Designing for Creativity in Computer-Supported Cooperative Work

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ABSTRACT

We are investigating the design of tools to support everyday scientific creativity in distributed collaboration. Based on an exegesis of theoretical and empirical literature on creativity and group dynamics, we present and justify three requirements for supporting creativity: support for divergent and convergent thinking, development of shared objectives, and reflexivity. We elaborate on these requirements by describing three implications for design to support creativity in context of computer supported cooperative work (CSCW): integrate support for individual, dyadic, and group brainstorming; leverage cognitive conflict by preserving and reflecting on minority dissent; and support flexibility in granularity of planning. We conclude by outlining a future research trajectory for designing and evaluating creativity support tools in the context of collaboratories.

Keywords: computer supported cooperative work (CSCW); distributed collaboration; everyday scientific creativity

INTRODUCTION

The social and collaborative nature of science has been emphasized by historians and philosophers of science, and sociologists interested in knowledge creation and diffusion (Crane, 1972; Thagard, 1998). To this end, history has documented numerous examples (Pycior, Slack, & Abir-Am, 1996; Watson, 1968).

A central aspect of and reason for scientific collaboration is creativity. Scientific creativity can be characterized as a process toward achieving an outcome recognized as innovative by the relevant community (Csikszentmihalyi, 1996). Creativity does not happen inside one person's head, but in the interaction between a person's thoughts and a socio-cultural context (Csikszentmihalyi, 1996).

Creativity has been a traditional focus of study in psychology. More recently, it has gained momentum as a research area in Human Computer Interaction (HCI) and Computer Supported Cooperative Work (CSCW). In context of these domains, we are interested in supporting—that is, evoking, enhancing, and sustaining—scientific creativity in distributed collaboration through socio-technical interventions. Requirements for such interventions have not been systematically investigated.

In this article, our goal is to articulate design requirements for supporting scientific creativity, drawing on diverse socio-psychological literature on creativity and group dynamics. Although our article does not present new empirical data, our integrated analysis marshals empirical findings from existing literature. We describe a working prototype to support the suggested design requirements and discuss the feasibility, effectiveness, and consequences of supporting creativity in distributed scientific collaboration with technology. We conclude by describing how our contribution fits into a broader research program for investigating creativity in CSCW.

RESEARCH SCOPE AND MOTIVATION

Creativity is critical to invention, innovation, and social progress at both the individual and societal levels (Candy & Hori, 2003; Florida, 2002, 2005; Sternberg & Lubart, 1999). Individuals are able to refine and improve their own performance, and groups, organizations, and societal institutions are able to sustain their existence and grow if and only if they can adapt and solve problems creatively in ever-changing circumstances (Feist, 1999).

The modern era of creativity research can be traced to Guilford's 1950 presidential address to the American Psychological Association (APA). Creativity in psychological and social sciences continues to be studied and written about in professional books (Boden, 2004; Sternberg, 1999) and journals (e.g., The Journal of Creative Behavior, since 1967; Creativity Research Journal, since 1988).

Since the early 1990's, computer and information science researchers have studied creativity in the context of technology. The first symposium on *Creativity and Cognition* (C&C) was held in 1993. Since then, five more C&C conferences have been held, with *ACM SIGCHI* sponsoring the conferences in 1999, 2002, 2005, and 2007. A special issue of *Communications of the ACM* was published in 2002 on *Creativity and Interface*. A special issue of *Inter-*

national Journal of Human Computer Studies on creativity was also published in 2005. In order to articulate a research agenda on creativity in HCI, the U.S. National Science Foundation (NSF) organized a summer workshop in 2005 on creativity support tools (http://www.cs.umd.edu/hcil/CST/).

Creativity is an important focus of study in HCI and CSCW (Candy, 1997; Edmonds, 1994). There are assertions that today's knowledge workers can benefit from the use of software tools to enhance their creative strategies (Candy & Hori, 2003). For example, workflow support tools in organizations can encourage creativity for articulating innovative business solutions. Studying creativity in HCI and CSCW is different than in engineering or business management domains. This is because different research questions are the focus of study. For instance, existing tools for individual and collaborative work often contain interface elements that stymie creative efforts (Burleson & Selker, 2002). HCI and CSCW specifically seek to address such questions.

In this article, we are driven by our impetus to support distributed scientists in working more creatively and thus effectively with their peers around the world through CSCW tools. We focus on scientific collaboration that involves *everyday* creativity, or "little C" creativity (Gardner, 1993), the sort that all of us evince in our daily lives—this involves everyday problem-solving and routinized scientific work. Although analyzing outstanding creative people (e.g., collaboration between Watson and his colleagues to discover the structure of DNA (Watson, 1968)) contributes toward establishing a framework for creativity (Gardner, 1993), understanding creativity in the context of everyday activities is equally important for letting people become more productive and create better work products (Fischer, 1999).

Although we are investigating how to support creativity in context of CSCW, it is important to mention how our research fits in the larger scope of e-collaboration. E-collaboration is broadly defined as collaboration using "electronic" and not just "computer" technologies among different individuals to accomplish a common task (Kock & D'Arey, 2002). Therefore, CSCW research—an interdisciplinary field that studies the way people work in groups and computer-supported solutions to support their dynamics—falls under the umbrella of e-collaboration (Kock, 2005).

RELATED WORK ON CREATIVITY SUPPORT TOOLS

Many collaborative tools for supporting the social creative process have been developed. For example, EVIDII allows designers to associate effective words and images, and then shows several visual representations of the relationships among designers, images, and words (Nakakoji, Yamamoto, & Ohira, 1999). Showing different representations evokes the individual designer's creativity by using design knowledge or representations created by other designers in the community, thereby supporting collective creativity.

Fischer (2005) argued that distances (across physical, temporal, and technological dimensions) and diversity (across different cultures) are important sources for social creativity. He discussed several examples of collaborative environments to support creative processes. For example, in the Envisionment and Discovery Collaboratory (Arias, Eden, Fischer, Gorman, & Scharff, 2000), participants collaboratively solve design problems of mutual interest such as urban transportation planning. The assumption is that complex design is a social creative process, and the integration of individual and social creativity takes place through face-to-face discussions in a shared construction space such as an electronic whiteboard.

The Caretta system (Sugimoto, Hosoi, & Hashizume, 2004) supports face-to-face collaboration by integrating personal (for individual reflections) and shared spaces (for group discussions) to support intuitivism. Interactive art (Giaccardi, 2004) is based on the premise that computational media enable people to operate at the source of the creative process by creating a pool of pixema, meaning individual pieces produced by different artists, which can be exchanged to synthesize new paintings. CodeBroker (Ye, 2001) monitors software developers' programming activities, infers their immediate task by analyzing semantic and syntactic information contained in their working products, and actively delivers task-relevant and personalized usable parts (Fischer, Nakakoji, Ostwald, Stahl, & Sumner, 1998) from a repository created by decomposing existing software systems. This ensures awareness of each other's work so that efforts are not duplicated and, therefore, developers can be more creative.

The aforementioned tools broadly support activities that are characteristic of creative HCI and CSCW endeavor (Shneiderman, 2000): (1) searching and browsing digital libraries; (2) consulting with peers; (3) visualizing data and processes; (4) thinking by free associations; (5) exploring solutions—what-if tools; (6) composing artifacts and performances; (7) reviewing and replaying session histories; and (8) disseminating results.

However, design requirements for creativity support tools have been cursory in nature, not systematically grounded in the vast creativity literature that exists. For example, the eight design requirements elicited above from the Genex framework (Shneiderman, 2000), although useful as a precursory research agenda for user interface design for creativity, are rooted largely in one theory, the Theory of Flow (Csikszentmihalyi, 1996). The framework certainly provided a foundation for investigating creativity support tools in HCI and CSCW, but the time is right to revisit and enhance it in context of broader literature on collaborative scientific creativity.

Other HCI and CSCW research on creativity has attempted to carry the baton forward by extending the Genex design requirements. For example, Greene (2002) asserts the need to support smooth exploration and experimentation in creativity tools. This implies that there should be an easy way to undo and redo all or part of one's work, there should be no big penalties for mistakes, and there should be meaningful rewards for success. Another study discusses the need for devising a shared language and developing a common understanding in interdisciplinary collaboration (Mamykina, Candy, & Edmonds, 2002).

Because creativity research is a fledging enterprise in CSCW, we wish to develop systematic methods for exploring the design space of supporting scientific creativity in distributed collaboration. We actualize this by developing *first-order approximations* (Ackerman, 2000), in the form of requirements to support creativity, emerging from theoretical extensions. Developing such approximations will attempt to bridge the gap between what is required socially and what we can do technically to support creativity. If CSCW merely contributes "cool toys" without fully understanding and leveraging the theoretical underpinnings of how people really work in groups to be creative, it will have failed its intellectual mission, resulting in unusable systems (Ackerman, 2000).

REQUIREMENTS FOR CREATIVITY

In this section, we present three requirements for creativity with associated *design rationale* (Moran & Carroll, 1996). The design rationale derives from an exegesis of diverse theoretical and empirical investigations in socio-psychological literature on creativity and group dynamics.

Support Divergent and Convergent Thinking

Creativity in science, as in most other domains, involves both divergent and convergent thinking (Guilford, 1983; Levine & Moreland, 2004). Thus, we propose that creativity tools in distributed collaboration should support both these forms of thinking.

Divergent thinking is the ability to generate a set of possible responses, ideas, options, or alternatives in response to an open-ended question, task, or challenge. Convergent thinking involves narrowing this set to one alternative, and then implementing this alternative by empirically testing and communicating it to the scientific community. Because the process of creativity involves a continuous interplay of and achieving a dynamic balance between divergent and convergent thinking (Isaksen, 1995), we do not treat them separately. Instead, from literature, we illustrate different ways that both divergent and convergent thinking can be facilitated, and eventually supported through technology.

In his study of collaborative circles—a group of peers who share similar occupational goals and who, through long periods of dialogue and collaboration, negotiate a common vision that guides their work—Farrell (2001) argues that the bulk of a circle's creative work (during divergent and convergent thinking) occurs within dyads that have developed close relationships. This result is different from traditional theories of creativity, which assert that creative work is most likely to be done by highly-autonomous individuals working alone (Kohut, 1985). It is also important to note that Farrell's result applies to everyday creativity, and not just to extraordinary dyads such as creative couples in science that are often cited as prime examples of creativity (e.g., Pierre and Marie Curie, Carl and Gerty Cori, etc. (Pycior, Slack, & Abir-Am, 1996)).

Farrell says that dyad members engage in instrumental intimacy, characterized by trust, uninhibited exchange of ideas, and mutual support. New ideas, even though they may be experienced as coming from a third source, are more likely to emerge in creative dyads for several reasons (Farrell, 2001). First, creativity is a form of deviance—doing something that authorities do not approve. A "partner in crime" enables a dyad member to neutralize the guilt and anxiety inherent in the creative process. Second, as a consequence of the mirroring and the identification with one another, each dyad member feels more cohesive, invests more in the self, and takes his/her own ideas more seriously. Third, the open exchange in free, often playful interactions between dyad members allows the linking of conscious and unconscious thoughts from both minds. Each member consequently uses the mind of the other as if it were an extension of his/her own. Finally, as each plays the role of critic for the other, the ideas are reworked into useful components for the emerging shared vision.

Given that larger groups are less likely to elicit the levels of trust and support found in collaborative pairs (Levine & Moreland, 2004), how can divergent and convergent thinking be facilitated in such groups? One well-established technique to support divergent thinking is group brainstorming. Brainstorming can compensate for motivation losses (Steiner, 1972), which tend to increase in larger groups because there are fewer opportunities to participate productively, there is a sense that one's contributions are not critical or identifiable, and there is greater depersonalization (Arrow, McGrath, & Berdahl, 2000).

An interesting observation is that the process of brainstorming involving a group of scientists (who often use brainstorming effectively) differs significantly from a group of students (who typically do not) (Dunbar, 1997). For example, contrary to traditional brainstorming discourse in which group members are discouraged from criticizing others' ideas, evidence suggests that cognitive conflict within a scientific group can facilitate divergent thinking during brainstorming (Levine & Moreland, 2004). Group members often furnish new ideas that challenge group orthodoxy. Such challenges can facilitate learning, problem-solving at the individual level, and decision-making at the group level (Jehn, 1997). Evidence suggests that scientists are particularly likely to undergo conceptual change during laboratory meetings when they obtain surprising findings. This is not attributed to error discoveries, but rather to colleagues disagreeing with their interpretation (Dunbar, 1995) and a result of evolutionary "tinkering" (Dunbar, 1997), a series of small changes that produce major changes in a concept. Therefore, it follows that cognitive conflict, or "oppositional complementarity" (John-Steiner, 2000), has the potential to stimulate thoughtful consideration of new and creative ideas during brainstorming in scientific collaboration.

As noted previously, for group creativity to occur, groups must reach consensus on which idea is best, that is, convergent thinking. When it comes to creativity, available literature repeatedly demonstrates that groups rarely achieve the level of the sum of the individuals (McGrath, 1984). Part of the reason for the suboptimal performance of groups is that members strongly desire consensus, even straining for consensus, as argued by Janis (Janis, 1982), under the rubric of groupthink. The general phenomenon is as follows.

During consensus building, there is considerable evidence that discussion in a group of mostly like-minded members can extremize their views and enhance their confidence in those views, a phenomenon known as polarization (Fraser, 1971; Moscovici & Zavalloni, 1969). This results in premature movement to consensus (Hackman & Morris, 1975), thereby reducing the likelihood of creativity. There is evidence that majorities stimulate less novel or original thinking (Nemeth & Nemeth-Brown, 2003).

Given the problems associated with homogeneity, consensus, and majority views for both the quality of group decision-making and creative idea generation, one antidote appears to be *dissent* (Nemeth & Nemeth-Brown, 2003) rooted in minority influence theory. Based on such literature, it has been shown that dissent is a stimulus to divergent, convergent, and thus, creative thinking.

Minority dissent stimulates divergent thought, manifested in the search for information, the use of strategies, thoughts about the issue, detection of novel solutions, and creativity of solutions (Nemeth, 1995). Studies have invariably validated this basic theoretical premise (De Dreu & De Vries, 1993; Volpato, Maass, Mucchi-Faina, & Vitti, 1990). Some studies have even shown that minority dissent, even when wrong, stimulates a search for information on all sides of the issue (Nemeth & Rogers, 1996), and thus, thought is directed at more alternatives (Martin

& Noyes, 1996; Nemeth, Rogers, & Brown, 2001).

We also argue that dissent can facilitate convergent thinking. Studies have demonstrated that minority dissent stimulates a reappraisal of a situation (Nemeth & Nemeth-Brown, 2003). In general, people do not assume that the minority view is correct. However, during convergent thinking, when a group is narrowing a set of alternatives to a single idea, the minority's consistency of maintaining his or her dissenting view raises doubt about the majority position (Nemeth & Nemeth-Brown, 2003). Such an interaction evinces more complexity of thought, reevaluation of the majority position, and subsequently leads the group to make better decisions (Van Dyne & Saavedra, 1996).

In general, studies (e.g., Van Dyne & Saavedra, 1996; Volpato et al., 1990) have consistently shown that minority dissent can stimulate creative solutions to problems. For example, Nemeth et al. (2001) ran a simulated study of a work setting with two groups, one that was exposed to a dissenting opinion and the other that was not. When asked to generate solutions, the group exposed to minority dissent came up with more creative solutions than the other control group (no dissent). Another study by De Dreu and West (2001) on existing organizations shows that dissent increases innovation in work teams but primarily when individuals participate in decision-making.

Support Development of Shared Objectives

One condition for creativity flow is having clarity of goals (Csikszentmihalyi, 1996). We propose that creativity tools in distributed collaboration should support development of shared objectives that engender clarity of goals. Shared objectives imply a group vision of the goals of its work that members wish to achieve.

In context of group innovation, clarity of group objectives is likely to facilitate innovation by enabling focused development of new ideas, which can be filtered with greater precision than if group objectives are unclear (West, 2003). When group objectives are shared or distributed, it is critical that all members hold the same understanding of the goals, and that they are also aware of how others in the group perceive the situation (Hutchins, 1995).

Developing shared objectives involves group members to leverage their domain-specific knowledge, which does not always lead to creativity but does appear to be a relatively necessary condition for it (see discussion in Nickerson, 1999, pp. 409-410). This process also involves pooling information effectively (Stasser & Birchmeier, 2003) with high levels of interaction among group members. This can lead to cross-fertilization of perspectives that can spawn creativity and innovation (Mumford & Gustafson, 1988; Pearce & Ravlin, 1987). In general, high participation in decision-making (such as when group objectives are being formulated) means less resistance to change and therefore greater likelihood of innovations being implemented (Coch & French, 1948; Lawler & Hackman, 1969).

Theoretically, development of shared and clear objectives will facilitate innovation only if members are committed to the goals of the group (West, 2003). This is because strong goal commitment is necessary to maintain group member persistence for implementation in the face of resistance among other organizational members. For example, in a study of 418 project teams (Pinto & Prescott, 1987), it was found that a clearly-stated mission was the only factor that predicted success at all stages of the innovation process. Not having a shared commitment to common group objectives can result in breakdowns within local, global, and contextual group dynamics (Arrow et al., 2000). For example, lack of coordination between members (breakdown within local dynamics), greater disparity between a member's commitment to a group and the group's commitment to that particular member (breakdown within global dynamics), and/or lack of safety in the work environment (breakdown within contextual dynamics) can lead to dissolution of a group. Thus, due to a lack of shared vision of the group goals, such forces of group disintegration are likely to emerge (or become more apparent) and subsequently inhibit creativity (West, 2003).

An interesting finding from creativity literature is that even the intention to develop shared objectives is critical for creative endeavor. Henle (1962), for example, argues that we cannot find creative ideas by intentionally looking for them. She also argues, however, that if we are not receptive to them, they will not come—that their occurrence requires an appropriate attitude on our part. This attitude is typically manifested in the intention to be creative, which is important for creative activity.

Nickerson (1999) also argues that purpose is essential to creative expression, and that a prerequisite for purpose is intention. He broadly defines purpose as a deep and abiding intention to develop one's creative potential—a long-term interest, on cognitive and emotional levels, in some form of creative expression. Studies have corroborated the importance of purpose in this long-term sense (e.g., Dedek & Cote, 1994; Perkins, 1981).

Support Reflexivity

Knowing how well one is doing is essential to being creative (Csikszentmihalyi, 1996). In the context of groups, this means the extent to which members collectively reflect on the group's objectives, strategies, and processes as well as their wider organizations and environments, and adapt them accordingly. This is known as reflexivity (West, 1996), a process that creativity tools should support in distributed collaboration.

Group reflexivity consists of three elements: reflection, planning, and action (adaptation) (West, 2003). Reflection, in general, consists of attention, awareness, monitoring, and evaluation of the object of reflection (West, 2003), with evaluation particularly being stressed as an important constituent in creative thinking (Runco & Chand, 1994).

Specifically, reflection is a process to ruminate over the object of reflection deeply in more detail. It is about critical thinking, which is thinking that is focused, disciplined, logical, and constrained (Nickerson, 1999). In some sense, reflection is a form of convergent thinking—it evaluates what divergent thinking offers, subjects the possibilities to criteria of acceptability, and selects some among them for further consideration (Nickerson, 1999).

Planning is one of the potential consequences of the indeterminacy of reflection, because during this indeterminacy, courses of action can be contemplated, intentions formed, and plans developed, and the potential for carrying them out is built up (West, 2003). Collaborative planning, as conceptualized by Rogoff (1995), involves foresight and improvisation, and is inherently a creative process. Planning typically involves top-down goal decomposition with development and ordering of plan fragments (Sacerdoti, 1974), interleaving with the other two elements of reflexivity (reflection and action) (Miller, Galanter, & Pribam, 1960), and opportunistic plan revision (Suchman, 1986).

High reflexivity exists when planning is characterized by greater detail, inclusiveness of potential problems, hierarchical ordering, and long- as well as short-range planning (West, 2003). More detailed intentions or plans are more likely to lead to innovative implementations (Frese & Zapf, 1994). For example, Gollwitzer's work (1996) suggests that goal-directed behavior or innovation will be initiated when the group has articulated implementation intentions. This is because planning creates conceptual readiness for, and guides group members' attention toward, relevant opportunities for action and means to accomplish the group's goal.

Action, the third element of reflexivity, refers to goal-directed behaviors relevant to achieving the desired changes in group objectives, strategies, processes, organizations, or environments identified by the group during the stage of reflection (West, 2003). Overall, as a result of reflexivity, a group's reality is continually renegotiated during interactions between group members (West, 2003). Understandings negotiated in one exchange among group members may be drawn on a variety of ways to inform subsequent discussions, and offer the possibility of helpful and creative transformations and meanings (Bouwen & Fry, 1996). For example, research with BBC television program production groups, whose work fundamentally requires creativity and innovation, provides support for these propositions (Carter & West, 1998).

WORKING PROTOTYPE TO SUPPORT CREATIVITY

Integrating seamless access to tools, collaborators, and their activities are desirable requirements to facilitate creativity in collaborative environments to effectively support human-to-human communication (Candy, 1997; Shneiderman, 2000). Here, we describe our working prototype to support creativity.

Infrastructure and System

Our prototype is known as BRIDGE (Basic Resources for Integrated Distributed Group Environments; http://bridgetools.sourceforge.net) (Ganoe, Somervell, Neale, Isenhour, Carroll, Rosson, & McCrickard, 2003). The BRIDGE infrastructure is seamlessly integrated with browser-based wiki-style asynchronous editing and also supports synchronous shared editing of complex documents through replicated objects (Isenhour, Rosson, & Carroll, 2001). Replicated objects are objects that are retrieved by multiple collaborating sessions and whose state is kept synchronized when any replica is changed. The underlying code base is implemented in Java using software design patterns and components.

For accessibility and familiarity, BRIDGE client systems look and behave like a normal Web site, with all content rendered as HTML and images. Simple forms of authoring are supported. Each page has an "Edit" link which supports editing and new page creation using a simple shorthand notation that requires no external authoring tools or knowledge of HTML. This is designed to present the kind of easy transition from browsing to authoring, and from authoring to collaborative authoring, which is supported in similar wiki-based systems.

Each BRIDGE Web page also has a "Full Editor" link that launches an interactive Java-based client. The Java client supports interactive authoring functionality that is not possible or practical using HTML-based forms. Further, this client supports synchronous, distributed collaboration between users on shared artifacts, such as drawings, documents, data tables and charts, and interactive maps.

Suite of Tools

Text chat is a fundamental communication tool that, in the context of long-term collaboration, has both synchronous and asynchronous interaction modes. The chat is persistent, and so collaborators who join a shared session late or have missed the session completely can benefit from reviewing the content. For those who participated in the chat synchronously, a persistent copy will be valuable as a transcript, perhaps serving as a record of task decomposition or other negotiation between group members. Finally, groups may decide to use the chat tool as a message board for fully asynchronous conversations.

There is multitude support for graphical content generation. This includes drawing tools like a collaborative concept map, paintbrush-like editor for shared construction of drawings, and functionality for creating interactive maps (panning and zooming features) that can be jointly annotated. BRIDGE also provides table and charting tools, supporting basic data management and information visualization capabilities. Account management tools allow users to manage custom sets of restricted accounts with desired scope and privileges.

One notable characteristic of BRIDGE is its support for awareness. Social awareness (Erickson & Kellogg, 2000) is provided through a user list that indicates their activity (active vs. inactive). Workspace awareness (Gutwin & Greenberg, 2002) is supported by viewing synchronous changes to shared artifacts. For example, two group members could collaboratively co-construct a shared document and see each other's changes synchronously. Changes to shared artifacts can also be seen asynchronously through version histories.

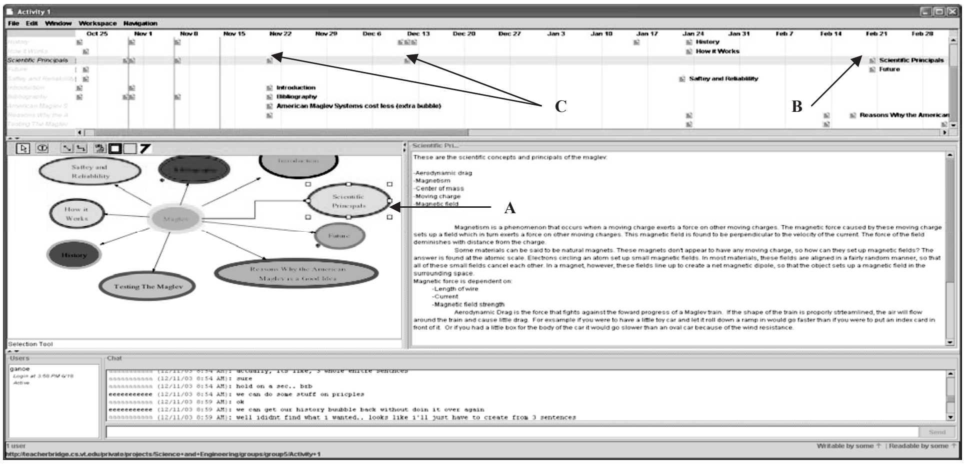
To be creative in a social setting, a collaborator needs to be aware of others and their work (Nakakoji et al., 1999) to establish and maintain a shared background of understanding. BRIDGE supports coordination and planning with activity awareness (Carroll, Neale, Isenhour, Rosson, & McCrickard, 2003): awareness of project work that supports group performance in complex tasks over long-term endeavors directed at major goals. A timeline interface provides a document history for a project along with a means for overlaying projects events like deadlines. As a user starts work on a shared document, a copy of the previous version is automatically stored for future reference. Figure 1 is a screenshot that illustrates many of these features.

Among many tools available in BRIDGE, the ones illustrated above generally support creativity in context of collaboratively accessing peers and their activities, planning, reflection on work, and idea generation.

DISCUSSION: IMPLICATIONS FOR DESIGN

The three requirements to support creativity with their design rationale (fourth section) suggest broader strategies to support scientific creative endeavors in distributed, computer-supported collaboration. At the most general level, the approach we are pursuing has three design heuristics. First, we are trying to *integrate support for individual, dyadic, and group brainstorming*. This approach contrasts with the strategy of just supporting *group* brainstorming. Second, we are trying to *leverage cognitive conflict for generating creative ideas by preserving and subsequently reflecting on minority dissent*. This is different from existing approaches of typically supporting majority-driven consensus. Third, we are trying to *support flexibility in the granularity of planning*, instead of constraining planning to some specific level of detail.

Figure 1. The BRIDGE workspace provides integrated timeline (top) and concept map (middle left) views of documents along with chat and a list of workgroup users logged (bottom). The selected note "Scientific Principles" (A) has the associated document displayed in the editor (middle right). The current version is also available from the timeline (B) as well as previous versions (C).



Integrate Support for Individual, Dyadic, and Group Brainstorming

During the creative work stage, group members alternate between times when they work alone, in pairs, and times when they meet as a group (Farrell, 2001). Therefore, supporting these different brainstorming modalities and the alterations between them seems feasible. In BRIDGE, a user can provide privileges to others for sharing (viewing and/or editing) an artifact such as a concept map. These privileges can be issued to individuals or groups (e.g., members of a research lab). In this way, the concept map, for instance, can be made accessible to individuals, dyads, or a group comprising any number of individuals.

A brainstorming tool should also allow switching modalities while maintaining the content of the previous and forthcoming brainstorming sessions. For instance, switching from a group brainstorming session to an individual session should preserve the collaborative group work, and then create a newer version for individual brainstorming session. Maintaining history of brainstorming sessions, which would be bookmarked at the times of modality switching, would allow users to refer back to previous versions, assess changes temporally, and keep track of who did what. Such session histories would facilitate the metacognitive process of reflection and self-awareness (Shneiderman, 2000), and establishment of a reward structure for making work visible (Suchman, 1995).

Brainstorming techniques—such as drawing concept maps, affinity diagrams, or storyboarding—are often codified as graphical visualizations of knowledge. One way to integrate support for individual, dyadic, and group brainstorming is to use role-specific multiple view visualizations (Convertino, Ganoe, Schafer, Yost, & Carroll, 2005). Given that breaking problems down into components and looking at problems from different angles facilitates effective brainstorming and thus creativity (Levine & Moreland, 2004), multiple view visualizations could then possibly represent different perspectives on how a problem should be broken down, not just from the role of a group but also the perspectives of individual and dyadic roles. For example, using the notion of public and private spaces (Greenberg, Boyle, & Laberge, 1999), an individual could add ideas to the group brainstorming view privately, and later propagate these ideas to the group through the shared view.

Distributed scientific collaboration will typically involve long-term creative endeavors, manifesting more asynchronous collaborations than synchronous. In face-to-face brainstorming, empirical evidence suggests that the specific mental activity in which a brainstormer is engaged during breaks is important (Mitchell, 1998). Contents of short-term memory during a brainstorming break affect an individual's post-break brainstorming performance. If the activity performed during the break does not allow the task-relevant ideas and concepts to remain active in short-term memory, then the relevant categories will have to be reactivated following the break. For long-term and distributed scientific collaboration, which involves all three modalities of brainstorming (individual, dyadic, and group), supporting the process of ideation continuously is especially critical. One way to address this is to use notification systems to inform individuals, dyads, and groups of relevant changes to a shared artifact during the breaks between asynchronous interactions. These notifications would alert users via email or other action-evoking stimuli such as an awareness feature (e.g., popup alerts in a MOO; see Farooq, Rodi, Carroll, & Isenhour, 2003). As a result, users would possibly react to the changes or at least think about the history of previous interactions, which would provide some level of cognitively preserving and tinkering prior brainstorming sessions.

Leverage Cognitive Conflict by Preserving and Reflecting on Minority Dissent

Moderate task-related conflict and minority dissent in a participative climate will lead to innovation by encouraging debate and to consideration of alternative interpretations of information available, leading to integrated and creative solutions. It seems that the social processes in groups necessary for minority dissent to influence the innovation process are characterized by high levels of team member interaction, influence over decision-making, and information sharing (West, 2003).

Preserving cognitive conflict and reflecting on minority dissent consists of two broad support mechanisms: documenting dissenting views and then finding these views during later consideration. A design feature that allows coding or flagging with an evocative, visual representation (e.g., user's avatar, color code) could be used to tag a dissenting opinion in a shared workspace. The shared workspace could represent a structured asynchronous discourse (Carroll, 1995) where group members can annotate discussion items. This scheme is somewhat similar to ones implemented in Issue-Based Information Systems (IBIS) developed by Horst Rittel (Rittel & Webber, 1973), where opinions could be tagged. Part of the difficulty with IBIS was the severe cognitive overhead dictated by the high degree of structure. User-directed annotations with open coding or flagging can alleviate such problems.

Annotations on a shared information repository, in addition to just tagging dissenting opinions, reinforce the idea of personal perspectives in the group context (Stahl & Herrmann, 1999). Stahl and Herrmann (1999) assert that during negotiation in computer-supported collaborations, it should always be possible for users to react to each other, at least by commenting. This maintains at least a partial overlap of their contents (both minority and majority views) that is key to reaching successful mutual understanding and coordination.

As mentioned before, part of the advantage of preserving dissenting opinions is to reappraise a specific situation at some later point in the long-term, asynchronous activity of distributed scientific collaboration. Viewing these cognitive conflicts temporally, say using a timeline view as in BRIDGE, can help to reevaluate orthodoxy especially at later stages of the group project when members tend to lose objectivity. Even the consideration of minority dissent, without implementation, can help strengthen the *autotelic* experience (Csikszentmihalyi, 1996).

Support Flexibility in the Granularity of Planning

Although more detailed plans can lead to creativity, imposing such constraints in collaborative systems can be problematic. For example, one of the classical findings in CSCW is that workflow systems for planning tasks are successful in supporting structured activity (Grudin, 1994), but otherwise may be too rigid, can potentially stymie creativity, and users often find ways to work around them.

We argue that a flexible, more opportunistic, and less imposing planning tool with different levels of detail would facilitate creativity. Planning can be conceptualized as strategic and operational (McGrath & Tschan, 2004). Strategic planning refers to a macro or purpose level of planning. It is knowledge- and intention-based: that is, it is driven by members' intentions, preferences, and information.

Operational planning involves hierarchical, temporal, referential, and technical structuring. "What will be done" (hierarchical) specifies the consequence of having intentions in strategic planning to develop shared objectives for collection action. "When" (temporal) refers to the sequence of tasks. "By whom" (referential) is about leveraging social resources in the coordination network, within and outside of the group. Finally, "how" (technical) refers to the division of labor and allocation of roles in the network to fulfill group objectives.

Separating and supporting different levels of planning can allow flexibility in planning tools. Instead of a Gantt chart supporting all planning activities, different representations for different levels of planning seems more plausible. For example, in our BRIDGE system, the timeline provides a temporal representation of plans, whereas the concept map supports a hierarchical way of structuring plans. The technical structuring of plans is supported through a shared workspace that corresponds to the planning milestones. Each milestone in the timeline can be specified in detail within the workspace, which supports collaborative discussion and writing among group members.

Not all planning is explicit (McGrath & Tschan, 2004) because structuring of actions (i.e., planning) often has a basis in traditions and history, either of that group or of groups to which its members have previously belonged. One design feature to support the referential level of operational planning is to incorporate a social network as part of the planning workflow system.

Our argumentation for incorporating a social network is based on two phenomena. First, scientists use digital library sources (e.g., ACM digital library) to access and use scientific artifacts in their own endeavors. Second, these scientific artifacts are not just tangible and passive resources. They embody social and active intellectual entities with respect to the scientists who created these artifacts. Thus, social relationships and interactions among scientists in a community of interest or practice (Wenger, McDermott, & Snyder, 2002), at the very least, influence the development and operationalization of plans. This is because plans continuously change, along with the situation (Suchman, 1986), and in scientific collaboration, an essential part of the situation are scientific peers and the knowledge they generate. It is then reasonable to expect that during scientific collaboration and specifically planning, collaborators not only want to leverage strong ties in their group (members of the group), but also weak ties outside of the group (larger scientific community) (Granovetter, 1973). Referential planning should not be narrowly construed as "who does what in the group", but more broadly as "who can be leveraged as a social resource within and outside of the group". Thus, social networks can enhance the depth of planning and articulation of work by facilitating horizontal informational flow across formal, recognized boundaries (Wellman, Salaff, Dimitrova, Garton, Gulia, & Haythornthwaite, 1996).

CONCLUSION AND FUTURE WORK

With the proliferation of advanced information and communication technologies, creative scientific work is increasingly being accomplished through collaboration between geographically-distributed peers. Our goal is to enhance such e-collaboration by designing CSCW tools to support scientific creativity in distributed computer-supported collaboration. Based on an exegesis of diverse literature on creativity, group dynamics, and their associated domains of study (e.g., organizational theory, collaborative problem solving, etc.), we presented three requirements to support creativity. These requirements appropriately update and enhance existing work in HCI and CSCW to support creativity because of their theory-based and empirical-rooted design rationale. These requirements are by no means exhaustive, but do represent a systematic effort toward developing first-order approximations for supporting creativity in context of CSCW. We chose these specific requirements among others because of their potential to be mediated by and supported through collaborative technology. We also proposed three implications for design as discussion items based on our earlier requirements for creativity. More broadly, these implications manifest technical challenges for the CSCW community for exploring the design space in supporting creativity.

Building on our requirements and implications for design, we briefly outline here a future research trajectory for designing and evaluating creativity support tools in context of collaboratories. A collaboratory can be defined as a "center without walls, in which the nation's researchers can perform their research without regard to geographical location—interacting with colleagues, accessing instrumentation, sharing data and computational resource, and accessing information in digital libraries" (Wulf, 1993). The vision of collaboratories is that access to special equipment (e.g., a supercomputer or a one-of-a-kind telescope) or special research sites (such as polar regions and the upper atmosphere) could be shared through the Internet, creating centers for geographically-distributed scientists to collaborate.

The logical connection between collaboratories and creativity is an obvious and important one; collaboratories are systems that can support creativity between geographically-distributed scientists. However, this connection has been understudied (Carroll & Farooq, 2006). This is because the original justification for collaboratories was more a matter of resource access and logistics than of enhancing creativity. We believe it is plausible that having better access to instruments, research sites, datasets, and critical mass of one's professional colleagues *ipso facto* facilitates opportunities for greater scientific creativity. It would be useful to directly design and evaluate creativity support tools for collaboratories.

Our research group is currently exploring the enhancement of CiteSeer (http://citeseer.ist.psu.edu) as a collaboratory to support creative work between distributed scientists in the computer and information science community. CiteSeer (Giles, Bollacker, & Lawrence, 1998) is a search engine and digital library of literature in the computer and information science disciplines that is a free resource providing access to the full-text of nearly 700,000 academic papers, and over 10 million citations. CiteSeer currently receives over 1.5 million hits a day and is accessed by 150 countries and over a million unique machines monthly.

We recently concluded the first requirements phase of enhancing CiteSeer as a collaboratory. Based on a survey of CiteSeer users and follow-up interviews (Farooq, Ganoe, Carroll, & Giles, 2007), results suggest that participants want support for upstream stages of distributed collaboration. These upstream stages were identified as creative and divergent activities of scientific work. For example, participants expressed the need to support brainstorming to collaboratively discuss and interpret research ideas and papers with others in the scientific community.

We think it is a worthwhile research pursuit and contribution to explore the design of creativity support tools in the CiteSeer collaboratory. Combining our results from this article with our parallel design effort to enhance CiteSeer as a collaboratory, we are currently implementing proof-of-concept prototypes of creativity support tools to be integrated with CiteSeer. For instance, we are integrating some of the existing creativity support tools that our BRIDGE system provides with CiteSeer. In addition to designing creativity support tools, there is also a need to formulate and codify measures for evaluating creativity in computer-supported collaborations. To this end, a promising direction that we are contemplating is to develop multi-method measurement approaches, grounded in theories of collaborative activity *and* creativity (for analogous argumentation with respect to usability evaluation issues in CSCW, see Neale, Carroll, & Rosson, 2004).

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REFERENCES

Ackerman, M. (2000). The intellectual challenge of CSCW: The gap between social requirements and technical feasibility. *Human-Computer Interaction*, *15*(2-3), 181-205.

Arias, E. G., Eden, H., Fischer, G., Gorman, A., & Scharff, E. (2000). Transcending the individual human mind - Creating shared understanding through collaborative design. *ACM Transactions on Computer-Human Interaction*, *7*(1), 84-113.

Arrow, H., McGrath, J. E., & Berdahl, J. (2000). *Small groups as complex systems: Formation, coordination, development, and adaptation*. Thousand Oaks, CA: Sage.

Bly, S. (1998). Special section on collaboratories. *ACM Interactions*, *5*(3), 31.

Boden, M. A. (2004). *The creative mind: Myths and mechanisms*. London: Routledge.

Bouwen, R., & Fry, R. (1996). Facilitating group development: Interventions for a relational and contextual construction. In M. A. West (Ed.), *The handbook of work group psychology* (pp. 531-552). Chichester, UK: Wiley.

Burleson, W., & Selker, T. (2002). Creativity and interface. *Communications of the ACM*, *45*(10), 89-90.

Candy, L. (1997). Computers and creativity support: Knowledge, visualization, and collaboration. *Knowledge-Based Systems*, *9*(6), 3-13.

Candy, L., & Hori, K. (2003). The digital muse: HCI in support of creativity: "Creativity and cognition" come of age: Towards a new discipline. *ACM Interactions*, *10*(4), 44-54.

Carroll, J. M. (1995). How to avoid designing digital libraries: A scenario-based approach. *SIGOIS Bulletin*, *16*(2), 5-7.

Carroll, J. M., & Farooq, U. (2006). Enhancing digital libraries to support creativity in distributed scientific communities: Making CiteSeer collaborative. *Designing for Usability in e-Science: An International Workshop on Interrogating Usability Issues in New Scientific Practice, within the Lab and within Society*, *Edinburgh, Scotland, January 26-27, 2006*.

Carroll, J. M., Neale, D. C., Isenhour, P. L., Rosson, M. B., & McCrickard, D. S. (2003). Notification and awareness: Synchronizing task-oriented collaborative activity. *International Journal of Human-Computer Studies*, *58*, 605-632.

Carter, S. M., & West, M. A. (1998). Reflexivity, effectiveness, and mental health in BBC-TV production teams. *Small Group Research*, *5*, 583-601.

Casper, T. A., Meyer, W. M., Moller, J. M., Henline, P., Keith, K., McHarg, B., Davis, S., & Greenwood, D. (1998). Collaboratory operations in magnetic fusion scientific research. *ACM Interactions*, *5*(3), 56-65.

Chin, G., Jr., & Lansing, C. S. (2004). Capturing and supporting contexts for scientific data sharing via the biological sciences collaboratory. *Proceedings of the ACM Conference on Computer Supported Cooperative Work* (pp. 409-418).

Coch, L., & French, J. R. (1948). Overcoming resistance to change. *Human Relations*, *1*, 512-532.

Convertino, G., Ganoe, C. H., Schafer, W. A., Yost, B., & Carroll, J. M. (2005). A multiple view approach to support common ground. *Proceedings of the 3rd International Conference on Coordinated and Multiple Views in Exploratory Visualization, London*.

Crane, D. (1972). *Invisible colleges: Diffusion of knowledge in scientific communities*. Chicago: University of Chicago Press.

Csikszentmihalyi, M. (1996). *Creativity: Flow and the psychology of discovery and invention*. New York: HarperCollins.

De Dreu, C. K. W., & De Vries, N. K. (1993). Numerical support, information processing, and attitude change. *European Journal of Social Psychology*, *23*, 647-662.

De Dreu, C. K. W., & West, M. A. (2001). Minority dissent and team innovation: The importance of participation in decision-making. *Journal of Applied Psychology*, *86*, 1191-1201.

Dudek, S. Z., & Cote, R. (1994). Problem finding revisited. In M.A. Runco (Ed.), *Problem finding, problem solving, and creativity* (pp. 130-150). Norwood, NJ: Ablex.

Dunbar, K. (1995). How scientists really reason: Scientific reasoning in real-world laboratories. In R. J. Sternberg & J. E. Davidson (Eds.), *The nature of insight*. Cambridge, MA: MIT Press.

Dunbar, K. (1997). How scientists think: Online creativity and conceptual change in science. In T. B. Ward, S. M. Smith, & S. Vaid (Eds.), *Conceptual structures and processes: Emergence, discovery, and change*. Washington, DC: APA Press.

Edmonds, E. A. (1994). Introduction: Computer-based systems that support creativity. In T. Dartnall (Ed.), *Artificial intelligence and creativity* (pp. 327-334). Dordrecht, Netherlands: Kluwer Academic.

Erickson, T., & Kellogg, W. A. (2000). Social translucence: An approach to designing systems that mesh with social processes. *ACM Transactions on Computer Human Interaction*, *7*(1), 59-83.

Farooq, U., Carroll, J. M., & Ganoe, C. H. (2005). Supporting creativity in distributed scientific communities. *Proceedings of the International GROUP Conference on Supporting Group Work, Sanibel Island, Florida, November 6-9, 2005* (pp. 217-226). New York: ACM Press.

Farooq, U., Ganoe, C. H., Carroll, J. M., & Giles, C. L. (2007). Supporting distributed scientific collaboration: Implications for designing the CiteSeer collaboratory. *Proceedings of the Hawaii International Conference on System Sciences*, *Waikoloa, Hawaii, January 3-6, 2007* (p. 26c). Washington, DC: IEEE Computer Society.

Farooq, U., Rodi, C., Carroll, J. M., & Isenhour, P. L. (2003). Avatar proxies: Configurable informants of collaborative activities. *Proceedings of the ACM Conference on CHI* (pp. 792-793).

Farrell, M. P. (2001). *Collaborative circles: Friendship dynamics and creative work*. Chicago: University of Chicago Press.

Feist, G. J. (1999). The influence of personality on artistic and scientific creativity. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 273-296). New York: Cambridge University Press.

Finholt, T. A., & Olson, G. M. (1997). From laboratories to collaboratories: A new organizational form for scientific collaboration. *Psychological Science*, *8*(1), 28-36.

Fischer, G. (1999). Symmetry of ignorance, social creativity, and meta-design. *Proceedings of the 3rd Conference on Creativity and Cognition* (pp. 116-123). New York: ACM Press..

Fischer, G. (2005). Distances and diversity: Sources for social creativity. *Proceedings of the 5th Conference on Creativity and*

Cognition (pp. 128-136). New York: ACM Press.

Fischer, G., Nakakoji, K., Ostwald, J., Stahl, G., & Sumner, T. (1998). Embedding critics in design environments. In M. T. Maybury & W. Wahlster (Eds.), *Readings in intelligent user interfaces* (pp. 537-559). San Francisco, CA: Morgan Kaufmann.

Florida, R. (2002). *The rise of the creative class: And how it's transforming work, leisure, community, and everyday life*. New York: Basic Books.

Florida, R. (2005). *The flight of the creative class: The new global competition talent.* New York: HarperCollins.

Fraser, C. (1971). Group risk taking and group polarization. *European Journal of Social Psychology*, *1*, 493-510.

Frese, M., & Zapf, D. (1994). Action as the core of work psychology: A German approach. In H. C. Triandis, M. D. Dunnette, & L. M. Hough (Eds.), *Handbook of industrial and organizational psychology, 2nd ed.: Vol. 4* (pp. 271-340). Palo Alto, CA: Consulting Psychologists Press.

Ganoe, C. H., Somervell, J. P., Neale, D. C., Isenhour, P. L., Carroll, J. M., Rosson, M. B., & McCrickard, D. S. (2003). Classroom BRIDGE: Using collaborative public and desktop timelines to support activity awareness. *Proceedings of ACM UIST, Vancouver* (pp. 21-30).

Gardner, H. (1993). Seven creators of the modern era. In J. Brockman (Ed.), *Creativity* (pp. 28-47). New York: Simon & Schuster.

Giaccardi, E. (2004). *Principles of metadesign: Processes and levels of co-creation in the new design space*. Doctoral dissertation, CAiiA-STAR, School of Computing, Plymouth, UK.

Giles, C. L., Bollacker, K., & Lawrence, S. (1998). CiteSeer: An automatic citation indexing system. *Proceedings of the Conference on Digital Libraries, Pittsburgh, PA, June 23-26, 1998* (pp. 89-98). New York: ACM Press.

Gollwitzer, P. M. (1996). The volitional benefits of planning. In P. M. Gollwitzer & J. A. Bargh (Eds.), *The psychology of action: Linking cognition and motivation to behaviour* (pp. 287-312). New York: Guilford.

Granovetter, M. (1973). The strength of weak ties. *American Journal of Sociology*, *78*(6), 1360-1380.

Greenberg, S., Boyle, M., & Laberge, J. (1999). PDAs and shared public displays: Making personal information public, and public information personal. *Personal Technologies*, *3*(1), 54-64.

Greene, S. L. (2002). Characteristics of applications that support creativity. *Communications of the ACM*, *45*(10), 100-104.

Grudin, J. (1994). Groupware and social dynamics: Eight challenges for developers. *Communications of the ACM*, *37*(1), 92-105.

Guilford, J. P. (1983). Transformation: Abilities or functions. *Journal of Creative Behavior*, *17*, 75-86.

Gutwin, C., & Greenberg, S. A. (2002). Descriptive framework for workspace awareness for real-time groupware. *Computer Supported Cooperative Work*, *11*(3-4), 411-446.

Hackman, J. R., & Morris, C. G. (1975). Group tasks, group interaction processes, and group performance effectiveness: A review and proposed integration. In L. Berkowitz (Ed.), *Advances in experimental social psychology: Vol. 8* (pp. 45-99). New York: Academic Press.

Henle, M. (1962). The birth and death of ideas. In H. Gruber, G. Terrell, & M. Wertheimer (Eds.), *Contemporary approaches to creative thinking* (pp. 31-62). New York: Atherton.

Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT.

Isaksen, S. G. (1995). CPS: Linking creativity and problem solving. In G. Kaufmann, T. Helstrup, & K. H. Teigen, (Eds.), *Problem solving and cognitive processes: A festschrift in honour of Kjell Raaheim* (pp. 145-181). Bergen-Sandviken, Norway: Fagbokforlaget Vigmostad & Bjørke AS.

Isenhour, P. L., Rosson, M. B., & Carroll, J. M. (2001). Supporting interactive collaboration on the Web with CORK. *Interacting with Computers*, *13*, 655-676.

Janis, I. L. (1982). *Groupthink: Psychological studies of policy decisions and fiascoes, 2nd ed*. Boston: Houghton Mifflin.

Jehn, K. A. (1997). Affective and cognitive conflict in work groups: Increasing performance through value-based intragroup conflict. In C. K. W. De Deru & E. Van de Vliert (Eds.), *Using conflict in organizations* (pp. 87-100). Thousand Oaks, CA: Sage.

John-Steiner, V. (2000). *Creative collaboration*. New York: Oxford University Press.

Kibrick, R., Conrad, A., & Perala, A. (1998). Through the far looking glass: Collaborative remote observing with the W. M. Keck Observatory. *ACM Interactions*, *5*(3), 32-39.

Kock, N. (2005). What is e-collaboration? *International Journal of e-Collaboration*, *1*(1), i-vii.

Kock, N., & D'Arey, J. (2002). Resolving the e-collaboration paradox: The competing influences of media naturalness and compensatory adaptation. *Information Management and Consulting* (Special Issue on Electronic Collaboration), *17*(4), 72-78.

Kohut, H. (1985). *Self psychology and the humanities*. New York: W. W. Norton.

Kouzes, R. T., Myers, J. D., & Wulf, W. A. (1996). Collaboratories: Doing science on the Internet. *IEEE Computer*, *29*(8), 40-46.

Lawler, E. E., III, & Hackman, J. R. (1969). Impact of employee participation in the development of pay incentive plans: A field experiment. *Journal of Applied Psychology*, *53*, 467-471.

Levine, J. M., & Moreland, R. L. (2004). Collaboration: The social context of theory development. *Personality and Social Psychology Review*, *8*(2), 164-172.

Mamykina, L., Candy, L., & Edmonds, E. (2002). Collaborative creativity. *Communications of the ACM*, *45*(10), 96-99.

Martin, R., & Noyes, C. (1996). Minority influence and argument generation. In C. J. Nemeth (Ed.), *British Journal of Social Psychology: Special Issue on Minority Influence*, *35*, 91-103.

McDaniel, S. E., Olson, G. M., & Olson, J. S. (1994). Methods in search of methodology—Combining HCI and object orientation. *Proceedings of the ACM Conference on CHI* (pp. 145-151).

McGrath, J. E. (1984). *Groups: Interaction and performance*. Englewood Cliffs, NJ: Prentice Hall.

McGrath, J. E., & Tschan, F. (2004). *Temporal matters in social psychology: Examining the role of time in the lives of groups and individuals*. Washington, DC: APA.

Miller, G. A.,Galanter, E., & Pribam, K. (1960). *Plans and the structure of behavior*. New York: Rinehart & Winston/Holt.

Mitchell, K. A. C. (1998). *The effect of break task on performance during a second session of brainstorming*. Unpublished master's thesis, University of Texas, Arlington.

Moran, T. P. (1983). Getting into a system: External-internal task mapping analysis. *Proceedings of the ACM Conference on CHI* (pp. 45-49).

Moran, T. P., & Carroll, J. M. (Eds.). (1996). *Design rationale: Concepts, techniques, and use*. Hillsdale, NJ: Lawrence Erlbaum.

Moscovici, S., & Zavalloni, M. (1969). The group as a polarizer of attitudes. *Journal of Personality and Social Psychology*, *12*, 124-135.

Mumford, M. D., & Gustafson, S. B. (1988). Creativity syndrome: Integration, application, and innovation. *Psychological Bulletin*, *103*, 27-43.

Nakakoji, K., Yamamoto, Y., & Ohira, M. (1999). A framework that supports collective creativity in design using visual images. *Proceedings of the 3rd Conference on Creativity and Cognition* (pp. 166-173). New York: ACM Press.

Neale, D. C., Carroll, J. M., & Rosson, M. B. (2004). Evaluating computer-supported cooperative work: Models and frameworks. *Proceedings of the ACM Conference on CSCW*, 112-121.

Nemeth, C. (1995). Dissent as driving cognition, attitudes, and judgments. *Social Cognition*, *13*, 273-291.

Nemeth, C., & Nemeth-Brown, B. (2003). Better than individuals? The potential benefits of dissent and diversity. In P. B. Paulus & B. A. Nijstad (Eds.), *Group creativity: Innovation through collaboration* (pp. 63-84). New York: Oxford University Press.

Nemeth, C., & Rogers, J. (1996). Dissent and the search for information. *British Journal of Social Psychology*, *35*, 67-76.

Nemeth, C., Rogers, J. D., & Brown, K. S. (2001). Devil's advocate vs. authentic dissent: Stimulating quantity and quality. *European Journal of Social Psychology*, *31*, 707-729.

Nickerson, R. S. (1999). Enhancing creativity. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 392-430). New York: Cambridge University Press.

Olson, G. M., Atkins, D. E., Clauer, R., Finholt, T. A., Jahanian, F., Killeen, T. L., Prakash, A., & Weymouth, T. (1998). The upper atmospheric research collaboratory (UARC). *ACM Interactions*, *5*(3), 48-55.

Pearce, J. A., & Ravlin, E. C. (1987). The design and activation of self-regulating work groups. *Human Relations*, *40*, 751-782.

Perkins, D. N. (1981). *The mind's best work*. Cambridge, MA: Harvard University Press.

Pinto, J. K., & Prescott, J. E. (1987). Changes in critical success factor importance over the life of a project. *Academy of Management Proceedings* (pp. 328-332).

Pycior, H. M., Slack, N. G., & Abir-Am, P. G. (Eds.). (1996). *Creative couples in the sciences*. New Brunswick, NJ: Rutgers Press.

Rittel, H., & Webber, M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, *4*, 155-169.

Rogoff, B. (1995). Observing sociocultural activity on three planes: Participatory appropriation, guided participation, and apprenticeship. In J. V. Wertsch, P. del Rio, & A. Alvarez (Eds.), *Sociocultural studies of mind* (pp. 139-164). New York: Cambridge University Press.

Runco, M. A., & Chand, I. (1994). Problem finding, evaluative thinking, and creativity. In M. A. Runco (Ed.), *Problem finding, problem solving, and creativity* (pp. 40-76). Norwood, NJ: Ablex.

Sacerdoti, E. D. (1974). Planning in a hierarchy of abstraction spaces. *Artificial Intelligence*, *5*, 115-135.

Schur, A., Keating, K. A., Payne, D. A., Valdez, T., Yates, K. R., & Myers, J. D. (1998). Collaborative suites for experiment-oriented scientific research. *ACM Interactions*, *5*(3), 40-47.

Shneiderman, B. (2000). Creating creativity: User interfaces for supporting innovation. *ACM TOCHI*, *7*(1), 114-138.

Sonnenwald, D. H., Whitton, M. C., & Maglaughlin, K. L. (2003). Evaluating a scientific collaboratory: Results of a controlled experiment. *ACM TOCHI*, *10*(2), 150-176.

Stahl, G., & Herrmann, T. (1999). Intertwining perspectives and negotiation. *Proceedings of ACM GROUP* (pp. 316-325).

Stasser, G., & Birchmeier, Z. (2003). Group creativity and collective choice. In P. B. Paulus & B. A. Nijstad (Eds.), *Group creativity: Innovation through collaboration* (pp. 85-109). New York: Oxford University Press.

Steiner, I. D. (1972). *Group process and productivity*. New York: Academic Press.

Sternberg, R. J. (Ed.). (1999). *Handbook of creativity*. New York: Cambridge University Press.

Sternberg, R. J. & Lubart, T. I. (1999). The concept of creativity: Prospects and paradigms. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 3-15). New York: Cambridge University Press.

Suchman, L. A. (1986). *Plans and situated actions*. New York: Cambridge University Press.

Suchman, L. A. (1995). Making work visible. *Communications of the ACM*, *38*(9), 56-64.

Sugimoto, M., Hosoi, K., & Hashizume, H. (2004). Caretta: A system for supporting face-to-face collaboration by integrating personal and shared spaces. *Proceedings of the ACM Conference on Computer-Human Interaction* (pp. 41-48).

Thagard, P. (1998). Ulcers and bacteria II: Instruments, experiments, and social interactions. *Studies in History and Philosophy of Biological and Biomedical Sciences*, *29*, 317-342.

Van Dyne, L., & Saavedra, R. (1996). A naturalistic minority influence experiment: Effects on divergent thinking, conflict, and originality in work groups. *British Journal of Social Psychology*, *35*, 151-168.

Volpato, C., Maass, A., Mucchi-Faina, A., & Vitti, E. (1990). Minority influence and social categorization. *European Journal of Social Psychology*, *20*, 119-132.

Watson, J. D. (1968). *The double helix*. New York: Signet.

Wellman, B., Salaff, J., Dimitrova,, D., Garton, L., Gulia, M., & Haythornthwaite, C. (1996). Computer networks as social networks: Collaborative work, telework, and virtual community. *Annual Review of Sociology*, *22*, 213-238.

Wenger, E., McDermott, R., & Snyder, W. (2002). *Cultivating communities of practice: A guide to managing knowledge*. Harvard Business School Press.

West, M. A. (1996). Reflexivity and work group effectiveness: A conceptual integration. In M. A. West (Ed.), *Handbook of work group psychology* (pp. 555-579). Chichester, UK: Wiley.

West, M. A. (2003). Innovation implementation in work teams. In P. B. Paulus & B. A. Nijstad (Eds.), *Group creativity: Innovation through collaboration* (pp. 245-276). New York: Oxford Press.

Wulf, W. (1993). The collaboratory opportunity. *Science*, *261*, 854-855.

Ye, Y. (2001). *Supporting component-based software development with active component repository systems*. Doctoral dissertation, University of Colorado at Boulder.

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