource provides the social glue necessary for surviving potentially divisive moments, buffering stress and dissention, and encouraging members to continue cooperating. Social capital refers to the accumulation of the social benefits of past social interactions in order to mitigate conflict and other risks in future interactions.

The fourth facet of activity awareness is human development, clearly the most general of the contributing sub-processes. Of course, no one would expect participation in a laboratory exercise or routine training task to change people very profoundly. Participants might learn something, but we would expect the learning to be more a matter of accretion than restructuring (Rumelhart and Norman, 1978). In contrast, when people plan, negotiate and coordinate with others in open-ended, real-world endeavors over significant spans of time, solving problems that are ill-defined and consequential in circumstances of high uncertainty, they quite typically are changed.

We do not claim that the processes of common ground, communities of practice, social capital, and human development are absent from traditional laboratory exercises or routine training tasks. It is likely that team members engage these processes without conscious intention, but the limited scope of relatively anonymous, brief, or well-structured tasks reduces their impact. However, these more extended mechanisms are essential for complex human activity in the real world. Like activity in general, activity awareness is best understood as a dynamic process in which a variety of information is constantly shared, tested, and updated to guide group behavior.

5. The dynamics of activity awareness

Describing four facets of activity awareness is a starting point for better understanding how to analyze and support coordinated team performance. Indeed, one objective of our current work is to articulate a theory of activity awareness that is founded on these four facets. To this end, Activity Theory (Engestrom, 1990; Kuuti, 1991) has offered a useful framework for viewing these four facets as interacting sub-processes in the activity of a group. Activity Theory construes activity as fundamentally a collective phenomenon. Activity is pursued by individual or groups within a community, working toward shared objectives or motives, and recruiting and transforming the material environment, including shared tools, data, social and cultural structures, and work practices. Current activity is continuous with the community's prior history and future planning; it is not constituted through stand-alone tasks.

Activity Theory raises several important issues with respect to collective activity. Interaction among community members is a central ongoing process that is socially

mediated by members' shared understanding of roles, community values, and a division of labor; their activities are also mediated by available tools, task resources, and other artifacts. In our analysis these mediating effects are analyzed through the sub-processes of common ground and communities of practice, where the former provides a general context for human communication and the latter a more subtle and domain-specific praxis. Activity Theory also emphasizes the importance of shared goals and motivation, including the dynamic processes of recognizing and addressing breakdowns (e.g. social conflicts, tool faults, or resource limitations) in an activity. In our analyses the motivational and evolutionary aspects of the activity are analyzed as social capital construction and human development. Most importantly, Activity Theory emphasizes the dynamic and self-correcting nature of collective activity.

Fig. 1 visualizes how the four constructs might contribute to activity awareness in teamwork. A team's basic communication processes are founded on common ground, analyzed by Clark (1996) as a pervasive process of seeking and providing evidence of shared understanding in language use. These acts are woven into the fabric of interaction, enacted repeatedly as we behave in the world. Consider a simple exchange:

A Recognizes that B arrives without the hat he usually wears.
B 'Brr, it's cold'

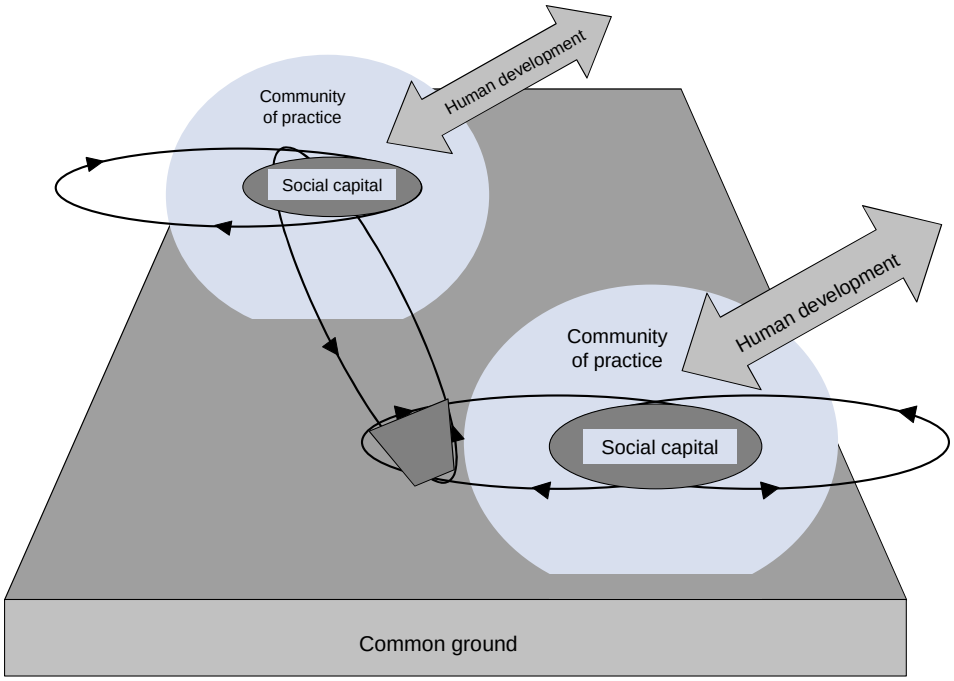

Fig. 1. A team's activity awareness is supported by four types of sharing: the general process of common ground formation and maintenance; the domain-specific evolution of communities; the action-oriented construction and exchange of social capital; and the motivation and recognition of human development.

A 'You lose most body heat through your …'
B (interrupting) 'I know; my gaffe'

This is very efficient interaction. A's remark acknowledges B's opening, but also points both to a shared understanding of a standard behavior pattern and the current exception to it. B's interruption demonstrates comprehension and acceptance, and enables rapid and unambiguous convergence. As Clark shows, such patterns of grounding allow people to reach the mutual belief that they understand one another well enough to carry out the collaborative activity at hand with the least possible effort. Common ground provides a casual, low-cost, testing process to vet potential collaborators. From the standpoint of collaborative work, common ground testing verifies and elaborates basic prerequisites for successful joint activity. Common ground protocols are important because they emphasize how people can go about recognizing mutual belief through patterned linguistic and meta-linguistic activity, as opposed to merely assuming they can do this in virtue of some body of knowledge in common.

With common ground as a base, teams construct and act within a community of practice. Members of communities of practice share more than language, they share praxis-domain-specific ways of thinking, organizing roles, doing work. Communities of practice develop a sense of joint enterprise and identity around a particular area of knowledge and activity. These practices emerge over time from the sustained pursuit of a shared activity (Smith, 2003), as people address recurring sets of problems together (Wenger, 1998). The focus in this case is on action and applied knowledge rather than the knowledge itself.

Shared praxis involves associations among people, not merely chunks of knowledge held in common. Through shared activity, members of a community of practice come to similarly categorize problematic situations, and streamline problem solving diagnosis and response. This personal investment in the goals, values and practices of the community, and the fact that the praxis is only shared through making such an investment in collective activity, entails a significant personal identification. Membership in a community of practice often becomes an important part of the self.

Where common ground provides a relatively thin and universal foundation for collaboration, communities of practice provide a rich and more narrowly-scoped foundation. However, carrying out complex and open-ended work activities in the real world entail and require communities of practice. Common ground is not enough for such work. Indeed, this is one way of reconstructing the difference between the work activity we are concerned with and the simpler laboratory tasks and training exercises that have concerned investigators of shared mental models. The latter do not involve communities of practice.

Team members understand their collaborators' actions within a community as motivated by shared values and goals; people's willingness to accept and act according to these goals and values constructs social capital. Social capital is a framework for thinking about active connections among people emerging over time in social life: trust, mutual understanding, shared values and behaviors that bind the members of communities and make cooperative action possible (Cohen and Prusak, 2001). The focus of social capital is neither on knowledge nor on action, but on the co-construction of norms and

values of reciprocity that motivate behaviors among the members of a group, a community, or a society.

Social capital can be generalized via reciprocity norms, such that social goods are accumulated and dispersed social goods across larger social structures-an organization that incorporates a given group, or even society itself (Putnam, 2000). People infer from specific instances of social capital formation that they experience or observe that other instances are occurring at other times and places. Consequently, successful team activities can have a generalized benefit for all of the embedding social structures within which that team exists. This is quite important in real world group behavior. Consider for example, an emergency management team organizing for a complex and chaotic work activity like managing a large-scale environmental clean-up and evacuation, assembled from various regional fire departments, state police, national guard, federal agencies, and so on. The team cannot take the time to identify members' knowledge in common or go through consensus exercises. Rather, they transparently build common ground in everything they say and do, enact shared goals, values and practices to affirm their identity in a community of practice, and leverage existing social capital to create a framework of mutual trust.

This network of immediate and generalized social capital formation anticipates and softens the consequences of inevitable differences of opinion, conflicts, and even outright misbehavior. In this respect it acts as an exception handling mechanism, preserving the well-being and the smooth functioning of groups, despite occasional problems. Social capital mechanisms are critical to the development and maintenance of social institutions, but they require authentic activity contexts. Thus, like communities of practice, they would not be relevant or observable in laboratory exercises or formal training.

Through their participation in activities, team members and subgroups regularly experience opportunities for learning and personal growth. The myriad contingencies of collaborative activity entrain frequent improvisation with respect to strategies. The complexities of real world activity often require significantly innovative solution approaches. In a community of practice, members have the opportunity to see a variety of performance levels and styles, and are able to receive in situ guidance and other support from their counterparts, creating a 'zone of proximal development' (Vygotsky, 1978) in which members are helped to perform beyond their personal capacities, and through that assisted activity, acquire concepts and skills that raise the level of their own subsequent unassisted activity.

While social capital buffers the divisive affect of conflict, human development capitalizes on the learning opportunities provided by conflicts. Both are essential. Conflict can tear groups apart and preclude further collaboration. But conflict is also the most efficient way to precipitate novel problem analysis, the emergence of new domain concepts and personal roles, and new group missions. Without some mechanism for growth, individuals and groups would rapidly attain stable states of mediocre performance and eventual entropic decline.

The concept of human development draws on socio-cultural psychology (Vygotsky, 1978; Leontiev, 1978, 1981; Luria, 1976; Engestrom, 1987). In this view, history, culture and concrete social relationships provide identity to individuals and catalyze their development through a dialectic in which practical social activity (praxis) shapes thought, while at the same time thought regulates activity. With respect to the other three facets,

human development is more general because it may pertain to phenomena at very different levels of analysis from individual to organization. We adopt this theory of human development to characterize long-term group collaboration and explain the relation between individual and group development in the course of group activity.

Our conception of group work is activity-oriented—praxis-based, relative, and dialectic. It contrasts with the conceptions we discussed earlier that are knowledge-oriented—abstract, absolute, and static. This activity-oriented perspective helps to reconcile some of the most basic paradoxes of the knowledge-based perspective. For example, real work groups regularly experience conflict, communication breakdowns, and failures in coordination, yet often these are not merely pathologies of inadequate shared knowledge, rather these same divergences actually foster dialogue and development within the group, and promote change and evolution at both individual and group levels (Sinnott, 1993).

6. A scenario of activity awareness

As a concrete example of the dynamic construction and maintenance of activity awareness—via the interacting threads of common ground, communities of practice, social capital, and human development-we explore a hypothetical emergency management scenario in which forest fighters battle a blaze distributed over a canyon ridge. The scenario develops over time and we use each segment to highlight one of the four contributory sub-processes. In addition to exemplifying the four facets, the narrative serves as a 'problem scenario', a description of current practices that sets up opportunities and challenges addressed in our discussion of implications for design and evaluation (Rosson and Carroll, 2002).

> Joe and Faraz were the first firefighters to arrive at the new outbreak on the north ridge of the canyon. Joe saw from Faraz' vest that he's from the Sheyanne fire company and wondered how much experience he's had with canyon fires. As they walked toward the hottest part of the new blaze, Faraz heard Joe's walkie talkie crackle and guessed it was central control checking in. Faraz listened to the exchange while he surveyed the damage. From the sound of the fire, trucks, yelling, and other commotion, he revised his guess, thinking it must be colleagues of Joe who are at the main blaze several miles from here; he shouted a question over the background noise to confirm the location of Settler's Creek. Joe's contact acknowledged that it cuts between the two blazes to their northwest. Joe glances at Faraz and sees that he also knows what to do: they must push the blaze back toward the creek.

The exchange between Joe and Faraz illustrates the unconscious nature of common ground. Partners in a situation look around, gather information about the situation, make inferences, test their inferences, draw further inferences from the results, seemingly with little or no effort.

This episode is brief, perhaps just a couple minutes long. But the two firefighters begin building common ground as soon as they arrive, making inferences based on one another's

Table 2
Examples of processes contributing to activity awareness

Facet	Example from firefighting scenario
Common ground	Joe sees Faraz' vest and knows where he's from; Joe knows that Faraz can hear his exchange with control center; Faraz signals knowledge of terrain by confirming creek location
Communities of practice	Heading off in the same direction to start work on the fire; recognizing the import of the animal track; ceding control to the meteorologist
Social capital	Recognizing that other crew members are fighting the same fire in different locations; conveying willingness to work an extra shift
Human development	Remembering a unique piece of personal history; Faraz showing the confidence to redirect the group; a commander who listens, responds

clothing and on the questions they raise or ask (Table 2). Joe to guesses at an institutional association, activating further inferences about what he might and might not expect from Faraz during their work together—will a 'city' firefighter know what to do in this context? Faraz infers what the interruption of the walkie talkie is likely to be about, then revises his inference based on the additional details concerning noise at the other end. By doing this, he is able to join the conversation in an appropriate fashion, raising his voice to the right level, and asking a meaningful questions. Faraz' demonstration to Joe that he is aware of key geographical details (a creek) and the location of the main blaze both reassures and continues to add to the common ground, as does their shared inference about what to do next.

Many cues contribute to communication partners' common ground-body language (and attire), situation features, knowledge about the world (e.g. national or local culture), and most explicitly the conversations that take place. If Faraz had arrived with no identifying information, Joe may well have asked him about his unit, and Faraz would have understood that his answers were doing more than satisfying another's curiosity. The nods, 'uh huhs', raised eyebrows, and so on that conversation partners take for granted function as a rich set of checks and balances that constantly test and confirm the process of common ground formation. As Joe and Faraz encounter new events or receive orders, they understand what is happening and negotiate what to do next. As their common ground grows, so does their awareness of each other's history, perspectives, values, and so on, facilitating their ability to plan and work together toward a shared goal.

> Without further comment, Joe and Faraz jogged off to the eastern side of the blaze, because they both know that the river is north and west and thus that their first point of attack must be from the east. Silently they surveyed the landscape. Joe pointed to an animal track; this would give them a critical head start in clearing an open area in the path of the fire while they waited for reinforcements. They went to work with shovel and ax. As more firefighters arrived, they joined the effort, working frantically to clear a five-foot swath. But after 20 min of work, the wind changed and the firefighters became confused as flames rebounded in previously clear areas. As they pulled back to re-group, a meteorologist at the control center sent word that they were in the midst of a freak pressure inversion and that this had led to temporary

> wind gusts. None of the firefighters understood what was happening, but they followed his suggestion to angle their clear-path directly toward the river.

In this exchange, the firefighters begin their task, which immediately leverages their shared membership in a community of practice. By carrying out expected behaviors, negotiating implicitly and explicitly about steps to take, they are enacting a praxis. Activity awareness is enhanced in the presence of shared praxis because the community's conventions, best practices, values, and so on become active and available for guiding action.

Having established common ground, Faraz and Joe quickly become productive co-workers. They share priorities and know without even having a discussion what to do to head off the fire from the east. Although they do not belong to the same firefighting crew, they are able to recruit and build from their experience with the subsuming community of practice (firefighters). In their profession, identifying and leveraging features of the landscape like a deer track are basic skills. But firefighters are not meteorologists. So when an unexpected weather condition emerges, the control of the plan shifts tacitly from the local crew to an expert from a distinct but supporting community of practice.

The fact that the firefighters are willing to cede control to the meteorologist shows a higher level of shared understanding—when and how interdependent communities of practice should coordinate their efforts. The firefighters' understanding of their own expertise includes an understanding of its boundaries. In the face of an unexpected weather event, the team could have responded with their own intuitions, but in this situation an informal response is superceded by the implicit agreement that meteorologists have the final say about weather abnormalities. The firefighters do not need explicit rationale from the other expert; they recognize him as a member of a complementary expert community. If there were ever any question about who 'owns' such a problem, it would be the role of management (i.e. central control) to ensure such cooperation. Most of this coordination and role acceptance happens implicitly but is crucial to maintaining an awareness of the shared goals and plans that the many individuals are pursuing in parallel.

> The incident with the wind shift put the firefighters more than an hour behind, and the blaze was in danger of getting out of control. As the first on the scene, Joe and Faraz had been at it for almost ten hours and were exhausted, in need of a break. A new team radioed in: they were on their way but delayed by traffic stoppages due to even more blazes starting up near the freeway. A helicopter was sent out to collect and transport them but it will be at least an hour before they can make it to this area. When the control center checked in to dismiss Joe, he looked at Faraz, who looked over at the raging fire and almost imperceptibly shook his head. Joe told control that he and Faraz will stay until the new team arrives or the fire is under control. As he attacked the flames with renewed intensity Faraz remembered a fire last year when he broke an arm and had to leave unexpectedly. Not this time.

In this episode we see the interplay between activity awareness and social capital. The awareness of others who are contributing their efforts is promoted by the awareness that comes from a shared community of practice—this is what happens at complex fire scenes. The distributed awareness also contributes to a new facet of their activity awareness,

a trust that emanates from the consequences of having all of these experts doing their job, and an intimacy that comes from standing side by side (virtually or not) in the face of an immediate danger.

Joe and Faraz did not know each other prior to arriving at the scene. But their work toward a shared goal creates an immediate bond; their general experience as firefighters reinforces the social capital built during their brief collaborative activity. They trust one another and the other firefighting teams and emergency personnel; each individual will do everything he or she can to get the fire under control. When other concerns intrude—the new team's delay in traffic, or on another occasion an injury—they know that other team members will pick up the slack. The firefighters' willingness to put in extra hours is partly attributable to their membership in a community of practice (emergency personnel are commonly called upon to accept personal risks and physical hardships) and partly to the creation of social capital and feelings of mutual reciprocity (Joe and Faraz are willing to go the extra mile because others will do the same for them when a need arises).

Many experiences related to social capital are not observable, perhaps not even conscious. For instance in a firefighting situation it is crucial that each team member trust that others are doing the 'right thing;' that they are watching each others' backs in a sense so as to quickly warn or intervene if a dangerous situation arises. With respect to the fire at large, each member of a co-present team also trusts that a range of other stakeholders are engaged and operating effectively—the control center, men and women working at other locations, evacuation crews, and so on. All team members know that tens or hundreds of other experts are shoveling, chopping, and spraying flames throughout the emergency area; this knowledge is comforting at a socio-emotional level, and it enriches the social capital underpinning their efforts. It also contributes to the team's awareness that as a whole they are coordinating their efforts, working together to complete a large and complex task.

> Twelve hours into the fire fight, a shout arose as a dust storm was sighted. They would be engulfed in less than 15 min. Frantic discussion ensued as everyone had different views on how best to prepare for onslaught of wind and dust. Joe thought that flattening the fire line might minimize damage from the fierce and unpredictable winds. The ranking on-site commander argued for a random zigzag contour. The chief at central control just listened without comment, with the opinion that there was no certain answer and realizing that the best he could hope was that the crew would attempt different strategies, adjust in real time, and that in the end this would be a huge learning experience. He directed his assistant to check in with other teams out fighting the fire to see if anyone had ever encountered this but no replies came in as he tracked the dust storm's progress on his radar.
>
> Back at the site, Faraz stared at the dust storm and suddenly recalled a house fire 10 years ago in Shiloh just as a tornado moved through on the other side of town. Afterward his team had speculated that the odd V-shape of fire had intercepted the brunt of the whipping winds, minimizing damage elsewhere. He grabbed the on-site commander and told him quietly and urgently what had happened. The commander nodded and Faraz rushed in to lead a re-shaping effort.

In complex teamwork, problems and exceptions will always arise, just as they did at this fire scene. All of the factors contributing to the team's activity awareness are recruited in their efforts to deal with the problem; the shared problem solving efforts continually feed back into activity awareness, as the shared experience shifts from panic and confusion to a sense of direction and temporary control.

All the firefighters understand that a dust storm will fan the fire in unpredictable ways. The combination of a dust storm and a forest fire is very unusual; not even the senior team members at central control have specific experience to draw from. Because the chief is not in the field he cannot fully analyze the situation, and even if he could he may not have relevant experience himself. Fortunately, the group has been working as a team, building social capital and trust. Faraz is willing to take a risk, to make a proposal grounded in a somewhat bizarre aspect of his own personal experience. His personal memory and conviction is important in swaying the on-site commander's view. Just as Faraz trusts the group enough to make his argument, his odd but clearly related experience gives the group confidence in his temporary leadership. In emergency response communities, personal initiative and insights are expected and accepted because decisive action cannot wait; part of this community's trust in Faraz is that he will not push his ideas unless he knows what he is talking about. As Faraz takes control, all participants update their activity awareness to reflect their appreciation of his specific expertise and its implications for their ongoing efforts.

The acceptance of Faraz's recommendation has an immediate effect on group dynamics as others look to him for guidance. But it will also have more prolonged effects. Each involved person will remember Faraz's willingness and success in taking control; although the chief may have never encountered Faraz before he will never forget this episode. The fact that the group was arguing and frantic up to the point of Faraz's suggestion will help the group also to grow as a group because they have shared an episode of intense conflict and resolution. The chief will have increased confidence that this team can meet new challenges with success. In this sense activity awareness has both immediate and persistent effects on the team's effectiveness at working together toward shared goals. Faraz will also see himself differently: whereas before he possessed a specific piece of unusual history, he now sees that experience as a valuable pattern or lesson that he might apply or share in future firefighting situations. The experience will also increase his confidence in his own decision-making and leadership skills.

Our discussion of this hypothetical problem scenario serves two purposes. Its situational details and the personal experiences of Joe, Faraz, and the rest of the team illustrate our view of activity awareness, namely that it is comprised of and maintained by the interacting processes of common ground, communities of practice, social capital, and human development. At the same time the scenario points to the challenges and the opportunities for supporting activity awareness in complex task domains like emergency management. By exploring the situational and social features that evoke or help to maintain common ground, social capital, and so on, we can begin to articulate how to promote activity awareness through design, and how to evaluate systems and interactions with respect to activity awareness.

7. Implications: designing for activity awareness

Support for awareness is one of the most active areas of design research for computer-supported collaboration. One general design concern is that awareness support must rely chiefly on incidental information. From any actor's point of view, being aware is not a primary goal, but is presupposed and prerequisite to all other goals. Awareness falls into the category of 'articulation work' that is required for coordination but not directed at a goal itself (Schmidt and Bannon, 1992). Taking the conscious time and effort to 'become aware' takes time and effort away from the task at hand, and this can be particularly damaging in a complex real time task like emergency management. Thus, the ideal is to support activity awareness with no extra attention and effort.

A large body of design work has been aimed at better establishing and maintaining common ground among collaborators. For example, several projects have explored support for social awareness, that is, conveying to collaborators who is present in a shared space. Early collaborative environments like MUDs (multi-user domains) provided textual listings of which users were online together (Haynes and Holmevik, 1998.). More recent work on video tunnels and media spaces depicts distributed collaborators in more vivid detail (Olson and Bly, 1991). These awareness displays promote common ground in that collaborators know (and know that others know) who is in the potential audience for communication, who has recently joined or left, who is active or distracted, and so on.

Collaborators often need to know more than who is present to coordinate their activities. A finer level of support has been discussed as workspace awareness or action awareness. A common awareness technique of this sort is a radar view: As two or more persons work together in a single information space, each is provided with a miniature view of the whole space, indicating where each collaborator is currently working—for example, where each cursor is pointing, what subview of the information space is currently displayed for each person, and so on (Gutwin and Greenberg, 1996; Smith, 1992). With a radar view, one is able to keep track of who is editing what portions of shared data, and thus can make sense of a collaborator's references to features in the data, such as 'the river'.

From the standpoint of the interacting processes visualized in Fig. 1, social and workspace awareness supports team activity at a relatively low level. User lists, media spaces, and radar views all help to establish and maintain common ground. One way to develop and apply our broader perspective of activity awareness is to consider the broader implications for design suggested by the four constructs of activity awareness we have discussed. Our ability to couch substantive design hypotheses, and to identify specific designs embodying these hypotheses, is a way to test and refine our activity awareness framework (see also Carroll et al., 2003a). Table 3 summarizes a few interesting or feasible design implications, with special focus on the problems and opportunities raised by the firefighting scenario.

As the techniques for supporting social, workspace and action awareness suggest, common ground can be enhanced by designs that make shared information public: to the extent that all collaborators see or hear something, ipso facto it becomes part of their common ground. Fire fighters do not wear special equipment for social signaling, but a consequence of what they wear is that the mere sight of a colleague, as in the scenario

Table 3
Design goals and activity awareness techniques

Facet	Implied design goal	Example awareness techniques
Common ground	Public availability of shared information	Radar view or workspace overview, media spaces, virtual representations of physical environment
Communities of practice	Integration of team members' behavior or decisions into best practices or patterns	Community annotations, social networks, community discussions, recommender systems
Social capital	Aggregation of individual contributions into collective achievement	Activity log visualizations; resource usage indicators; recognition for selfless or altruistic behaviors
Human development	Contrast of individual capabilities and roles played through time	Personal profiles (including historical views), annotated workflow, first-person stories, critical episodes

example, is a signaling resource for common ground. Discovering that a colleague knows the same terrain, or the same type of terrain, or has worked the same type of fire before are further sources of common ground.

Most research on social or workspace awareness has focused on replacing information lost when collaborators are not co-located (Dourish and Bellotti, 1992; Gutwin and Greenberg, 1996, 1998). However, awareness techniques can also enhance common ground for group members who are collaborating in the same location. For instance in a middle school classroom setting, we have explored students' use of a project timeline that records versions of project components as the project evolves (Ganoe et al., 2003). The naming of the components, the different versions displayed, their relative position on the timeline—all of this public information contributes to and reinforces common ground as group members identify and negotiate steps in their activity.

In some cases information technology may be used to supplement the public information available through co-location (cf. the call by Hollan and Stornetta (1992) for 'Beyond being there'). Suppose for example, that the firefighters view an interactive map of the blaze area on a mobile device. The map might portray terrain features such as hills and streams that are relevant to the task, adding to the common ground (e.g. for crew members not already familiar with the region). The display might also be automatically augmented by global positioning system (GPS) location information to show field of view. Thus, when a firefighter mentions a house that may be in danger to the north, others in the field and at the control center could quickly distinguish the referenced house from nearby buildings. In this example, the public information is used to enhance or reinforce awareness that may be only weakly or partially available to a physically co-located colleague (e.g. regarding buildings, terrain, weather, etc.).

Communities of practice are ways of thinking and doing; they integrate information in current situations with pre-existing concepts and practices. This content is often tacit, but it is shared and mutually recognized throughout the community. Thus, communities of practice are associated with the integration of specific data into best practices or patterns. In the firefighter scenario, the clear-path, recognizing how dry the forest is or the current

wind direction, and plans like clearing toward the creek, are community-specific reactions and patterns that have emerged and been internalized across time.

Working from the general notion of best practices, we can again consider how information technology might enhance appreciation and reliance on communities of practice. Assuming that the forest fighters have mobile devices equipped with maps in the forest fire scenario, we can envision system-provided annotations that reinforce the tacit knowledge of the community, for instance highlighting task-specific features like a creek or already-cleared paths. If the devices are networked, weather tracking information can also be present, enabling the crew to anticipate and respond more quickly to the meteorologist's suggested plan changes.

Much of a community's praxis emerges and is reinforced across time, although its impacts are then felt in real time settings like emergency response or decision-making. Thus another view of integration is the analysis of team members' or other stakeholders' behavior and decisions across time. In another project studying the emergence and reuse of shared practices in an educator community, we have been exploring a variety of representations that extract and display community behavior (e.g. social networks, object history views, geographic or other physical relations; Carroll et al., 2003b). Similar techniques have been explored in the LifeLines project (Plaisant et al., 1996), a system that visualizes relationships between personal events using a timeline to support case analysis and interventions in medical and department of corrections applications. Recommender systems that track pervasive information seeking or behavior in a community might also be useful in surfacing shared behavior and norms (Resnick and Varian, 1997). A more informal approach could be to evoke, record, and share 'war stories' of important shared events or decisions (Orr, 1996).

Social capital articulates the networks of trust, understanding, and shared values that emerge in social life. Its function in activity awareness is to convey and maintenance members' awareness of other people's motivational state—their assumed willingness to act for the common good. The firefighters in the scenario do not pause to evaluate the meteorologist's advice, they just follow it. They work until their relief teams arrive, because their colleagues are depending on them, as they depend on their colleagues. Little of this behavior is explicitly stated or signaled. Social capital is cultivated through enacting social commitments and responsibilities. It is associated with the aggregation of personal contributions to the collective achievement.

In a tactical emergency like a forest fire, participants will not want, or even be able, to stop regularly and check the big picture. Nonetheless, they must maintain awareness of how individual contributions are aggregated into a collective achievement. Working still within a map display, graphical situation reports from different locations along the fire line can be integrated into an overall summary of resources and challenges. Color can be used to code current threat levels in regions of the map, or the priorities for plans of action currently being considered or pursued. More typically, and more strategically, such views of activity can be used to reallocate effort, perhaps enabling Faraz and Joe to obtain extra help because firefighters can be released from a nearby location. Such a map could be used to coordinate different functions—firefighters, search and rescue, meteorologists, and so on. They can also be used to analyze group performance after the fact for training and evaluation purposes.

Taking a longer view, accumulated records of firefighting episodes could help to build and convey social capital. During training, a new recruit may see concrete examples of crew members who choose to stay overtime or to volunteer for a challenging task; this emphasizes the presence and expectations for social goods. Observing the episode in which the local crew cedes control to the weather expert helps to convey the trust and respect that links these two communities. Noting the commander's decision to let the local crew argue about how best to proceed underscores his trust in the local team's information processing and decision-making.

Human development articulates patterns and trajectories for growth. When people collaborate they are not simply coordinating and aggregating individual performances, they are doing things that no one of them could achieve on his or her own. Through the experience of these collective achievements, each participant will become more capable in the future. This is more than mere gains in efficiency, in that participants develop the trust, confidence, and skills to assume new roles and perform new tasks, as Faraz did in the scenario example. Thus to a large extent, maintaining awareness of a team member's development is associated with recognizing changes and contrasts in the capabilities and roles of people over time. According to Klein (1998), people develop schemas of what is 'typical'; thus an experienced member of a community should easily be able to determine when someone's behavior deviates from the norm, causing it to be seen as more remarkable and possibly indicative of personal growth or some other sort of exception.

Designing awareness tools and displays that echo and reinforce human development involves making job roles and responsibilities salient not only as assignments in a current project, but as steps or phases in professional trajectories. This emphasizes the important role of history in developing and maintaining work relationships, perhaps supported through personal profiles or virtual cards that include a history as well as current responsibilities. Contemporary collaborative software systems often model team member roles within workflows based on authorization or access configurations; an activity view suggests that workflows should be dynamic and evolving (Dourish et al., 1996). In the forest fire scenario, a system that enables Faraz to 'seize' control when the decision is made to implement his plan (e.g. he controls the displays of others so that they become more tightly coupled to his behavior) would have the real time effect of emphasizing his leadership. If the software recorded this change to the default control flow, that record would highlight Faraz' personal development. More generally, eliciting critical incidents from employees as first-person stories could create a sharing culture that encourages colleagues to appreciate and leverage one another's professional growth and evolution.

8. Implications: evaluation of activity awareness

Evaluating awareness levels in computer-supported collaborative activities is difficult and relatively new as a research focus. User activity for collaborative systems is typically distributed in time and space (Neale and Carroll, 1999); some of the most important phenomena of work coordination and activity awareness develop through significant spans of time and activity (Carroll et al., 2003a). And most evaluation work is heuristically oriented-driven by methods rather than theories (Neale et al., in press). However, the four

Table 4
Implications for evaluating the four facets of activity awareness

Facet	What is measured	Research methods
Common ground	Inferences, non-verbal communication, back channel utterances, anaphora and deixis	Conversation or interaction analysis, simulated (confederate) partners, freeze technique
Communities of practice	Consensual behavior or values, resource sharing	Participant-observation, contextual inquiry, surveys, interviews, role-playing games or simulations
Social capital	Levels of trust and reciprocity, division of labor	Community surveys, trust-creation or -usage experiments, longitudinal studies of social networks
Human development	Person perception, attributions of self and other, achievement outcomes, self/collective efficacy	Case studies of conflict resolution, small group problem-solving, emergency or planning, etc.

facets of activity awareness suggest four theory-based foci for a CSCW evaluation framework (Table 4).

Several researchers have offered techniques for assessing common ground in a conversation (Watts et al., 1996; Monk et al., 1996; McCarthy et al., 1991). For example, interaction partners can provide self-reports of common ground (via questionnaires or interviews). More objective behavioral measures can also be created by analyzing video recordings, session observations, or system logs. Detailed transcripts of conversations or think-aloud tasks can also be analyzed for evidence of common ground tests or signals. If the team members do establish common ground they may verbalize fewer questions and make fewer coordination errors. Different measures can be collected and used as convergent evidence of shared meanings. For example, two firefighters working together may use a combination of brief utterances and hand signs to tell each other that they are ready to run a specific procedure together. Firefighters who incorporate the information display on a mobile device into their common ground would be expected to glance at it periodically and to make and respond to utterances that assume knowledge of its content.

Thinking more concretely about methods one might use to study activity awareness in the firefighting situation—and the role of common ground in supporting it-imagine a simulated collaboration scenario in which team members must generate a tactical solution to a problem. For example, suppose that Joe, Faraz and another colleague Phil are trainees interacting with a fire simulation who must recognize early signs of flashover and building collapse. As they work with the simulation, the trainees communicate with a remote battalion chief who coordinates operations, but who is in fact acting as a simulated partner (a confederate). Video recordings and session logs are captured to support post mortem analysis of coordination breakdowns and other critical incidents after the training exercise. These records and analyses can point to places where common ground was present (or not) and can also be as feedback and self-confrontation data for the trainees and as evaluation data for the training program.

Activity awareness can also be assessed through more intrusive awareness measures like the freeze technique, where participants' activities are interrupted to probe shared understandings at a specific point in performance of a problem scenario (Endsley, 1995). To test hypotheses in these situations, the composition of teams with respect to a priori

shared knowledge might be gathered and distributed via pre-testing. Using trained confederates as remote partners would allow experimenters to manipulate and study the process of grounding, as well as to develop and evaluate techniques for enhancing the grounding process (Vora and Helander, 1995).

In their study of communities of practice, Wenger et al. (2002) emphasize that measuring knowledge embedded in community practices is possible and useful, but costly. They suggest the gathering of stories that describe innovative community activities (e.g. using PDAs for planning operations), knowledge resources (e.g. annotated maps and shared tips for faster and safer teamwork), or performance outcomes (e.g. more effective coordination). Such stories can explain complex causal relationships among activities and incorporate tacit contextual factors that are difficult to codify or generalize. Stories can be supplemented by surveys and other quantitative techniques (Miles and Huberman, 1994) to provide an overall picture of how community activities create value by innovating, integrating, and refining practices.

As an example, consider an interview study in which members of a fire brigade offer multiple tellings of stories about new practices, such as how wireless computing and communications have been adopted and shaped by their community. Perhaps one team leader begins to use a wireless PDA to plan the intervention in collaboration with the control center while traveling to fire calls. These stories could be validated and elaborated by direct observation, possibly involving participant observers (researchers who are or become members of the community), or by scenario role-playing (members enact variants of a story and discuss issues).

Social capital can be analyzed at the societal level, where it is operationalized in terms of social variables such as norms, trust, civic engagement, and social cohesion (Coleman, 1990; Putnam, 2000), and at the individual level, where it is operationalized in term of resources such as the number of people in one's social network, and the exchanges through the network (Flap, 2002; Lin, 2001). Questionnaires are the most common measurement instrument, and have sometimes been incorporated into laboratory studies through pre-and post-questionnaires, for example, to study the rapid development and deployment of trust in distributed group collaboration (Bos et al., 2002). Longitudinal studies employing ethnographic methods are often used (Riegelsberger et al., 2003).

An empirical investigation of social capital might include profiling the social resources available to members—the size and structure of social networks, trust, cohesion, and reciprocity within and between the communities of firefighters, and associated professional communities (police, ambulance), and then tracking changes and possible consequences, such as choosing to work overtime, to expose oneself to danger, and so forth. Various qualitative and quantitative data would be integrated and analyzed to identify common themes and differences within and between teams, communities, and systems of communities.

Human development is the most general process contributing to activity awareness in team performance; it encompasses patterns of continuity and change over time in both members and their groups. These patterns are operationalized as stages and transitions in the skills and abilities of the group and its members (Truckman and Jensen, 1977; Worchel, 1994).

Human development occurs over time, so it is most appropriately assessed via longitudinal research methods. For example, one might develop a case study of an individual, the challenges and opportunities that she/he faced, the decisions and behaviors exhibited, and the impacts of these changes on team behaviors. Note though that the skills and capacities at issue are far broader than attitudes and the coordination of social networks. Specific research tactics might include focusing on modal and extreme cases to detect developmental patterns or themes (Miles and Huberman, 1994). Because development is a response to conflict or some other catalyst, these awareness issues might be more conveniently studied in situations that are inherently conflict- or stress-laden (e.g. emergency planning), or in experimental settings that have been manipulated to include conflict-resolution or rapid problem-solving tasks.

Also, as in the case of social capital, cross-sectional methods can be used to form a rough understanding of how human development contributes to activity awareness. For example, team members can be surveyed with respect to particular self-efficacies or collective efficacies (Bandura, 1997). They can interviewed and asked to describe their team members' and their own professional development in terms of stages and with respect to specific skills and capacities. These descriptions can then be correlated with observable team behavior (e.g. role assignment, performance expectations, monitoring, help offers, etc.).

9. Conclusion

Working and learning together online is becoming commonplace. But as is often the case in technology-driven innovation, this is not because anyone really knows how to do it well. Our question in this paper addresses one part of this challenge, namely, the question of what collaborators need to be aware of in order to work and learn together online effectively.

We were initially struck by Mohammed and Dumville's (2001) critique of the knowledge-in-common thesis held by shared mental models research, particularly their point that complementary knowledge and skills, roles and divisions of labor in team performance, and social, cultural and physical indexing, as in transactive memory are required for an adequate account of shared mental models.

Our analysis of ill-structured and long-term collaborative work emphasized four facets of articulation in group work: the establishment of common ground, performance in a community of practice, trust and social support through the formation of social capital, and human development. Our conjecture is that collaborators need to become and remain aware of one another in all four facets in order to work and learn together effectively.

Further investigation should be directed at systematizing relationships among the facets. For example, a refinement of the conceptualization presented here would articulate the four facets with respect to different levels of group functioning (Arrow et al., 2000; Korpela, 2001; McGrath, 1984). Human development can be conceptualized for individuals, but groups also have developmental trajectories. Common ground is often negotiated dyadicly, but the negotiations presuppose a system of conventions belonging to an encompassing group. Communities of practice can be densely interconnected but

relatively inert social networks, or they can be vague subsets in a broad network of diverse individuals. Social capital pertains both to aggregated effects of member behavior in very large units, like societies, but also to individual acts that create and consume the resources of other members. An interesting theory development project would be to implement the four facets within the Arrow et al. framework.

We focused on substantial and ill-structured work activities, which we illustrated with an example from firefighting, and which we contrasted with the relatively simple and well-structured laboratory tasks cited by Mohammed and Dumville, and the training protocols studied by the shared mental model researchers they critiqued.

Using the example of a firefighting team, we analyzed activity awareness problems that could arise and could be addressed at each in these four facets. We derived four design goals, or requirements, each associated with one facet of articulation: public display of shared information to level perceptions and expectations, integration of data into community metaphors to facilitate analysis, planning, and performance, aggregation of individual contributions into collective overviews to engage collaborators and evoke trust and commitment, and contrast of individual capabilities and roles to invite collaborators to perform beyond themselves.

Although current collaborative software environments do not support activity awareness beyond the level of common ground, we briefly described design approaches to providing such support at higher levels. We surveyed empirical methods and techniques to investigate empirical consequences of different facets of activity awareness.

Further investigation should be directed at implementing a diverse sample of these designs and assessing them in laboratory and field studies of awareness. Our studies of shared timelines and concept maps in a collaborative project environment are just a start at this (Convertino et al., in press; Ganoe et al., 2003; Humphries et al., in press).

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