The Pennsylvania State University

The Graduate School

College of Information Sciences and Technology

SUPPORTING CREATIVITY: INVESTIGATING THE ROLE OF AWARENESS IN DISTRIBUTED COLLABORATION

A Dissertation in

Information Sciences and Technology

by

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Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Doctor of Philosophy

August 2008

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ABSTRACT

Creativity is the cornerstone of collaborative scientific work. As distributed collaboration is becoming an increasingly dominant model of creative scientific work that goes on in our daily lives, it is essential to understand how creativity can be supported in such contexts. The objective of this dissertation is to investigate the feasibility, effectiveness, and consequences of supporting creativity with computer-supported awareness in distributed collaboration. This research is conducted in five phases. The first phase is a survey of creativity literature to speculate how awareness, and in particular activity awareness, can support creativity in distributed collaboration. The second phase is an exploratory experiment that identifies four breakdowns in creativity in distributed collaboration. The third phase is the design and prototyping of three novel activity awareness strategies and mechanisms to support creativity. The fourth phase is a main experiment that studies the effectiveness and consequences of using the activity awareness mechanisms. The fifth phase validates results from the main experiment through follow-up analysis.

The results show that groups with activity awareness support were more likely to be among the most creative than groups without activity awareness support. 62% of the groups with activity awareness support were ranked in the upper tier of being creative versus 37.5% of the groups without activity awareness support. The most significant results involved structured activity updates, one of the three activity awareness mechanisms, which allowed group members to update and share their work status. The structured activity updates increased awareness of group members with respect to what they had worked on. Further, the structured activity updates increased awareness of group members over time with respect to what they will do next, a relationship that was stronger for the groups with structured activity updates than groups without structured activity updates. Group members with higher metacognitive knowledge found the

structured activity updates more useful than group members with lower metacognitive knowledge.

This dissertation contributes to the basic science of creativity, to the design science of supporting creative activity, and to the empirical science of measuring creativity. The application of creativity theories from the social sciences in Human Computer Interaction (HCI) and Computer Supported Cooperative Work (CSCW) contexts improves our general understanding of creative collaboration. Second, prototypes of awareness mechanisms broaden the science of design by developing new tools for supporting creativity. Third, extension of existing evaluation metrics and frameworks advances our ability to measure creativity using both quantitative and qualitative methods. The broader impact of this dissertation is to enhance the process and product of creative collaboration.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

This dissertation is a result of several years of hard work and toil. Many individuals supported me during this life changing period in several capacities. Foremost, I would like to thank my advisor, Jack Carroll, without whom this dissertation would not be possible. His visionary thinking has been transformational for my intellectual development. I am deeply indebted to Mary Beth Rosson for bringing out the best in me during my first semester as a graduate student at Virginia Tech. Without her early guidance and encouragement to work in the HCI lab, graduate school would have been an underwhelming experience.

I was fortunate to have a diverse group of committee members whose criticisms and feedback have been instrumental not just for my dissertation but also for my career. Chris Hoadley shepherded me during my formative semesters at Penn State and has since believed in my research initiatives. Working with Lee Giles on CiteSeer research projects has been an illuminating experience that has led to many quality publications. Rosalie Ocker has influenced my research methods directly through many detailed discussions over the past couple of years. Jim Farr has helped me maintain a balance in my research by expanding my knowledge base in the social sciences.

My family was a pillar in supporting my efforts, particularly during times when I was ready to give up. My parents, Azhar Farooq and Sumbla Farhat, have blessed me every step of the way. Without their spiritual guidance and wisdom, I would be a far less than complete human being. There is no way I can repay their unflinching determination and belief in my goals. My sister, Natasha Farooq, has provided me with reality checks during the past two years. Her practical outlook on life made me realize how my dissertation fits in the larger scheme of things. I am thankful to my brothers, Bilal and Hassam Farooq, and brother-in-law, Ali Saeed, for always looking up to me and seeing me as their role model. My wife, Anam Hafiz Farooq, deserves special thanks, without whom I would not have scheduled my defense. She held my hand during the very last moments of my schooling and is a continuing source of love and inspiration in my life.

I would like to express my gratitude to my uncle, Najam Saeed, for encouraging me to apply to graduate school in the first place and continuing to pursue my Ph.D. after my Master's degree. It was his final endorsement that led to me to make one of my most difficult decisions to transfer from Virginia Tech to Penn State. My aunt, Musarrat Saeed, has always supported me through her love and care, especially during my winter breaks. Over the years, I have learned to embrace my uncle, Masood Akbar, as a father, who has been a counselor throughout my graduate school. Without the prayers of my grandfather, Iqbal Bhatti, I would not be here today.

I also wish to thank several colleagues with whom I have worked with and enjoyed many critical lunch conversations regarding graduate school experiences. Without Craig Ganoe's technical insight and help during odd hours of the night, this dissertation would not be possible. Without Thomas Kannampallil's collaboration, my work would surely be of lesser quality. I would also like to thank Lu Xiao, Gregorio Convertino, Karthik Umapathy, Joshua Gross, John Daughtry, and Phil Ayoub for giving me the opportunity to reflect on my research ideas. The entire IST community has been a wonderful source of support.

Several friends supported my cause along the way, though most of the support came indirectly through constant nagging to finish my Ph.D. I would like to thank Ali Farooq, Shabeeh Haider, Emad-ul-Hasan, Afzal Nanji, Nabiha Farooq, and Aisha Hasan for their friendship and understanding, especially during times when I did not return their phone calls.

I would like to acknowledge Levine and Moreland's paper [2004] that first led me to pursue creativity as a research topic. Thanks to the National Science Foundation for partially supporting my research work (NSF CRI-0454052, NSF SGER IIS-0749172).

To

My family and friends

Chapter 1

Introduction

Popular myth about creativity conjures lightning bolts of inspiration striking individual innovators without warning. A more typical, and perhaps even more important form of creativity than the isolated lightning bolt is relatively long-term and collaborative development of innovative ideas. Indeed, many industries and professions—research and development in information technology, for example—depend on this latter form of routine and deliberate creativity. Collaborating on writing a research paper is a typical example of routine creativity.

When creativity is thought of as a vital and continual characteristic of intellectual work activity, instead of as unpredictable and singular lightning bolts, support for creativity can be considered far more broadly. For example, when collaboratively writing a research paper, creativity support tools such as a shared whiteboard application may support the brainstorming phase of a group's creative process. But this is just a piece of what it could mean to support creative work. When creativity is taken as a long-term, complex activity, support for awareness is also required for group members to monitor the development of ideas, track how these ideas got narrowed down to a few alternatives, and to stay cognizant of how the alternatives are being implemented and integrated by other group members. The objective of this dissertation is to investigate the feasibility, effectiveness, and consequences of supporting creativity with awareness in distributed collaboration.

Motivation

Creativity is critical to invention, innovation, and social and scientific progress at multiple levels of analysis [Candy and Hori, 2003; Sternberg and Lubart, 1999]. Individuals are able to refine and improve their own performance, and groups, organizations, and societies 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 importance of creativity to society and the need to investigate creativity as a research topic has been widely acknowledged [Candy and Hori, 2003; Sternberg and Lubart, 1999; Florida, 2002; Florida, 2005]. Specifically in Human Computer Interaction (HCI) and Computer Supported Cooperative Work (CSCW), research on creativity continues to flourish and provide fertile ground for making significant contributions to the field [Candy and Edmonds, 1999]. The National Science Foundation (NSF) has recently promoted creativity to the forefront of its research agenda through two workshops on creativity support tools (http://www.cs.umd.edu/hcil/CST/) and on the synergies between creativity and technology, science, and design (http://swiki.cs.colorado.edu:3232/CreativeIT/).

Creativity as a research topic in HCI is important for many reasons [Candy, 1992; Candy, 1997; Edmonds, 1993; Edmonds, 1994]. First, there are assertions that today's knowledge workers can benefit from the use of software tools to enhance their creative strategies [Candy and Hori, 2003]. Second, existing tools for individual and collaborative work often contain interface elements that stymie creative efforts [Burleson and Selker, 2002] and thus can be enhanced. Third, HCI and CSCW as inter-disciplinary fields with strong foundations in the social sciences [Carroll, 2006] are conducive to more integrated investigations across traditionally diverse areas such as computing, psychology, art, music, and design among others.

Though creativity continues to be studied in HCI and CSCW, it has not been investigated as a persistent, routine, and collaborative characteristic of complex human activity. Creativity does not just happen inside a person's head, but in the interaction between a person's thoughts and a socio-cultural context [Csikszentmihalyi, 1996]. It is not yet clear what, where, and why breakdowns in creativity occur during collaboration, and what could be done to avoid or mitigate these breakdowns with CSCW mechanisms.

Scope

The scope of this dissertation is defined on three dimensions with respect to the research investigation: type of creativity, type of collaboration, and type of support mechanisms. Each of these dimensions is explained below.

Type of creativity

Among many definitions of creativity, it is generally agreed upon that creativity is the ability to produce work that is innovative, implying both *novelty* and *usefulness* [Mayer, 1999; Lubart, 1994; Ochse, 1990; Sternberg, 1988; Sternberg and Lubart, 1991; Sternberg and Lubart, 1995; Sternberg and Lubart, 1996; Thomas and Carroll, 1979]. Novelty implies originality (e.g., a new idea) and usefulness implies relevance (e.g., application of the new idea and its relevance to the underlying task). It follows from this general definition that creativity is also a *process* and *product*; that is, creativity involves a series of actions directed to some end.

The type of creativity being considered is *scientific* and *everyday* in nature. Csikszentmihalyi [1996] defines scientific creativity as a process toward achieving an outcome recognized as innovative (both novel and useful) by the relevant community. The outcome of scientific creativity—essentially the goal of science—is the production of new knowledge.

The everyday aspect of scientific creativity implies that the process is not an occasional occurrence (e.g., an “Aha” moment) but rather a routine practice. Everyday creativity is also known as “little C” creativity [Gardner, 1993], the sort that all of us evince in our daily lives. 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].

Type of collaboration

The new knowledge as a result of scientific creativity can be produced by individuals, groups, communities, or even societies. The *co-construction* of new knowledge is being considered by *small groups*, typically three to six members [Arrow et al. 2000], over *long-term* activities. *Co-construction* emphasizes coordination and resource sharing among group members (versus individual members independently doing their own tasks and only coming together to collate their contributions as a final product). The long-term aspect of scientific creativity implies that the process is a significant endeavor directed at a major goal (such as collaborating on writing a journal paper).

The type of collaboration being considered is *distributed* (or fully distributed). Group members are not face-to-face, that is, they are collaborating synchronously and/or asynchronously with the support of CSCW tools (e.g., online chat, shared editors, and whiteboards). With the proliferation of fast and reliable Internet technologies, distributed collaboration is becoming an increasingly dominant model of work and typifies much of the scientific work that goes on in our daily lives.

Type of support mechanisms

Creativity can be broadly supported by a range of CSCW mechanisms such as large-screen displays, collaboratories, and so forth. This dissertation is investigating how creativity can be specifically supported through awareness mechanisms. Computer-supported awareness is an understanding of the activities of others, which provides a context for one's own activity [Dourish and Bellotti, 1992; Schmidt, 2002]. The motivation for investigating awareness support draws on Burleson's [Burleson, 2005] articulation to promote metacognitive strategies for creative pursuits. In this sense, awareness can support creative collaboration at a metacognitive level by allowing members to monitor and appropriately react to the group's creative process over time.

Problem statement and overall research questions

The field of CSCW has extensively studied collaborative phenomena in face-to-face contexts. When the context is distributed, problems in collaboration are exacerbated. It is more difficult to coordinate resources, achieve common ground, keep track of contributions, and so forth. Although CSCW has also studied distributed contexts, much of the focus has been on relatively direct performance phenomena like productivity, workflow, coordination, and individual motivation. Investigating and supporting creativity poses greater and less-defined challenges, none of which have been studied from the perspective of awareness.

Consider the following scenario to motivate the problem statement:

> On her sabbatical in Spain, Dr. Meyer is writing a journal paper with her graduate student, Ken, at Penn State. She also wants Dr. Baker, her long-time

> collaborator at IBM, to give input on the data analysis section. They use Google Docs, a shared word processor, to collaborate online. Dr. Meyer is unsure of which changes Ken recently made to the document. After Dr. Baker takes out time from his busy schedule to refine the data analysis section, Dr. Meyer posts a newer version of the paper that has taken a different approach to data analysis. Dr. Baker is confused as to which version he should work with. To make the collaborative process smoother, he doesn't share his corrections and complies with Dr. Meyer's newer version. Meanwhile, Ken is wondering why his contribution has not been taken into account and what others are doing. As the deadline approaches, Dr. Meyer haphazardly collates all the sections that everyone has readily agreed to and submits a suboptimal journal paper.

In the above scenario, three collaborators are working on a creative activity to write a journal paper. Ken is unsure of how his contribution is being integrated with the final product. Dr. Meyer and Dr. Baker are in conflict over how data analysis should be done, and as a result, Dr. Baker does not share his ideas with the rest of the group. Toward the end, group members pre-maturely converge on a less than creative solution.

Given the literature gap and motivational scenario, the problem statement for this dissertation can be summarized as: *How can creativity be supported through awareness in distributed collaboration?* This is depicted in Figure **1-1**.

Hence, there is a need to first study what kinds of awareness mechanisms can support creativity in distributed collaboration. Given the design of such awareness mechanisms, there is a need to then study the feasibility and consequences of these mechanisms in supporting creativity. Therefore, this dissertation is driven by two overall research questions (RQ):

- RQ1: What awareness mechanisms can support creativity in distributed collaboration?
- RQ2: How are these awareness mechanisms used and with what consequences?

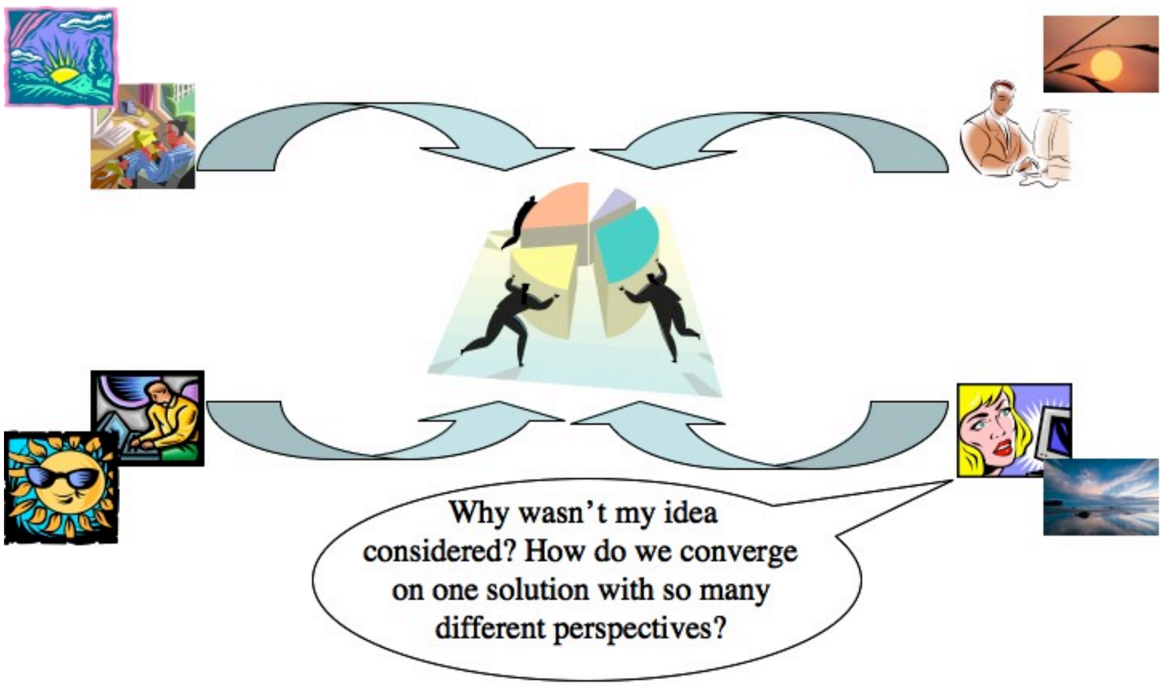

Figure **1-1**: Depiction of problem statement: how can creativity be supported through awareness in distributed collaboration.

Approach

The two overall research questions (RQ1 and RQ2) are answered through two empirical studies respectively.

Study 1: Exploratory experiment

This study is a requirements analysis to investigate awareness mechanisms that can support creativity in distributed collaboration. The exploratory experiment is a qualitative study to understand of what, where, and why breakdowns in creativity occur during distributed collaboration, and what could be done to avoid or mitigate these breakdowns through awareness mechanisms. The result of this exploratory experiment is the design and prototype development of awareness mechanisms to support creativity, the effectiveness and consequences of which are evaluated in the subsequent study. A framework to qualitatively analyze creativity is also presented.

Study 2: Main experiment

This study is a comprehensive evaluation to investigate how the awareness mechanisms from the exploratory experiment are used and with what consequences. The main experiment is a control group study with awareness mechanisms as the independent variable. Following a mixed-method data analysis approach (quantitative and qualitative), the result of this main experiment is the evaluation of the awareness mechanisms to support creativity. Design implications to enhance the awareness mechanisms and new metrics to quantitatively evaluate creativity are also presented.

Significance

The contributions of this dissertation are interdisciplinary in nature: (1) Integrated theoretical framework that establishes the need for awareness in creative collaboration; (2) Requirements analysis (Study 1: Exploratory experiment) to identify types of awareness mechanisms specifically required to support creativity; (3) Design and prototype development of awareness mechanisms; (4) Comprehensive evaluation (Study 2: Main experiment) to assess the effectiveness and consequences of awareness mechanisms; (5) New metrics and frameworks to measure creativity.

This dissertation contributes to the basic science of creativity, to the design science of supporting creative activity, and to the empirical science of measuring creativity. The application of creativity theories from the social sciences in Human Computer Interaction (HCI) and Computer Supported Cooperative Work (CSCW) contexts improves our general understanding of creative collaboration. Second, design and prototypes of awareness mechanisms broadens the science of design by developing new tools for supporting creativity. Third, extension of existing evaluation metrics and frameworks advances our ability to measure creativity using both quantitative and qualitative methods. The broader impact of this dissertation is to enhance the process and product of creative collaboration.

Overview

This dissertation is organized as follows. Chapter 1 introduces the topic of creativity and motivates the need to study creativity in HCI and CSCW. Specifically, the feasibility, effectiveness, and consequences of supporting creativity with awareness in distributed collaboration are being investigated. This dissertation explores this problem by investigating which awareness mechanisms can support creativity, and how are they used and with what consequences. The remaining chapters of this dissertation correspond to this approach using five phases.

Chapter 2 is the first phase. The first phase is a survey of creativity literature in HCI and CSCW, speculating how awareness, and in particular activity awareness, can support creativity in distributed collaboration. This literature review motivates the second phase of this research to understand where and how creativity can be supported with awareness.

Chapter 3 is the second phase. The second phase is an exploratory experiment (Study 1) that partially addresses the first research question (RQ1: What awareness mechanisms can support creativity in distributed collaboration?) by identifying breakdowns in creativity that mandate awareness support. This empirical study motivates the third phase of this research to fully address the first research question.

Chapter 4 is the third phase. The third phase is the design and prototyping of three novel activity awareness strategies and mechanisms to support creativity. This design cycle motivates the fourth phase of this research to evaluate these activity awareness mechanisms.

Chapter 5 is the fourth phase. The fourth phase is a main experiment (Study 2) that addresses the second research question (RQ2: How are these awareness mechanisms used and with what consequences?) by investigating the effectiveness and consequences of using the activity awareness mechanisms. This study reflects on the design of the awareness mechanisms and discusses the implications of the results.

Chapter 6 is the fifth phase. The fifth phase validates findings from the main experiment (Study 2). Using a sample of four groups from the main experiment, this follow-up analysis compares and contrasts extreme cases in terms of their creativity.

Chapter 7 considers the previous chapters and draws overall conclusions. This final chapter summarizes the main results, contributions, and benefits of this dissertation, and offers possibilities for future research.

Chapter 2

Literature review

In this chapter, the literature review is presented, which highlights the gap of supporting creativity with awareness in distributed collaboration. Literature on creativity is first reviewed, particularly the state of the art in HCI and CSCW. Requirements to support creativity in CSCW are presented with design implications. Literature on computer-supported awareness is then reviewed with emphasis on the argument that activity awareness—a specific type of computer-supported awareness—can potentially support creativity in distributed collaboration.

Creativity

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 (e.g., [Boden, 2004; Sternberg, 1999]) and journals (e.g., The Journal of Creative Behavior, since 1967; Creativity Research Journal, since 1988). While the literature on creativity in the social sciences is vast and interesting, the focus of this section is to review creativity literature in HCI and CSCW.

Human Computer Interaction (HCI)

Creativity is an important focus of study in HCI, evident from the multiple conference, magazine, and journal publications. The first symposium *on Creativity and Cognition* (C&C) was held in 1993. Since then, *ACM SIGCHI* (Association for Computing Machinery; Special Interest

Group in Human Computer Interaction) has been co-sponsoring the conferences in 1999, 2002, and 2005, and 2007, now a biannual event. A special issue of *Communications of the ACM* was published in October 2002 on *Creativity and Interface* and December 2007 on *Creativity Support Tools*. In January 2005, the *International Journal of Human Computer Studies* ran a special issue on *Computer Support for Creativity*. *Digital Creativity* is an interdisciplinary journal at the intersection of creative arts and digital technologies that encompasses research in HCI. The US National Science Foundation (NSF) held a workshop on creativity support tools in June 2005 to boost research efforts in HCI and creativity.

Most creativity research in HCI builds on the Genex framework [Shneiderman, 2000]. The Genex framework describes four general areas of activity in which technological tools can support creativity: consulting and collaborating with peers and mentors, generating a set of novel ideas, narrowing these ideas to a smaller set of alternatives, and disseminating ideas and results to the larger community. Though these activities relate to creativity in general, they do not cast creativity as a long-term, scientific, and everyday activity in small group settings, which is the scope of this dissertation.

In general, specific design requirements for creativity support tools have been cursory in nature, not deeply rooted in the vast creativity literature that exists in the social sciences. For example, the Genex framework has eight associated design requirements [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. Supporting such activities through creativity tools could reshape many forms of evolutionary creative work such as in scientific communities. Although useful as a precursory research agenda for user interface design for creativity, these design requirements are rooted largely in one theory, that is, the *Theory of Flow* [Csikszentmihalyi, 1996].

Other strands of HCI research on creativity have attempted to go beyond 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.

There is also a lack of proper methods for measurement and evaluation of creativity in HCI. For example, in the interface analysis of the Upper Atmospheric Research Collaboratory [McDaniel et al. 1994], general techniques that were not related to creativity were used, such as object-action analysis [Moran, 1983], to identify consistency problems in the interface. Even in recent endeavors to evaluate collaboratories, such as in the Biological Sciences Collaboratory [Chin and Lansing, 2004], the authors acknowledge the lack of research on evaluation and resort to traditional methods such as artifact analysis [Kellogg, 1990] to analyze not only the features of collaboratory tools but also the products of creative scientific collaboration that are produced. Multiple methods are required for assessing different aspects of people, processes, and products involved in creative work [Hewett et al. 2005]. One specific contribution of this dissertation with respect to creativity research will be the development of new metrics to measure creativity as a long-term activity.

Computer Supported Cooperative Work (CSCW)

In addition to the many tools that support personal creativity (e.g., see [Abrams et al. 2002; Terry and Mynatt, 2002; Amitani and Hori, 2002]), collaborative tools for supporting social creativity have also been developed. For example, TEAM STORM [Hailpern et al. 2007] is a system that supports the divergent phases of creative group work in design teams. The system allows collaborators to creative, organize, and share multiple design ideas using personal workspaces, group workspaces, and shared large-screen displays.

EVIDII allows designers to associate effective words and images, and then shows multiple visual representations of the relationships among designers, images, and words [Nakakoji et al. 1999]. Providing alternative representations evokes 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 et al. 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 discussions in a shared construction space such as an electronic whiteboard.

The Caretta system [Sugimoto et al. 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, individual pieces produced by different artists, which can be exchanged to synthesize new paintings.

Jones and Edmonds [1995] describe an environment that supports collaborative design as a creative activity between colleagues. Their environment emphasizes integrated access to tools and awareness of collaborators' contributions to the design process through shared access to jointly-authored artifacts.

CodeBroker [Ye, 2001] monitors software developers' programming activities, infers their immediate programming task by analyzing semantic and syntactic information contained in their working products, and recommends task-relevant and personalized usable parts [Fischer et al. 1998] from a reuse repository created by decomposing existing software systems. Supporting awareness of collaborators' activities eases the effort required to coordinate, allowing developers to be more creative.

Prior work on supporting creative scientific activity in collaboratories has focused on enabling general functions such as designing, sketching and generating ideas, and viewing and exploring materials, rather than explicitly analyzing needs and opportunities specific to creativity. For example, Sonnenwald's [2003a, 2003b] collaboratory environment facilitated scientific collaboration, but the tool support (such as word processing and white-boarding applications) for creativity was generic, and creativity per se was not among the explicit system design requirements or evaluation criteria.

Recent work on tool support for creativity has identified the obstacle of weakly integrated productivity tools. Shneiderman [1998] says that the main challenge for designers is to ensure smooth integration across creativity support tools and with existing tools such as word processors, presentation graphics, email, databases, spreadsheets, and web browsers. Since collaboration is a key component of creative work, integration of tools is even more important for collaborative creativity to provide a seamless environment, within which users participate and interact through mediated tools in a shared environment, and work independently at the same time [Candy, 1997].

Because creativity research is a fledging enterprise in CSCW, systematic approaches are required for exploring the design space of supporting creativity with collaborative technology. One way to actualize this goal is by developing first-order approximations, in the form of requirements to support creativity, emerging from theoretical extensions [Ackerman, 2000]. Developing such first-order 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, three requirements are presented for creativity with associated design rationale [Moran and Carroll, 1996]. The design rationale derives from diverse theoretical and empirical investigations in socio-psychological literature on creativity and groups.

Support divergent and convergent thinking

Creativity in science, as in most other domains, involves both divergent and convergent thinking [Guilford, 1983; Levine and Moreland, 2004]. Thus, creativity tools in computer-supported 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] the two constructs are not treated separately. Instead, based on literature, different ways are illustrated to show that both divergent and convergent thinking can be facilitated and 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 et al. 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 and 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 tends 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 et al. 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 and 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 much 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 [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 and Zavalloni, 1969]. This results in premature movement to consensus [Hackman and Morris, 1975], thereby reducing the likelihood of creativity. There is evidence that majorities stimulate less novel or original thinking [Nemeth and 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 and 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 (e.g., [De Dreu and De Vries, 1993; Volpato et al. 1990]). Some studies have even shown that minority dissent, even when wrong, stimulates a search for information on all sides of the issue [Nemeth and Rogers, 1996], and thus, thought is directed at more alternatives [Martin and Noyes, 1996; Nemeth et al. 2001].

It is also argued that dissent can facilitate convergent thinking. Studies have demonstrated that minority dissent stimulates a reappraisal of a situation [Nemeth and 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 and 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 and Saavedra, 1996].

In general, studies (e.g., [Van Dyne and 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 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]. It is proposed that creativity tools in computer-supported collaboration should support development of shared objectives that engenders 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 on 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]). This process also involves pooling information effectively [Stasser and 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, 1988; Pearce and 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 and French, 1948; Lawler and 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 and 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 pre-requisite 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., [Dudek and Cote, 1994; Perkins, 1981]).

Support reflexivity

Knowing how well one is doing is essential to being creative [Csikszentmihalyi, 1996]. In 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 computer-supported 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, 1996], with evaluation particularly being stressed as an important constituent in creative thinking [Runco and 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 et al. 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 and 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 and Fry, 1996]. For example, research with BBC television program production groups, whose work fundamentally requires creativity and innovation, provides support for these propositions [Carter and West, 1998].

Implications for CSCW design

The above-mentioned three requirements to support creativity with their design rationale suggest broader strategies to better support creative endeavors in distributed, computer-supported collaborations. At the most general level, there are three associated design heuristics. First, integrate support for individual, dyadic, and group brainstorming. This approach contrasts with the strategy of just supporting group brainstorming. Second, 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, support flexibility in the granularity of planning, instead of constraining planning to some specific level of detail.

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. 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 et al. 2005]. Given that breaking problems down into components and looking at problems from different angles facilitates effective brainstorming and thus creativity [Levine and 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 et al. 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 [Farooq et al. 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 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 and 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 and 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 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 of group members during the creative work process (see [Csikszentmihalyi, 1996] for discussion of autotelic experience in creativity).

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], and otherwise may be too rigid, can potentially stymie creativity, and users often find ways to work around them.

It is argued 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 and 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, a timeline can provide a temporal representation of plans, whereas an associated concept map can support 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 and 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., CiteSeer: http://citeseerx.ist.psu.edu) 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 et al. 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 et al. 1996].

Computer-supported awareness

From the above literature review of creativity in HCI and CSCW, it is clear that the cognitive and social facets of creative activities have been only directly supported by tools. For example, in the Envisionment and Design Collaboratory, the social facets of creative activities are supported by novel interaction techniques with large tabletop displays. While supporting creative activities through direct mechanisms of tool support is important, it is also critical to consider indirect mechanisms that support creativity at a meta-cognitive level. For example, while novel interaction techniques with large tabletop displays can lead to higher levels of creativity in groups, it is essential to support members' shared understanding that can also lead to higher levels of creativity. Supporting creativity at a meta-cognitive level requires tools to make collaborators cognizant of each other's work. One way to achieve this goal is to support creativity through computer-supported awareness.

Computer-supported awareness is cognizance about other's work, which is critical for successful collaboration [Dourish and Bellotti, 1992]. The concept of awareness in CSCW literature has taken many forms. For example, social awareness [Erickson and Kellogg, 2000] involves knowing who else is present in a shared workspace; workspace awareness [Gutwin and Greenberg, 1996; Gutwin et al. 1996] conveys who is doing what in the sense of manipulating shared artifacts; and so forth (for a detailed review of awareness in CSCW, refer to [Schmidt, 2002]). Below, activity awareness is reviewed with the argument that this specific type of computer-supported awareness can potentially support creativity.

Activity awareness

Activity awareness [Carroll et al. 2003; Carroll et al. 2006] is awareness of collaborators' work that supports performance in complex tasks over long-term endeavors directed at major goals. This dynamic and long-term view of activity awareness has its roots in Activity Theory [Bertelsen and Bødker, 2003; Bødker, 1991; Bødker, 1996; Engestrom, 1990; Kuutti, 1991]. Activity awareness emphasizes the role of social processes of grounding, the construction and testing of common ground, the importance of cultivating and enacting practices and otherwise participating in communities of practice, the processes of social capital formation, and the role trust, and the centrality of human development, including learning and exploration, improvisation in routine behavior, etc. Activity awareness implies cognizance of other people's plans and understandings, knowledge of what one's collaborators are doing, and identifying, coordinating, and carrying out different types of task components, such as assigning roles, making decisions, negotiating, and prioritizing.

One way activity awareness can be operationalized is through notification systems. Notification systems [McCrickard et al. 2003] are typically lightweight, event-triggered displays of information peripheral to a person's current task-oriented concern, for example, system status updates, email alerts, stock tickers, and chat messaging. They animate and enrich the display areas outside the primary application window(s), and help to keep people aware of events beyond their current task-oriented interactions.

An example of providing activity awareness through notification systems is shown in Figure **2-1**. Figure **2-1** is a screenshot of an online, collaborative workspace that supports activity awareness through temporal (timeline) and semantic (concept map) representations. These representations provide multiple views on a set of underlying shared activities and artifacts [Ganoe et al. 2003]. Further, the timeline view also supports reflection on work activity through session histories. The timeline depicts artifacts versions, evolving plans, task decomposition, and changing roles of group members.

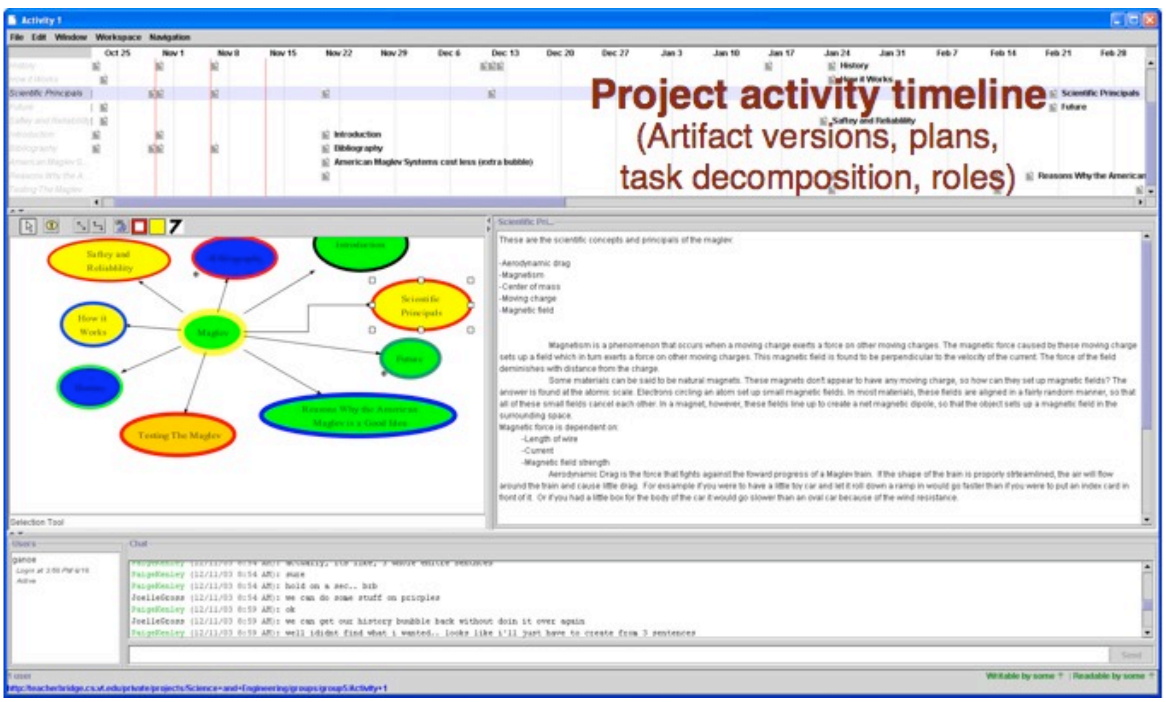

Figure **2-1**: The timeline provides activity awareness by depicting artifact versions, plans, task decomposition, and roles.

Relationship between activity awareness and creativity

Based on logical argumentation from literature, activity awareness can potentially support creativity. One condition for creativity is having clarity of goals [Csikszentmihalyi, 1996]. In group collaboration, 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 on the group perceive the situation [Hutchins, 1995]. Activity awareness seeks to support such cognizance of other people's plans and understandings.

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]). This process also involves pooling information effectively [Stasser and 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 and Gustafson, 1988; Pearce and 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 and French, 1948; Lawler and Hackman, 1969]. One way activity awareness supports higher participation in decision making is to engage users in the identification, coordination, and execution of different types of task components, such as making decisions.

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 and

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]. Activity awareness can encourage goal commitment by prodding members to reflect on their own work activities in the context of the overall group goals.

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 creative ideas cannot be found by intentionally looking for them. She also argues, however, that if people are not receptive to them, they will not come—that their occurrence requires an appropriate attitude. 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 pre-requisite 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., [Dudek and Cote, 1994; Perkins, 1981]). Activity awareness can help group members to think about what they will do next by prodding them to internalize other's intentions and externalize their own.

In general, the central theme of activity awareness is to inform group members of their own activities in the context of other's work. Activity awareness implies shared understanding, evaluation, and renegotiation of plans, which inform subsequent discussions and offers the possibility of helpful and creative transformations and meanings. In fact, knowing how well one is doing is essential to being creative [Csikszentmihalyi, 1996]. In context of group collaboration, 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 activity awareness seeks to support directly.

From the logical argumentation above, activity awareness seems to be a plausible and feasible way to support creativity. However, this conjecture needs to be empirically validated. The empirical contribution of this dissertation—Study 1 (exploratory experiment) and Study 2 (main experiment)—intends to fulfill this goal.

Summary

Research on creativity is continuing to flourish in HCI and CSCW. Many tools exist that support personal and social creativity. One of the most successful ways of support collaboration in CSCW contexts has been through computer-supported awareness mechanisms. However, review of the literature reveals that support for creative collaboration through awareness mechanisms has not been investigated before. This gap in literature provides the central motivation for the research in this dissertation. Thus, the remaining chapters of this dissertation seek to answer the following two research questions:

- RQ1: What awareness mechanisms can support creativity in distributed collaboration?

- RQ2: How are these awareness mechanisms used and with what consequences?

Chapter 3

Exploratory experiment

In this chapter, the exploratory experiment is presented, which partially addresses RQ1: What awareness mechanisms can support creativity in distributed collaboration? This is a qualitative study that uses a naturalistic research strategy using comparative case studies [Arrow et al. 2000].

Goal of the study

Decomposing the overall research question RQ1, it is first important to understand the challenges in the process of creativity that can potentially be addressed by awareness mechanisms in distributed collaboration. Once these challenges are identified and codified, awareness mechanisms need to be designed and developed, which can then be evaluated through a subsequent empirical study. Thus, the goal of this study is to address the first of the following two specific research questions; the second specific research question is addressed in Chapter 4 of this dissertation:

- RQ1(a): What are the challenges in the process of creativity that occur in distributed collaboration?
- RQ1(b): What awareness mechanisms can address these challenges?

Study details

Participants

Three groups comprising three members each worked in a distributed setting on a collaborative task for eight days (D0 to D7, where 'D' stands for 'Day'). Eight days or approximately one week was considered as an appropriate baseline to characterize long-term activity. It was thought that a shorter task duration would have resembled an artificial setting that would not have allowed group dynamics and nuances in creativity to play out and be observed by the researcher.

Group members were recruited from the graduate student population at a large university majoring in computer and information science. The three groups were formed opportunistically based on availability of participants to volunteer for the study.

Overall task

Each group was asked to write an opinion piece (approximately 1000 words) related to computer science education, specifically on teaching software programming to new computer science students. This task was chosen as being appropriate for the participant sample because of their background in the domain (i.e., computer and information science). Further, the task was relevant to contemporary research literature – recently, in *Communications of the ACM*, opinion pieces have been published on the topic of teaching software programming to new computer science students (e.g., [Martin, 2006]).

The groups were instructed that they would be assessed on the creativity of their opinion piece. As guidance to the groups, they were given a foundation paper by Westfall [2001], and were asked to expand, critique, and/or base their opinion piece on this paper. See Appendix A for full set of instructions.

Tools

Group members worked on the shared task in a collaborative environment called BRIDGE (Basic Resources for Integrated Distributed Group Environments; http://bridgetools.source forge.net; see [Ganoe et al. 2003]). The BRIDGE Java-based client supports shared editing of documents through replicated objects. Replicated objects are objects that are retrieved by multiple collaborating sessions and whose state is kept synchronized on all clients and a server when any replica is changed. The following collaborative artifacts were provided in BRIDGE: persistent chat tool (to communicate), wiki-based brainstorming space (to develop ideas), concept map (to visualize ideas), and wiki-based opinion piece (to write the final opinion piece). All these artifacts supported synchronous and asynchronous collaboration.

Procedure

For each group, all three members were invited to an initial kickoff face-to-face meeting that lasted approximately 25 minutes. Each member was introduced to the others and given an informed consent form. The researcher explained the task, demonstrated the use of BRIDGE, and clarified any issues related to the task or tools. The researcher emphasized that the collaboration should be carried out only through BRIDGE (i.e., distributed collaboration) and that the final opinion piece would be evaluated based on its creativity. Approximately five minutes toward the end of this meeting were allotted for *social grounding* [Levine and Moreland, 2004]. Based on pilot testing, it was considered essential to provide group members with a face-to-face opportunity to establish initial common ground and strategize about their collaboration for the subsequent duration of eight days.

Data collection

Demographic and background data was collected during the kickoff meeting. Participant creativity scores were also obtained using a 30-item creativity scale derived from the adjective checklist (ACL) [Gough, 1979]. There are 18 positive items and 12 negative items on this scale. Each positive item adds one point to an individual's creativity score and each negative item results in a one-point deduction. Thus, the minimum and maximum creativity scores are -12 to +18. Table **3-1** summarizes the participants' background data (all names have been anonymized).

Table **3-1**: Background data of participants.

Name	Group	Academic background	Individual creativity score
Ahmed	Bravo	Computer science/psychology	6
Chris	Bravo	Computer science	-4
Judy	Bravo	Computer science/psychology	2
Dipak	Echo	Computer science/communications	5
Sam	Echo	Computer science/mathematics	13
Wendy	Echo	Computer science	-3
Hasan	Foxtrot	Computer science	2
Jay	Foxtrot	Information science	-1
Marie	Foxtrot	Computer science engineering	10

During the experiment, all interactions in BRIDGE were logged on the server. For example, communication messages in the chat log and changes to shared data were recorded with time stamps. To periodically check on the group's progress, the researcher e-mailed each participant individually on D2 and D4 asking for a brief update (approximately 2-3 sentences) on the task. See Appendix B for progress update email.

After the experiment, semi-structured interviews (approximately 30 minutes) with each participant were conducted. The questions asked participants about their reflections on the creative process (e.g., How were novel ideas generated and implemented?). See Appendix C for semi-structured interview questions.

Data analysis

Following a case study approach [Yin, 2003], each group was treated as a distinct case. Each case was read, summarized, re-read, and compared with the others, thus providing a rich cross-case interpretation. A qualitative analysis approach was followed to understand and identify breakdowns in creativity. Some quantitative measures are also reported as secondary sources of data collection to understand the holistic process of creativity, though they have not been taken into account in the data analysis because of the small sample size (three cases).

Understanding group participation

Data related to group participation was extracted from the server logs. For example, the total number of sessions for the brainstorming space and final opinion piece was determined. A session was defined as one continuous interaction during which group members change an artifact. The number of words typed in the chat tool was counted. The number of synchronous chat sessions was also counted. A synchronous chat session was defined as an instance during which at least two group members are logged in at the same time and communicate interchangeably.

Breakdown analysis and coding scheme

The communication in the chat logs was analyzed for content. The chat logs were coded for breakdowns in creativity. A breakdown is a problem in system use that interrupts a person's activity, making him or her more conscious of the system, and less able to focus on the activity that the system is supporting [Winograd and Flores, 1986]. Carroll's et al.'s [2003] method for analyzing collaborative breakdowns was adapted for the context of using CSCW systems to support creative group activity. Collaborative breakdowns involve multiple inter-related problems experienced by different collaborators, and they typically require a combination of actions taken by multiple agents to diagnose and repair.

A theory-driven conceptual framework from Farooq's prior work [Farooq et al. 2005] was used to deductively develop an integrated coding scheme for analyzing breakdowns in creativity from the chat logs. Breakdown occurrence rather than frequency was coded because the goal of this exploratory experiment was to identify a range of issues that led to breakdowns in creativity. This approach is appropriate for exploratory data analysis where the focus is on hypothesis generation rather than hypothesis confirmation [Carroll et al. 2003].

The theoretical coding scheme consists of five *macro*-level codes, each comprising several *micro*-level codes, as shown in Table **3-2**. The codes are briefly discussed below. Coded examples from the data are provided in Appendix D.

Table **3-2**: Theoretical coding scheme.

Categories	Codes	References
Social influences	*SI*	Ocker, 2005; Nemeth and Nemeth-Brown, 2003;
Groupthink	SI_GTK	Janis, 1982;
Normalization	SI_NZN	Moscovici, 1974;
Majority influence	SI_MJI	Moscovici, 1974; Nemeth, 1995;
Polarization	SI_PZN	Fraser, 1971; Moscovici and Zavalloni, 1969;
Minority dissent	SI_MND	Nemeth and Nemeth-Brown, 2003;
Information sharing	*IS*	Stasser and Birchmeier, 2003;
Common information pooling	IS_CIP	Stasser and Birchmeier, 2003;
Unique information pooling	IS_UIP	Stasser and Birchmeier, 2003;
Shared understanding	*SU*	West, 2003;
Reflexivity: reflection	SU_RRF	West, 1996; West, 2000;
Reflexivity: planning	SU_RPL	West, 1996; West, 2000;
Reflexivity: action/adaptation	SU_RAA	West, 1996; West, 2000;
Divergent thinking	*DT*	Milliken et al. 2003;
Generation of multiple perspectives	DT_GMP	Guilford, 1950; Torrance, 1969;
Reflection of multiple perspectives	DT_RMP	Guilford, 1950; Torrance, 1969;
Unique information pooling	DT_UIP	Guilford, 1950; Torrance, 1969;
Convergent thinking	*CT*	Milliken et al. 2003;
Critical evaluation of perspectives	CT_CEP	Moneta, 1993; Torrance, 1969;
Perspective implementation	CT_PIM	Moneta, 1993; Torrance, 1969;

(1) Social influence. Five types of social influence were identified that affect creativity in groups:

(a) *Groupthink*: Part of the reason for suboptimal performance in creative groups is that members desire consensus. This is known as groupthink, arising from a situation marked by homogeneity of its members, strong and directed leadership, group isolation, and high cohesion [Janis, 1982].

(b) *Normalization*: This is the process whereby the "reciprocal influence of group members induces them to formulate or to accept a compromise" [Moscovici, 1974, p. 208]. Normalization can occur within creative groups where the majority of members do not have a well-defined norm or solution, and they converge on an average response [Ocker, 2005].

(c) *Majority influence*: This can occur in situations when a minority opinion holder(s) exist among a group of otherwise majority opinion holders [Ocker, 2005]. The majority achieves influence as it exerts social pressure on the deviant minority opinion holder, causing him or her to conform to the majority opinion so that the group can achieve uniformity [Ocker, 2005].

(d) *Polarization*: When group members favor a particular side of an issue but differ in their specific judgments, discussion often leads to consensus, but the consensus position is more extreme than the average of the individual judgments [Nemeth and Nemeth-Brown, 2003]. This is known as polarization, the notion that shared beliefs exacerbate perceptions and behaviors [Nemeth and Nemeth-Brown, 2003].

(e) *Minority dissent*: Dissenting opinions stimulate divergent and creative thought [Nemeth and Nemeth-Brown, 2003]. It is the situation when initially unpopular views still get considered and remembered, thus making the group's total inventory of ideas richer.

(2) Information sharing. A necessary condition for creativity is for group members to develop shared objectives, which requires them to leverage their domain-specific knowledge and engage in information sharing [Nickerson, 1999]. Broadly, a group can pool information in two ways [Stasser and Birchmeier, 2003]:

(a) *Common information pooling*: This is information known by all members prior to discussion.

(b) *Unique information pooling*: This is information held by one member before group discussion.

(3) Shared understanding. Shared understanding is the extent to which members collectively reflect on the group's objectives, strategies, and processes [West, 1996]. Also known as group reflexivity [West, 2000], shared understanding consists of three elements:

(a) *Reflection*: This consists of attention, awareness, monitoring, and evaluation of the object of reflection. It is about critical thinking, which is thinking that is focused, disciplined, logical, and constrained [Nickerson, 1999].

(b) *Planning*: This is one of the potential consequences of the indeterminacy of reflection because courses of action can be contemplated, intentions formed, plans developed, and the potential for carrying them out is built up [West, 2003].

(c) *Action/adaptation*: This 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].

(4) Divergent thinking. This is the process of taking different perspectives and generating alternative solutions. Divergent thinking can be manifested in three ways:

(a) *Generation of multiple perspectives*: This involves generating a set of novel ideas. A wider range of perspectives is more likely when several members approach an issue or problem from different angles or backgrounds [Milliken et al. 2003].

(b) *Reflection of multiple perspectives*: Another way that divergent thinking promotes creative cognition is the degree to which a group considers multiple alternatives before committing to any one decision or course of action [Hackman, 1990].

(c) *Unique information pooling*: Another manifestation of a group's capacity for divergent thinking is the degree to which members are willing to share unique information [Milliken et al. 2003]. Note that this micro-level code also occurs under "information sharing", implying that unique information pooling can even happen beyond the group's stage of divergent thinking.

(5) Convergent thinking. In addition to divergent thinking, convergent thinking allows groups to select from available options and put these ideas into practice. This involves two steps:

(a) *Critical evaluation of perspectives*: This involves funneling down a set of ideas or opportunities into a manageable decision from which to proceed to implementation [Milliken et al. 2003].

(b) *Perspective implementation*: Selected ideas must be not only novel but practically feasible as well [Milliken et al. 2003]. Perspective implementation involves the execution of a selected idea.

Breakdowns in creativity were identified based on the data from the three cases and literature review in [Farooq et al. 2005]. Positive episodes of group creativity were identified, which were used as comparative benchmarks to identify breakdowns in the specific study context.

An independent researcher, not part of our team but who was familiar with creativity research, reviewed the theoretical coding scheme and discussed practical issues of applying the codes with the researcher. With a small data sample, one of the issues discussed was the evidence in the chat communication that is required to categorize a data snippet with a particular code. For example, it was agreed that a unique idea (as a result of "unique information pooling") was one that had not been discussed before in the group communication.

In addition to the theoretical coding scheme, group dynamics were also recorded. For example, in Bravo, it was observed that Ahmed's minority idea caused group conflict that eventually led him to be marginalized. Though such group dynamics are interweaved with creativity, for the scope and goal of this experimental study, precedence is given to the dynamics of creativity and its associated breakdowns over group dynamics.

Assessing creativity of product

Based on Amabile's [1996] consensual technique for creativity assessment, the level of creativity in each group's final opinion piece was assessed independently by two judges. The average of the judges' ratings was taken on a creativity scale from 1 (low) to 10 (high) (see details of assessing creativity of product in [Ocker, 2005]).

Triangulation

User quotes were culled and collated from the two progress reports and interviews by identifying appropriate instances that helped to triangulate on rigorous interpretations of the data. The use of other shared artifacts (e.g., brainstorming space) by group members also facilitated this process of triangulation.

A research challenge that was encountered was the accurate identification of breakdowns, given their subjective nature. For example, group members may not consider what the researcher perceives as groupthink. The progress reports helped the researcher perform member checking by corroborating his analytical perspective on the data with the group members.

Results: Breakdowns in creativity

Four breakdowns in creativity emerged from the data analysis. These breakdowns can be potentially supported with awareness mechanisms.

Table **3-3** summarizes group level descriptives. Members in Bravo communicated and collaborated the least in comparison to the other two groups. Only two members (Ahmed and Chris) changed the brainstorming space thrice among themselves; Judy did not contribute to this space. Chris and Judy individually wrote their final opinion pieces (that were integrated by the investigator into one piece for assessment); Ahmed did not contribute content to Chris or Judy's opinion piece.

Table **3-3**: Group level descriptives.

	Bravo	Echo	Foxtrot
Brainstorming space			
# of words	338	929	1797
# of sessions	3	10	14
Final opinion piece			
# of words	537	1780	716
# of sessions	0	20	3
Chat communication			
# of chat words	1443	3689	1712
# of synchronous sessions	2	4	2
Group creativity score	4	15	11
Creativity of opinion piece	3.8	5	4.5

Members in Echo communicated the most. They collaborated moderately using their brainstorming space but collaborated the most on their final opinion piece by iterating twenty times. Echo members decided to finish their opinion piece a couple of days before the due deadline. All members contributed to the brainstorming space and opinion piece.

Members in Foxtrot communicated moderately. Foxtrot members indicated in their interviews that they also used the brainstorming space for communication, which explains the high frequency of words and sessions in the brainstorming space. Hasan and Jay were relatively more active than Marie. Marie was not part of any session changes to the final opinion piece and only contributed to one session change in the brainstorming space.

Table **3-3** also shows the group creativity score (sum of individual creativity scores). Groups with higher group creativity scores scored higher on the creativity of their opinion piece. Following are the four breakdowns that were identified from the data analysis.

Minority ideas under-considered

During cognitive conflict and dissent, one of the breakdowns in creativity that was observed was the under-consideration of minority ideas. This was mainly due to normalization or majority influence in the group, resulting in the dismissal of dissenting ideas that may have been novel. The following snippets from Bravo and Echo's group dynamics illustrate this point.

Bravo: Ahmed's "debate" idea dismissed readily

Ahmed joined the group discussion late on day D2, apologized for being absent, and indicated that he is "caught up on the reading". Ahmed proceeded immediately to share his view of the task and proposed a "point-counterpoint type debate" among the Bravo members. Judy replied the same day and was hesitant to further explore Ahmed's idea; she said: "I don't think we have time or space for a debate". At the same time though, she did ask Ahmed for "educational-like examples" to elaborate on his debate topic, which Ahmed did not provide.

In the second set of progress reports, Chris said he was open to Ahmed's idea of a debate; but Judy dismissed Ahmed's approach, attributing this decision as a collective process ("we have kind of decided…"). After a hiatus, Ahmed only reappeared in the group discussion on D7. Communication on this day was chaotic. Ahmed and Judy exchanged multiple threads of synchronous communication, with Ahmed pushing for his debate idea and Judy chiding at his approach, providing explanation of why the debate topic is not worthwhile. Judy abruptly ended her communication by concluding, "it is too late". In his interview, Ahmed was candid about his feelings toward Judy, expressing his discontent by asserting that "she {Judy} said it was too late repeatedly and it wasn't too late".

Echo: Misunderstanding about Sam's "syllabus" idea

On D2, Sam and Wendy chatted synchronously about materializing their top-down approach to programming. Sam proposed to include an "outline of the course" that would summarize the topics to teach as part of the top-down approach. Wendy asked, "Do we need to?", trying to understand whether "advocating a course" was part of the task scope. Sam said that without a concrete example, such as a course outline, the opinion piece would not be able to "show what we mean by top-down approach". Wendy agreed. Dipak missed this chat session on D2.

When Echo reconvened for another synchronous chat session on D3, they started to divide the sections with Sam asserting, "I can do why this is a novel approach and the syllabus". Dipak, not knowing the context of the prior meeting, immediately replied in confusion: "Why are we making a syllabus, again?" Sam proceeded with his arguments once again, reiterating his rationale that he communicated to Wendy the previous day, after which Dipak implicitly agreed and asked if the syllabus would better fit in the "teaching methods" section rather than the "novel approach" section. Wendy immediately reacted: "it appears so". Thereafter, Dipak summarized the content of the proposed opinion piece without any reference to the "teaching methods" section. During task allocation, Sam opted for the "novel approach" section and asked Dipak whether he will do the "proposed teaching methods" section. Dipak complied. However, the syllabus was never written about in the final opinion piece.

In his interview, Sam, whose idea it was to include the syllabus, reflected deeply on what happened: "After one meeting…the syllabus part got into the outline. But then it got removed in the next outline. It was Wendy who said that {to remove the outline}". Sam displayed a strong feeling while reflecting on his contribution. When Wendy was probed about the syllabus idea during her interview, she hedged her feelings toward the syllabus and gave a defensive response:

"We kind of like agreed with him {Sam} in the end. It {the syllabus} did become part of the final piece." In actuality, it never did.

Discussion

From the analysis, there is clearly a need to preserve minority ideas and make it easier to retrieve, reconsider, and reflect on them. Documenting cognitive conflict and dissent, the rationale for such minority ideas, and how group members influenced and decided their outcome can allow collaborators to reappraise the situation and enhance their confidence in the group's creative solution.

Novel ideas easily lost

The novel ideas generated and narrowed down by group members in prior interactions did not fully carry over to subsequent interactions, were not readily available for review, and/or could not be easily integrated. As a result, novel ideas were easily lost, either for part of the group interaction such as in Bravo, or for the entire duration of the task as it happened in Foxtrot.

Bravo: Ahmed did not know about the "animation" idea

On D0 and D1, Chris and Judy brainstormed the possibility of doing "something with the animation idea" as an approach to teaching software programming. Because Ahmed joined late, he did not know about this "animation" idea. Ahmed claimed to have caught up on the reading but did not read or reflect on the previous chat communication between Chris and Judy. As a result, Ahmed did not fully reflect on the animation idea that Chris and Judy agreed upon as a topic for the final opinion piece. The first set of progress reports corroborated this lack of shared understanding among the group members. Ahmed seems disappointed, as he does not have a "real sense" of what his collaborators were doing.

Foxtrot: Hasan's "sequencing concepts" idea did not carry over

On D1, Foxtrot members communicated effectively with each other by sharing different perspectives and narrowing their approach to "teach students with no programming experience". On D4, for which all the group members had planned to meet synchronously at a common time, only Hasan and Jay came online. Hasan decided that he and Jay should proceed as Marie "can read this chat window next time she log{s} on". Both of them contributed ideas and integrated them to narrow their teaching approach toward separating "OO programming philosophy from coding". When Hasan suggested deciding on "concepts" that would be "introduced to new students and in what sequence", Jay had to leave and said: "How about we just stop here today". Jay then volunteered to write a "summary" in the brainstorming space "so that Marie can read it later."

Jay's summary of his discussion with Hasan in the brainstorming space (D4) was quite detailed. However, the summary did not include Hasan's last idea in D4's chat session regarding the sequence of concepts to be taught to students. As a result, Hasan's idea was never incorporated into the final opinion piece.

Discussion

The analysis suggests that a recap of interaction history, specifically for novel ideas, is important for group members to have access to. Prompting group members to create interim summaries or automatically summarizing interaction history across time can provide context for future interactions and facilitate a meaningful codification of the novel ideas during divergent and convergent thinking.

Lack of critical evaluation of perspectives

Another breakdown that was observed was the hasty decision by groups in choosing which ideas to converge on and implement. This resulted in a lack of critical evaluation of perspectives. In the case of Bravo, this was due to time limitations, whereas in the case of Echo, it was apparent that the members experienced groupthink.

Bravo: Time-pressured consensus

Since their first interaction on D0, Chris and Judy agreed on the "animation" idea. Instead of developing or reflecting on this idea further, the group was mired in conflict over Ahmed's debate idea. Bravo found themselves racing against time. On D6, Judy reflected on the looming deadline ("We need to get on this today") and shared a few concrete ideas to implement. On D7, Chris was still confused about the overall task requirements and asked whether it would be appropriate to just submit "an idea report".

Echo: Quickly decided on "top-down" approach

On D0 and D1, Echo members communicated synchronously in an organized manner. Each member contributed to the discussion, generated ideas, and converged early on "a top-down approach, introducing students to programming via projects that are 'fun' and likely more engaging" (brainstorming space). The first set of progress reports indicated that all the group members were on the same page. Part of the reason for quickly deciding on an approach without critical evaluation was Echo's highly cohesive and complacent approach to the creative group task.

During the whole collaborative process, group members efficiently allocated tasks. Wendy asked if they should "divide sections" to which Sam replied, "we can make an outline…and then everyone can contribute to any section". The chat communication was supplemented by work summaries written in the brainstorming space. For example, on D3 and D4, Dipak posted the following respectively in the brainstorming space: "We have decided to split the writing of the final piece…{outline of final piece}" and "We briefly met to agree…{summary of chat discussion}". Even during synchronous chat sessions, Echo members summarized their work periodically. For example, on D2, Wendy said in the beginning of Echo's synchronous chat session: "ok so lets summarize wat {what} we have".

Discussion

In addition to summarizing interaction history, group members need a workspace for reflection where they can discuss pros and cons of novel ideas, provide an exegesis, and decide how a particular idea would be implemented.

Weak reflexivity during convergence

Part of producing a creative output is to have a shared understanding to allow for focused implementation of novel ideas. The data analysis suggested that Bravo and Foxtrot exercised weak reflexivity during convergent thinking during which the groups dissipated in their collective effort to develop a coherent opinion piece.

Bravo: No one knew the status of the opinion piece

Individual interviews indicated that none of the group members knew exactly what happened to the final opinion piece. Judy said she “was hoping” that Chris would add to her contribution and then asked the investigator if s/he knew the outcome. Chris implied that there were “no big differences” between what he and Judy wrote, and said that he did not know what Ahmed produced. Showing dismay over the collaborative process, Ahmed said his group members “were just sort of doing their own things”.

Foxtrot: Every man for himself

After D5, the discussion between Foxtrot members petered out and only Jay contributed to the brainstorming space thereafter. On D6, Jay requested his group members to converge on their ideas in order to meet the deadline on D7: “And since tomorrow morning we will deliver our final product, I suggest all of us make our ideas clear and see how we can put them together.” Receiving no reply, either in the chat tool or brainstorming space, he integrated prior ideas and informed his group members: “…here is…what I get based on what we discussed so far. If you have other ideas, just put in it, or revise it directly.” On D7, yet again without any reply, Jay wrote his last message in the brainstorming space: “…I put…what I have in the ‘Final opinion piece’…Feel free to modify or add new stuff in it.” Only Hasan added content on D7 to the final opinion piece but did not alter Jay’s contribution.

Jay's reaction in the interview reflected on the "weak" collaborative process, especially "towards the end". Hasan thought that their opinion piece was not as creative as it could have been. He expressed a desire to see a "summary" and "history" of previous interactions so that ideas are not lost. He said: "I would like to see what happened yesterday related to something the day before". Marie reiterated Hasan's thoughts, strongly expressing a need for tools to create a "chain" between the ideas being shared, which otherwise seem like unconnected "blurbs" that people leave "up there".

Discussion

This breakdown was a result of more than just a lack of explicit task allocation. Group members need an integrated view that networks and combines their contributions in a meaningful way and provides a social and temporal index of who is doing what and when.

General discussion

The breakdowns identified from the exploratory experiment are characteristic of distributed collaboration, though they may also occur in face-to-face collaboration. Understand the process of creativity in distributed settings has not been directly investigated. For example, Sonnenwald and colleagues [2003a, 2003b] compared the processes and outcomes of scientific work between face-to-face and distributed (collaboratory) settings and found no statistically significant quantitative difference between the two conditions. Further, creativity was not directly investigated. Other research in distributed scientific collaboration has focused on relatively direct performance phenomena like productivity, workflow, coordination, and individual motivation, albeit with fairly limited success [Olson et al. 2008]. The exploratory experiment complements this body of research by advancing our understanding of the creative process in distributed settings.

Moving creativity research to a more solid footing requires developing a better foundation in measurement. The study demonstrated the application of five characteristics (social influence, information sharing, shared understanding, divergent thinking, and convergent thinking) to analyze the process of creativity as a long-term, collaborative activity. In an attempt to characterize and understand creativity as a long-term activity, product-oriented metrics do not provide as deep and rich of an interpretation as process-oriented metrics. The integrated theoretical framework was used to articulate thick descriptions of the breakdowns in distributed collaboration by capturing the developmental and evolving nature of the creative process. This could not have been achieved by solely relying on, for example, the group creativity score as a product-oriented measure.

Conclusion

This chapter addresses the first part of the first research question (RQ1: What awareness mechanisms can support creativity in distributed collaboration?), that is, RQ1(a): What are the challenges in the process of creativity that occur in distributed collaboration? Based on qualitative analysis of three groups collaborating on a long-term, creative activity in a distributed setting, four breakdowns in creativity are identified using an integrated theoretical framework: (1) Minority ideas were under-considered; (2) Novel ideas were easily lost; (3) There was a lack of critical evaluation of perspectives; (4) Reflexivity was weak during convergence. The breakdowns suggested that they occur from a lack of activity awareness.

Chapter 4

Design implications

In this chapter, design implications are presented, which fully address the second part of the first research question (RQ1: What awareness mechanisms can support creativity in distributed collaboration?), that is, RQ1(b): What awareness mechanisms can address these challenges? These design implications address the breakdowns in creativity identified from the exploratory experiment. The breakdowns, in general, highlight the need for groups to have their own interim work re-presented to them. The data analysis suggests that the breakdowns stemmed from a lack of activity awareness. Below, three design strategies are described to address these breakdowns, which were developed and integrated as awareness tools in BRIDGE for evaluation as part of the main experiment.

Brainstorm recap

The brainstorm recap design strategy addresses the breakdown of novel ideas being easily lost. The goal of this design strategy is to allow group members to identify and codify ideas generated during brainstorming.

Design rationale

Preserving novel ideas consists of two support mechanisms: identifying ideas and then finding these ideas during later consideration. A design feature that allows flagging could be used to tag a novel idea. This design feature is similar to the ones implemented in Issue-Based Information Systems (IBIS) [Rittel and Webber, 1973] where opinions could be tagged.

Figure **4-1** shows a design mock-up of the brainstorm recap design strategy. The novel ideas are being tagged using a widget (lightning bolt). Group members can identify novel ideas from the chat logs. In order to codify and find these ideas at a later point in time, the ideas are exported to a concept map representation where group members can define relationships between different ideas. The concept map provides a semantic space to preserve novel ideas in a structured way.

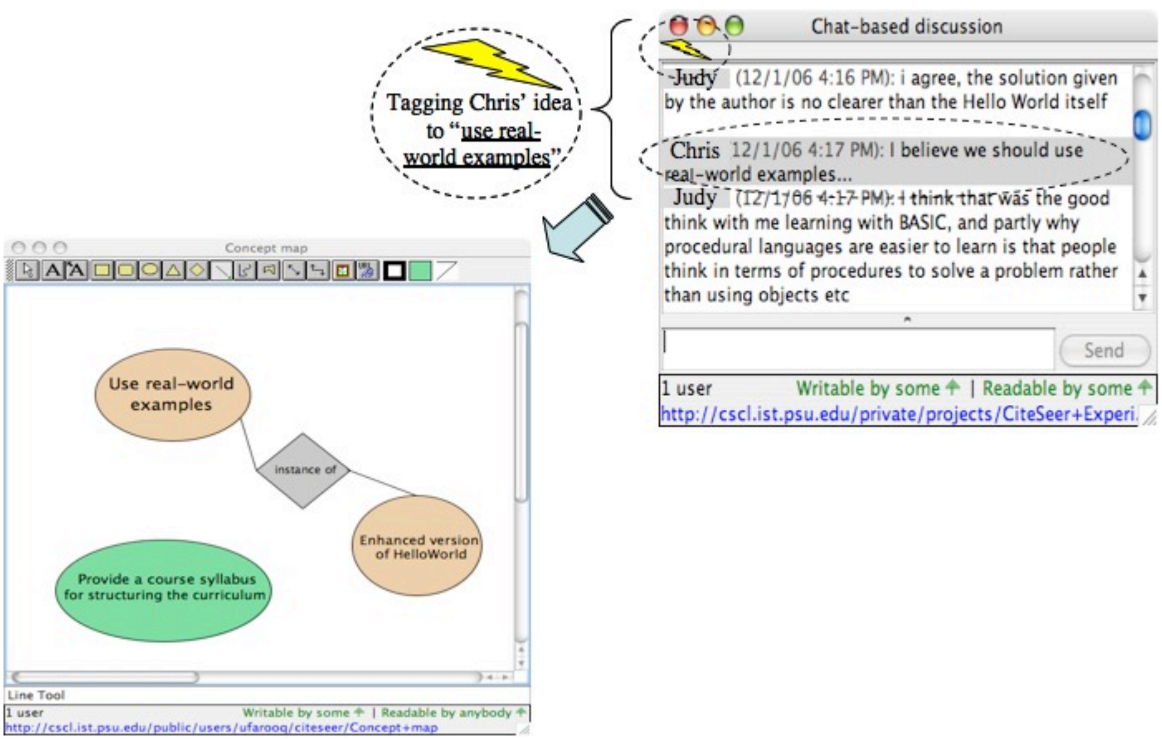

Figure **4-1**: Design mock-up of brainstorm recap.

Design issues

Part of the difficulty with IBIS was the severe cognitive overhead dictated by the high degree of structure. In the brainstorm recap design mock-up, the preservation of novel ideas depends entirely on the group members identifying these ideas. Further, it is likely that if all group members do not participate in identifying novel ideas, some ideas may get lost as the novelty of ideas depends on the user. It is plausible that a recommender system mines chat logs for patterns, uses machine learning techniques to learn from a training set, and then automatically identifies novel ideas based on past user behavior.

Prototype design and implementation

Given the scope of this dissertation, the brainstorm recap design strategy was developed as a Wizard of Oz (WOz) intervention. WOz is a useful prototyping approach to explore user interfaces that require complex sensing and intelligent control logic. In WOz studies, a human operator plays the role of a computer system, typically simulating the system's intelligence. WOz is a useful and popular approach in HCI and CSCW studies [Dow et al. 2005].

For the brainstorm recap design strategy, the researcher would create a summary of the group's ideas and present them in a codified way as shown in Figure **4-2**. To maintain consistency across groups, the researcher followed a script to generate the summary (see Appendix E).

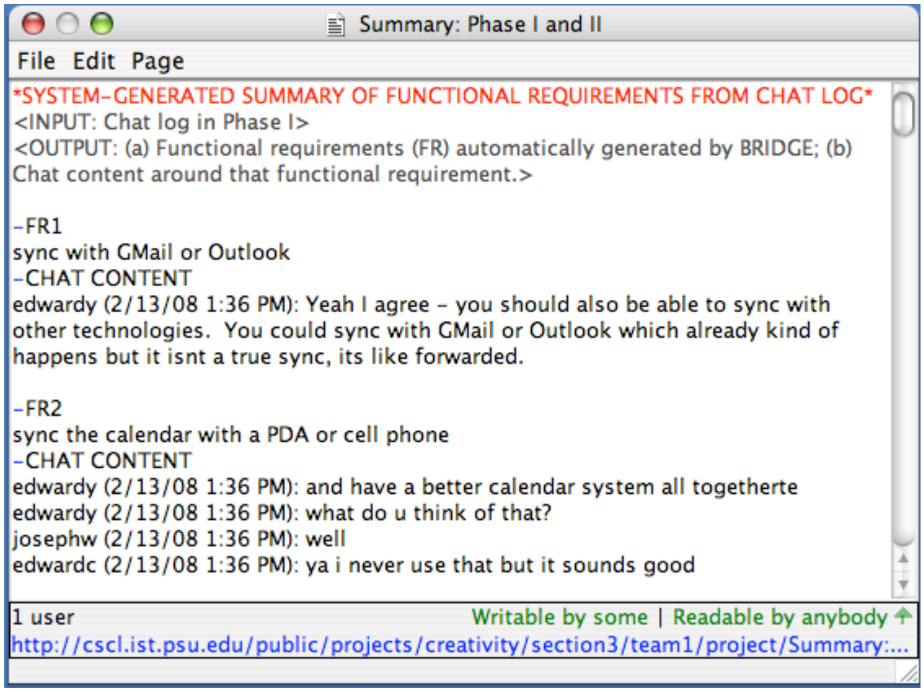

Figure **4-2**: Prototype screenshot of brainstorm recap.

The researcher would read, summarize, and re-read each group's chat log to generate an accurate summary. However, it is possible that some ideas may still have been lost in this process. The summary—which is uneditable—would then be presented to the group members to reflect on as part of their overall task. In Figure **4-2**, the brainstorm recap shows two ideas as functional requirements. Each idea is associated with a chat blurb to provide context for that idea. In cases where the chat blurbs occurred at different times for the same idea, all the blurbs were thus included.

Ideational summaries

The ideational summaries design strategy addresses the breakdowns of minority ideas being under-considered and a lack of critical evaluation of perspectives. The goal of this design strategy is to automatically summarize and recommend ideational activities from system logs.

Design rationale

Consider a creativity support tool that allows group members to enumerate ideas they are generating during divergent thinking, list pros and cons of each idea, and rank each idea along the creative process as more ideas come into play and/or pros and cons are added. Given that such an *idea workspace* is provided to groups and all actions in such a workspace are logged by the collaborative system, it is possible to summarize the activities of users by mining the system logs, coalescing user actions to generate a meaningful précis of changes in the idea workspace, and recommending further actions to the collaborators.

Consider the following scenario. In the design mock-up shown in Figure **4-3**, Ahmed from group Bravo adds his "point-counterpoint debate" idea to the workspace. He annotates an advantage to his idea by commenting that it is "very creative" and ranks it by either choosing "agree" or "disagree". At a later point, Judy logs into the system, comments on two disadvantages of implementing Ahmed's idea, and disagrees with the approach. Chris also disagrees with the debate idea.

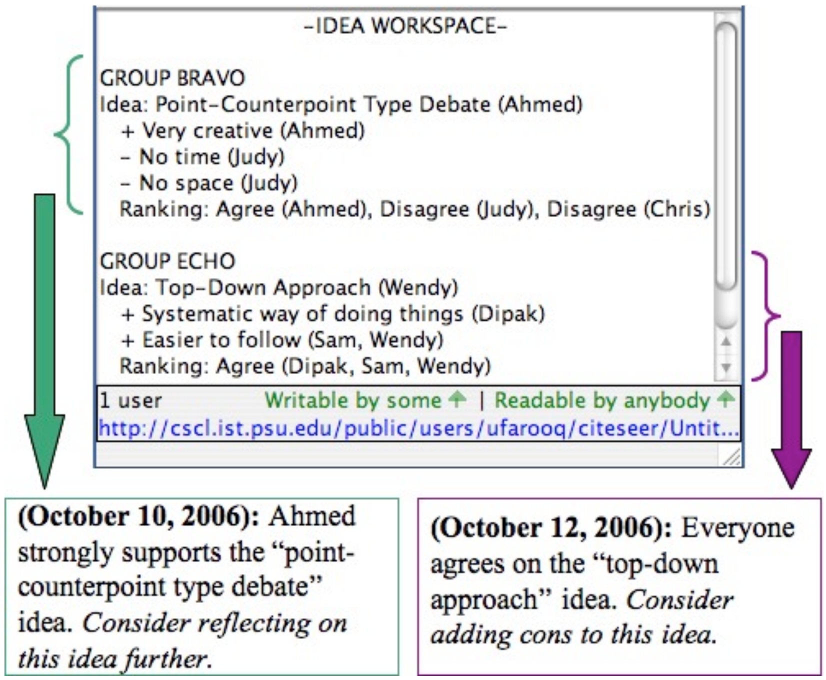

Figure **4-3**: Design mock-up of ideational summaries.

Based on system logs, the idea workspace can make an inference that Ahmed's point-counterpoint debate idea is a minority opinion, established by the conditions that he suggested the idea, he was the only one to comment on the idea's advantage, and he agreed, whereas the other group members commented on the idea's disadvantages and disagreed with the idea. A system recommendation, as shown in Figure **4-3**, makes the group aware of their activities by summarizing the changes in the idea workspace and prompts them to consider further reflection.

Consider another example. In the group Echo, all members quickly decided on the idea of a "top-down approach". As everyone agreed to the idea and commented only on the advantages of such an approach, the system could make an inference from the logs that the group should consider adding disadvantages to the idea. In a way, the system is making the group aware that their activities related to this idea may be a consequence of groupthink and is prompting them to ultimately reconsider their ranking.

An activity awareness mechanism such as providing log-based ideational summaries could be extended to other breakdowns in creativity. For example, the second breakdown suggested that novel ideas got lost. In the idea workspace, if an idea has not been commented upon and no one has ranked it based on some specified time threshold, the system can make the group aware that the idea has been dormant for some time and may require members to comment on it. In this way, the group is made cognizant of a possibly good idea that may otherwise get ignored. In general, recommendations to collaborators can serve as reminders to critically evaluate different perspectives in the idea workspace.

Providing log-based ideational summaries seems to be a feasible activity awareness mechanism to support creativity. Foremost, the activity awareness information is automatically being generated from system logs without the intervention of users. This is an attractive characteristic that is practically possible; other systems have implemented similar task support based on system logs [Rattenbury and Canny, 2007].

Design issues

Automatically generating log-based ideational summaries has design challenges. First, the design depends on having some sort of idea workspace where users go through the process of ideation in a structured manner. In the mock-up, the design innovation is not the "idea workspace" but rather the "log-based ideational summary", as the former is only proof-of-concept for a tool that supports creative activities. The notion of an idea workspace itself is not far-fetched. Ideational tools, where collaborators follow protocol and interact in a structured way so that systems are able to log user activities, have been studied in CSCW. A classic example of such a system is Cognoter [Foster and Stefik, 1986].

Another design challenge is the degree to which the system can generate relevant and useful ideational summaries. In the design mock-up, the system was simply aggregating the user activities and recommending further actions based on pre-defined rules (e.g., if all members agree to an idea, they are experiencing groupthink, so suggest further reflection). Defining a complete set of such pre-defined rules is a noteworthy challenge.

Prototype design and implementation

An idea workspace was developed that serves as a container for ideational summaries. The idea workspace affords the addition of new ideas, pros, and cons. The workspace is collaborative in that all group members can synchronize their view and work on the same artifacts (by pressing the "sync" button). Figure **4-4 (a)** shows a screenshot of the structured activity updates prototype.

The screenshot shows that Kristin added an idea of "problem-based learning". All three group members—Kristin, Patti, and Michael—add pros for this idea. Based on pre-defined heuristics, the system prompts all group members by presenting an ideational summary, encouraging them to add cons to the idea. The screenshot shows Michael's view, but all group members would receive the same ideational summary in this case.

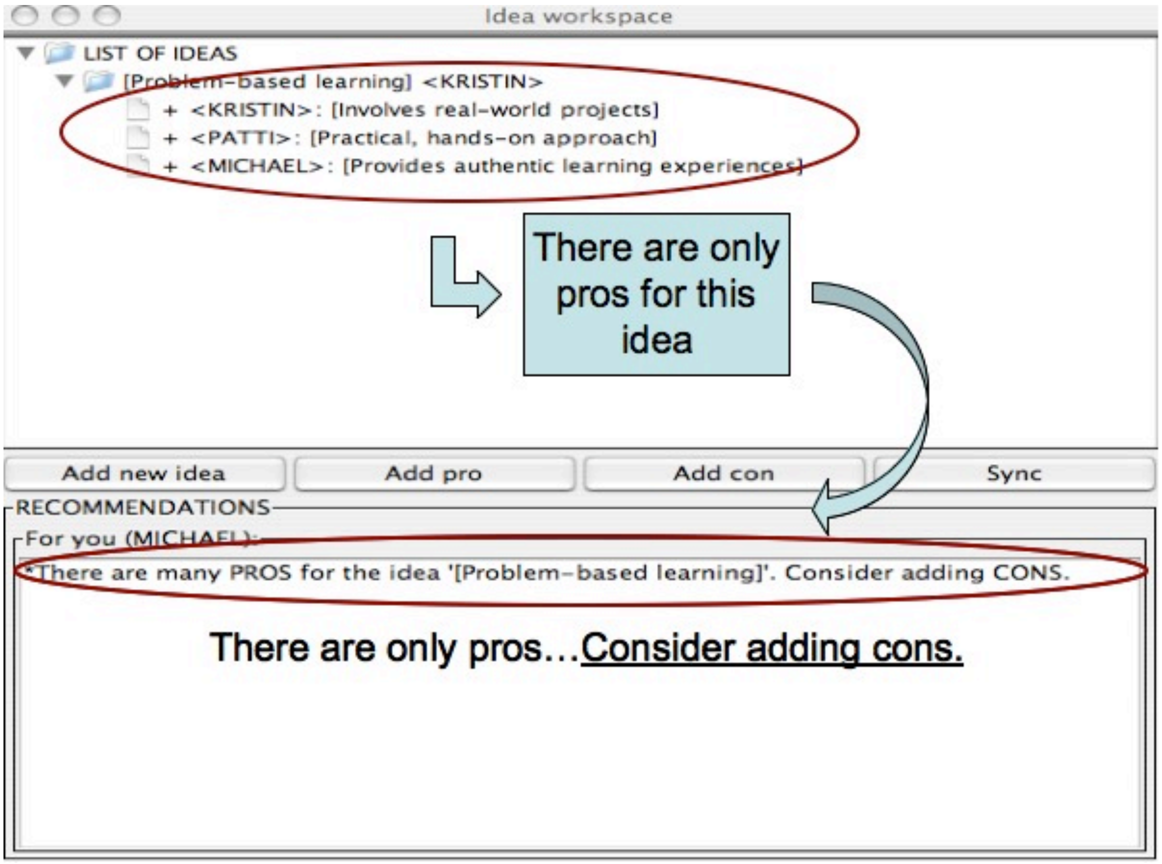

Figure **4-4 (a)**: Prototype screenshot of ideational summaries – Michael's view.

Consider another scenario as shown in Figure **4-4 (b)**. In this case, Michael added an idea of "top-down approach". Michael and Kristin added pros for this idea whereas Patti added a con, making her a minority opinion holder in the group. Based on pre-defined heuristics, the system detects this condition and prompts both Michael and Kristin to reflect on Patti's con and even consider adding some more cons. The screenshot shows Kristin's view, but Michael would receive the same ideational summary in this case.

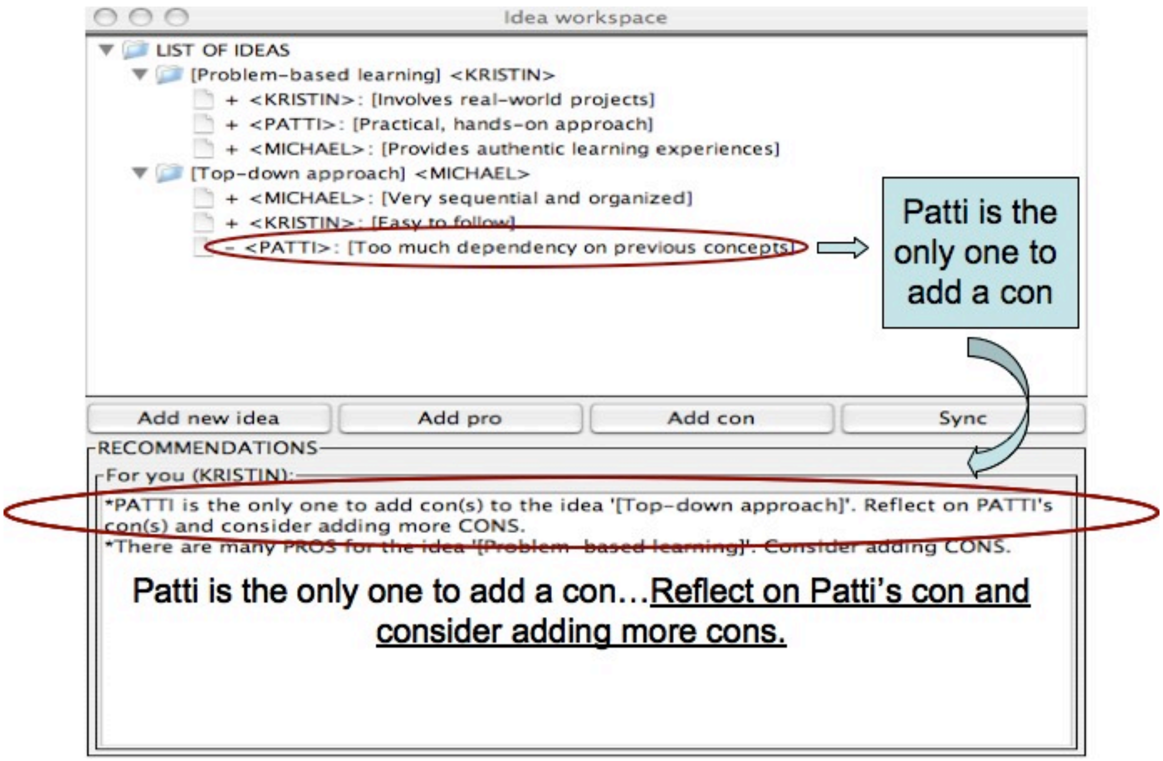

Figure **4-4 (b)**: Prototype screenshot of ideational summaries – Kristin's view.

An affordance that the ideational summaries provide is the addition of more pros and cons. This is because the ideational summaries prompts group members to consider adding pros and cons to certain ideas under different conditions. In the ideational summaries prototype, these conditions or heuristics were determined and specified by the researcher. Two categories of heuristics were identified: individual-based and group-based. Individual-based heuristics prompted individual group members with ideational summaries. Following were the individual-based heuristics and associated ideational summaries:

1. *Heuristic*: Individual did not add pro or con to an idea (e.g., bottom-up approach). *Ideational summary*: You did not add anything to the idea "bottom-up approach". Consider adding a pro or con.

2. *Heuristic*: If only one other individual (e.g., John) added pro(s) or con(s) to an idea (e.g., bottom-up approach). *Ideational summary*: John is the only one to add pro(s)/con(s) to the idea “bottom-up approach”. Reflect on John’s pro(s)/con(s) and consider adding more pro(s)/con(s).

Group-based heuristics prompted the group with ideational summaries. Following were the group-based heuristics and associated ideational summaries:

1. *Heuristic*: If no one added any pros or cons to an idea (e.g., bottom-up approach). *Ideational summary*: There are no pros and cons for the idea “bottom-up approach”. Consider adding some.
2. *Heuristic*: If there is only one pro or con for an idea (e.g., bottom-up approach). *Ideational summary*: There is only a pro/con for the idea “bottom-up approach”. Consider adding a con/pro.
3. *Heuristic*: If there are only pros or cons for an idea (e.g., bottom-up approach). *Ideational summary*: There are only pros/cons for the idea “bottom-up approach”. Consider adding a con/pro.
4. *Heuristic*: If there is only one pro and one con for an idea (e.g., bottom-up approach). Ideational summary: There is only one pro and one con for the idea “bottom-up approach”. Consider adding another pro or a con.
5. *Heuristic*: If there are more pros than cons or more cons than pros based on a difference of more than two for an idea (e.g., bottom-up approach). *Ideational summary*: There are many pros/cons for the idea “bottom-up approach”. Consider adding cons/pros.

The above individual-based and group-based heuristics are not exhaustive. They were identified based on conditional statements (if-then expressions) that could be detected by the idea workspace for prompting group members with ideational summaries.

Structured activity updates

The structured activity updates design strategy addresses the breakdown of weak reflexivity. The goal of this design strategy is to prompt group members to specify their work statuses to make others cognizant.

Design rationale

During collaboration, group members can be prompted to enter what they are currently doing. These updates can be structured based on the type of activity they are engaged in. In Figure **4-5**, three examples are illustrated. An *action* update (indicated by maroon arrow) allows collaborators to specify their current task. A *query* update (question mark) lets collaborators ask their group members a question related to their current task. A *comment* update (cloud callout) is a general remark on one's current task.

The activity updates are structured in the sense that each group member is presented with a template to update his/her status. For each of the three types of updates, a group member (take Sam as an example from the group Echo) could be presented with a template that resembles the following:

- Action: Sam is working on __________.
- Query: Sam is asking __________ to __________.
- Comment: Sam is thinking that his task is __________.

When Sam updates his activity status, he can choose one of the update types and enter text in the blank space or even choose from a drop-down list of possible updates. Figure **4-5** shows these structured activity updates that users can enter during their collaborative sessions.

Clicking on an icon for the update type (e.g., black mouse pointer clicking the maroon action update arrow) highlights the update in the "activity updates" console below the timeline.

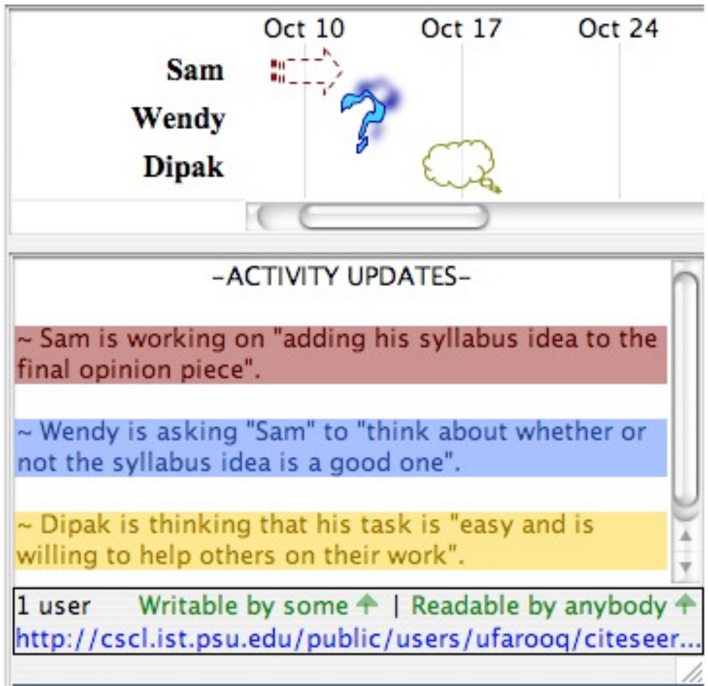

Figure **4-5**: Design mock-up of structured activity updates.

Showing activity updates on social and temporal dimensions can allow group members to easily identify who has updated their activity status and when. Such awareness information about collaborators' activities can facilitate reflexivity during divergence and convergence as group members can reinforce their shared understanding about who is doing what, how they need to recalibrate their tasks with respect to others, how everyone's tasks will come together as one final product, and so forth.

The structured activity updates design strategy was inspired by status prompts on social networking websites such as Facebook (http://www.facebook.com) and Twitter (http://twitter.com). These sites allow users to enter any general comment about themselves (e.g., "I am glad the semester is over"; "I am craving pizza") that is then broadcasted to others in their social networks. Whereas these social networking sites allow users to enter any informational updates, our proposed updates are activity-centric, that is, they are related to the collaborators' task at hand. By structuring the updates in pre-defined activity-centric templates, users may be prompted to think in terms of what they are doing with respect to their task.

Design issues

One of the design challenges to consider is how much structure in the activity updates is "too much" as one could argue that the open-ended nature of status updates on Facebook and Twitter has made the feature popular in social networking sites. Perhaps more importantly, status updates on these social networking sites have an implicit reward mechanism in that users are updating a huge critical mass of their friends in their network by entering a few words. Given the task context of this dissertation—members in small groups on the order of three to six collaborators—it may not be worthwhile for a group member to enter an activity update for apprising such a small number of collaborators. One way to address this challenge is for the design to be compelling enough so that users actually find entering their updates useful, not only in the service of others but also for themselves. In software teams, for example, Concurrent Versioning System (CVS) prompts programmers to enter comments when checking in their software code. A recent study has shown that such comments, when supplemented with lightweight communication, are useful for software coordination [Fitzpatrick et al. 2006]. This study is encouraging for the structured activity updates design strategy, as structured activity updates could be considered as lightweight communication mechanisms for collaborators. For example, in Figure **4-5**, Wendy's reflection on Sam's activity update could be considered lightweight communication between Wendy and Sam.

Another issue is how structured activity updates can be better represented as user interface widgets on social and temporal dimensions. In the design mock-up, one activity update per user was shown; supporting multiple updates for each user is probably desirable. A more considerable issue is how to visualize activity updates that are threaded. For example, one could imagine having a *response* update that acknowledges other activity updates later in time. Such threading can be shown by representing related activity updates with the same color on the timeline or by highlighting all related activity updates if one of them is selected.

Prototype design and implementation

Based on the data collected from this study, the chat communication transcripts were analyzed to understand what types of activities collaborators express and share. Ten distinct types of activities were identified that would serve as templates for group members to update their status: *planning*, *brainstorming*, *working*, *asking*, *suggesting*, *summarizing*, *dividing up work*, *proofreading*, *agreeing*, *disagreeing*. Figure **4-6** shows a screenshot of the structured activity updates prototype.

The activity workspace—which is the container for the structured activity updates—can be divided into three sections. In Section 1 ("Update Your Activity"), users can choose from among the ten activity templates and fill in the blanks to share their activities. The activity updates are displayed in Section 2 of the tool. Each user's previous activity update is also displayed. It was thought that providing a user's previous activity would be useful in contextualizing the current activity. Section 3 of the tool provides a mechanism for users to comment on group members' activity updates. The design rationale was that activity updates could instigate and provoke users to reflect on and possibly respond to group members' activities. By commenting on others' activities, group members could provide feedback and possibly engage in a discourse. For instance, in Figure **4-6**, Patti commented on Michael's activity update, which led Kristin to agree with Patti's comment.

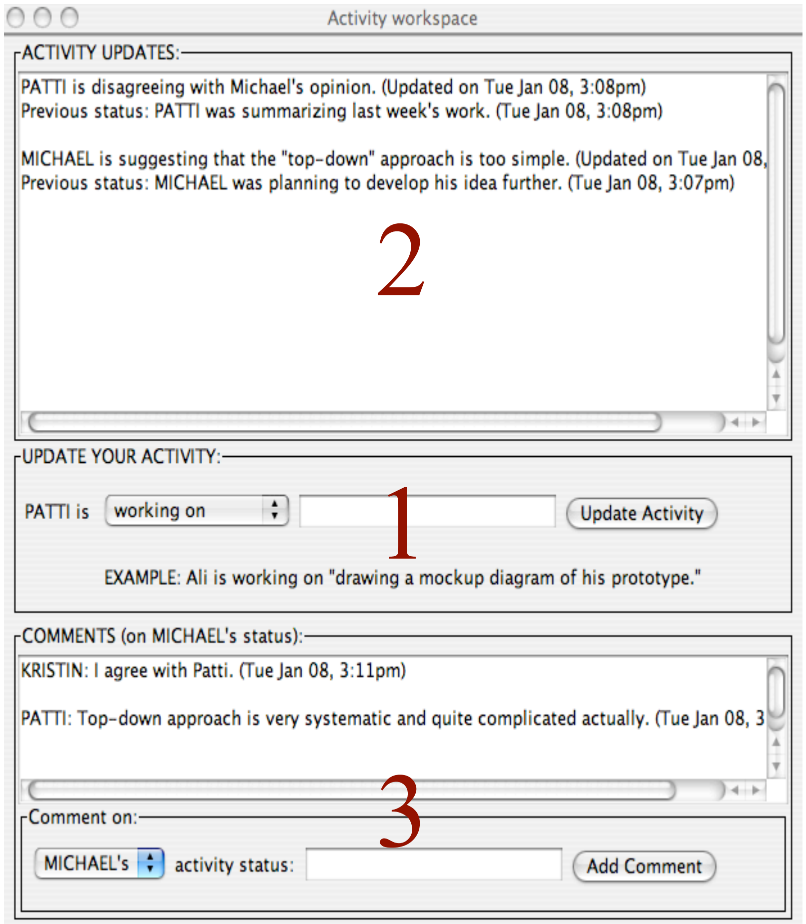

Figure **4-6**: Prototype screenshot of structured activity updates.

Summary

Three design strategies and awareness mechanisms are proposed, illustrated with prototypes, to address the four breakdowns in creativity identified as part of the exploratory experiment: (1) Brainstorm recap; (2) Ideational summaries; and (3) Structured activity updates. These mechanisms are first-order design approximations [Ackerman, 2000] to support creativity with activity awareness in distributed collaboration.

Chapter 5

Main experiment

In this chapter, the main experiment is presented, which addresses RQ2: How are these awareness mechanisms used and with what consequences? The main experiment is a control group study that uses both quantitative and qualitative data analysis to test hypotheses and answer open-ended research questions respectively.

Goal of the study

The goal of this study is to investigate the use and consequences of supporting creativity with awareness mechanisms. The experimental design is a control group study where experimental groups are provided awareness mechanisms and control groups are not provided awareness mechanisms. Such an experimental design allows the investigation of whether awareness mechanisms had an effect on creativity.

The overall research question RQ2 has been decomposed into several hypotheses and open-ended research questions with respect to the awareness mechanisms. The following three awareness mechanisms (AM) were incorporated into the experimental design: brainstorm recap (AM1), ideational summaries (AM2), and structured activity updates (AM3). Each of these awareness mechanisms has an associated hypothesis and open-ended research question. In addition, there are two overall hypotheses associated with all the three awareness mechanisms.

Awareness mechanisms (AM): Overall hypotheses

Based on previous studies (e.g., [Ocker et al. 1996]), quality is an important construct to investigate in studies of creativity. There is no empirical basis form literature to suggest why or how quality would differ between the experimental and control groups. However, on a logical basis, it can be argued that groups with awareness mechanisms are more cognizant of each others' work and that these higher levels of awareness leads to better quality solutions. This is because groups with higher levels of awareness have better joint experiences, which in turn enhances common ground [Convertino et al. 2007]. Common ground is an essential facet of awareness [Carroll et al. 2006]. Thus, the first overall hypothesis is the following:

- RQ2-AM(a): Experimental groups will generate solutions of higher quality than control groups.

Based on the logical argumentation that awareness can support creativity from the literature review and the design of awareness mechanisms to support creativity from the experimental study, it is expected that creativity be positively affected by awareness mechanisms. Thus, the second overall hypothesis is the following:

- RQ2-AM(b): Experimental groups will generate solutions of higher creativity than control groups.

Brainstorm recap (AM1): Hypothesis and research question

The brainstorm recap design strategy addresses the breakdown of novel ideas being easily lost. By presenting groups with a summary of all their ideas from the chat logs during brainstorming, it is likely that they will identify and consider more of these ideas during reflection than in the case of a summary not being provided. Thus, the brainstorm recap hypothesis is the following:

- RQ2-AM1(a): Experimental groups will generate more divergent ideas than control groups.

In addition to quantitatively understanding the effect of the brainstorm recap design strategy, it is also important to qualitatively understand how the awareness mechanism was used and with what consequences. Thus, the brainstorm recap open-ended research question is the following:

- RQ2-AM1(b): How is the brainstorm recap used and with what consequences?

Ideational summaries (AM2): Hypothesis and research question

The ideational summaries design strategy addresses the breakdowns of minority ideas being under-considered and a lack of critical evaluation of perspectives. By presenting groups with a synopsis of their ideation process, it is likely that they will specify and consider more tradeoffs (pros and cons) with respect to their ideas than in the case of a synopsis not being provided. Thus, the ideational summaries hypothesis is the following:

- RQ2-AM2(a): Experimental groups will generate more pro and con comments than control groups.

In addition to quantitatively understanding the effect of the ideational summaries design strategy, it is also important to qualitatively understand how the awareness mechanism was used and with what consequences. Thus, the ideational summaries open-ended research question is the following:

- RQ2-AM2(b): How are the ideational summaries used and with what consequences?

Structured activity updates (AM3): Hypothesis and research question

The structured activity updates design strategy addresses the breakdown of weak reflexivity. By presenting groups with information about member's work statuses, it is likely that they will experience higher levels of awareness than in the case of such information not being provided. Thus, the structured activity updates hypothesis is the following:

- RQ2-AM3(a): Experimental groups will have increased awareness than control groups.

In addition to quantitatively understanding the effect of the structured activity updates design strategy, it is also important to qualitatively understand how the awareness mechanism was used and with what consequences. Thus, the structured activity updates open-ended research question is the following:

- RQ2-AM3(b): How are the structured activity updates used and with what consequences?

Study details

Participants

Participants in the main experiment were undergraduate students enrolled in an introductory course on HCI in two sections at a large university. Section 1 was the experimental condition and Section 2 was the control condition. A different instructor taught each section, though during the experiment, the researcher was present in both sections to maintain experimental consistency. Section 1 and Section 2 comprised thirteen and eight groups respectively. All groups were randomly assigned and had zero history of working together. Table **5-1** shows the details of group membership.

Table **5-1**: Group membership in experimental (Section 1) and control (Section 2) conditions.

Section	Group number	# of members	# of males	# of females
1	1	4	4	0
1	2	4	3	1
1	3	4	4	0
1	4	4	3	1
1	5	4	4	0
1	6	4	3	1
1	7	4	4	0
1	8	4	3	1
1	9	4	4	0
1	10	4	4	0
1	11	3	3	0
1	12	3	3	0
1	13	3	3	0
2	1	4	4	0
2	2	3	3	0
2	3	4	4	0
2	4	4	3	1
2	5	4	4	0
2	6	4	4	0
2	7	4	4	0
2	8	4	4	0

Overall task

Each group was instructed to write a formal report exploring design enhancements to *Angel*, which is the university's course management system that all students must use. The report was to cover functional requirements to enhance the design of Angel's user interface accompanied with scenarios and storyboards that illustrate the functional requirements. Following is the overview of the project instructions given to each participant:

> You and your group peers are work-at-home employees of a high-tech startup company with creative ideas for a new and improved integrated product: "AngelX: Next Generation Angel". With the AngelX project, your group has the opportunity to enhance and re-engineer the basic offerings and operations of the existing Angel course management system. The company president has selected

> your distributed group to spearhead this project. You have been asked by the president to prepare a report exploring new services that AngelX could offer in the future. It is an honor being selected to work on the initial stages of this innovative project. Therefore, your group's success on this project will ensure your future with the company.

This task was modeled on previously documented tasks [Ocker et al. 1996; Olson et al. 1993] used in distributed collaboration. The instructions emphasized that group members were only allowed to collaborate virtually using a shared workspace. The task was structured based on a previous similar study of distributed collaboration [Ocker et al. 1996]. The groups followed a sequence of phases during their collaboration:

1. *Generation of alternatives (Phase I, D1)*: Groups were asked to brainstorm several functional requirements for Angel. The chat tool was used for this step.
2. *Period of critical reflection (Phase II, D2)*: Groups were asked to enumerate pros and cons for each of the functional requirements. The functional requirements generated from step 1 were added to the idea workspace; pros and cons were added to each idea.
3. *Evaluation of alternatives and implementation (Phase III, D3)*: Groups were asked to reach consensus on two functional requirements that were the most creative. Groups were then asked to write a scenario and draw a storyboard for each of the two functional requirements.
4. *Report writing (Phase IV, D4-D5)*: Groups were asked to write a formal report between 1500-2000 words.

The instructions given to Section 1 groups were different only with respect to the three awareness mechanisms being provided to them under the experimental condition. The full set of instructions is described under experimental procedure.

Tools

Group members worked on the shared task in BRIDGE. The following collaborative artifacts were provided in BRIDGE to both experimental and control groups: persistent chat tool, idea workspace, two wiki-based scenarios, two storyboards, and a wiki-based report. In addition, the experimental groups were provided the brainstorm recap and activity workspace. Further, their idea workspace incorporated the ideational summaries awareness mechanism. Figure **5-1** shows a screenshot of a typical BRIDGE workspace for the control groups.

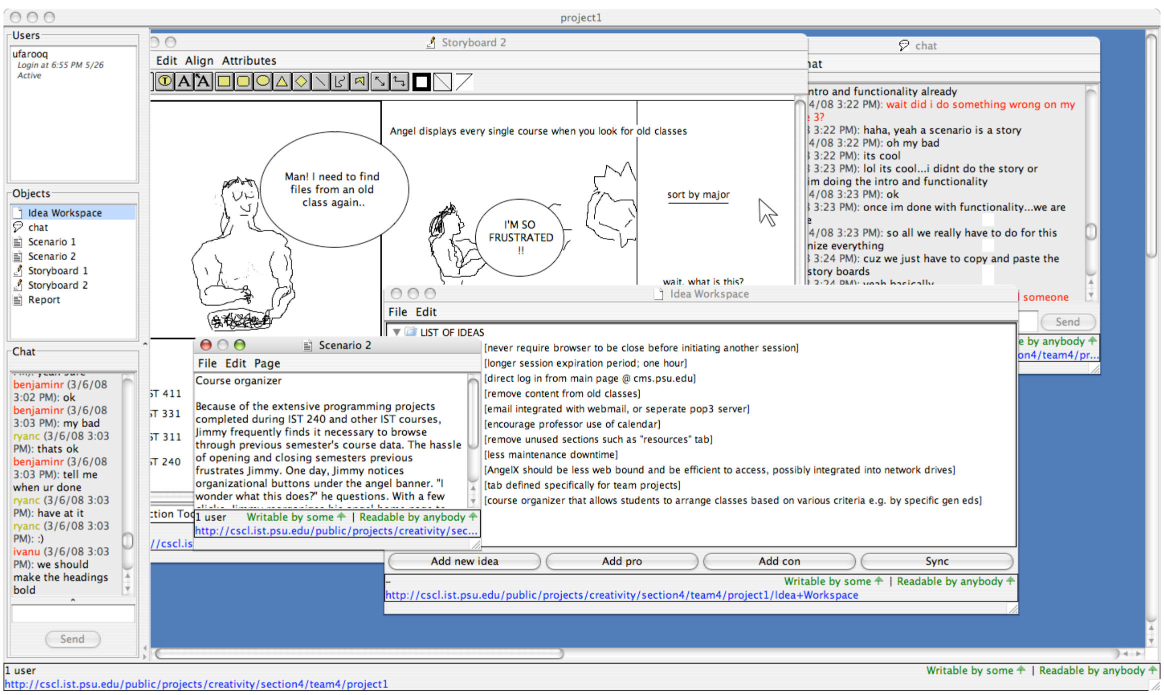

Figure **5-1**: Screenshot of typical collaborative workspace for control groups.

Figure **5-2** shows a screenshot of a typical BRIDGE workspace for the experimental groups.

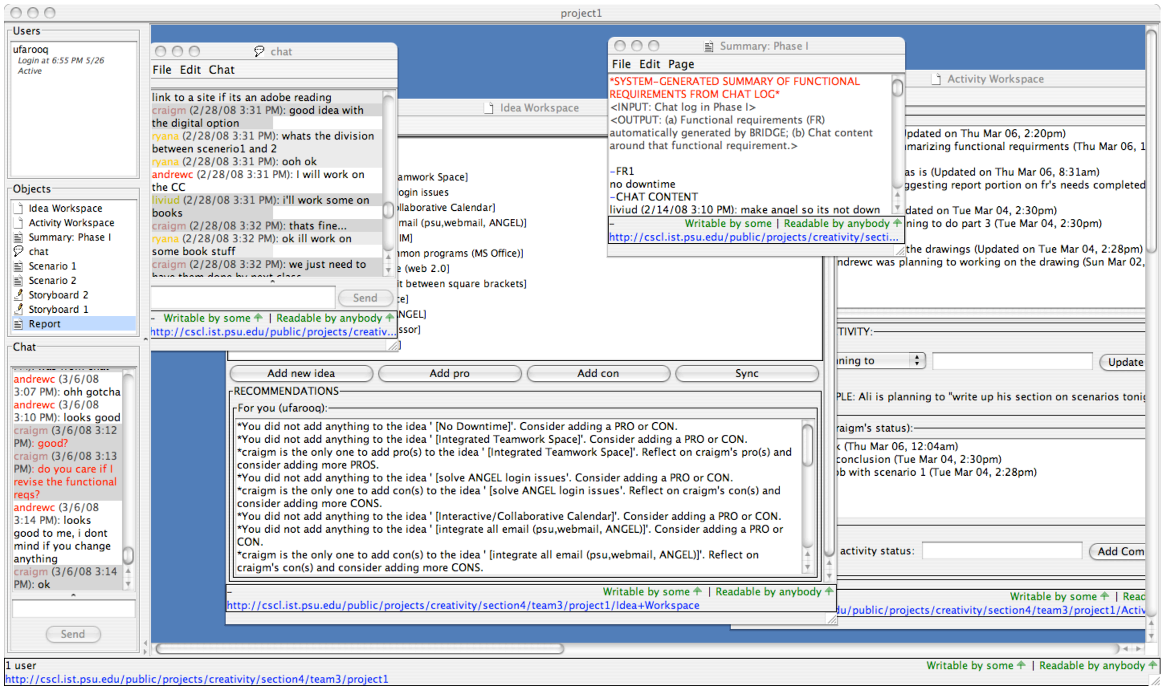

Figure **5-2**: Screenshot of typical collaborative workspace for experimental groups .

Procedure

All students were consented to participate in the experiment. Prior to the start of the experiment, all participants were trained to use BRIDGE. Two in-class sessions, approximately twenty minutes each, were used for training. Groups in the control condition were exposed to the chat tool and idea workspace without ideational summaries. Groups in the experimental condition were exposed to the chat tool, idea workspace with ideational summaries, and the activity workspace.

The duration of the experiment was two-and-a-half weeks. Participants collaborated synchronously and asynchronously. Five in-class sessions (D1 to D5, where 'D' stands for 'Day') were used for synchronous collaboration, each lasting approximately twenty minutes. The participants were instructed to collaborate online during out-of-class sessions between each of the in-class synchronous sessions. Specifically, participants were asked to login at least twice between two in-class sessions. This was done for two reasons. First, it encouraged participants to collaborate consistently over time. Second, it ensured that participants engaged in both asynchronous and synchronous collaboration, which typifies real-world activity.

Given that the goal of this main experiment was to study how awareness mechanisms are used and with what consequences, the instructions asked participants in the experimental condition to use the brainstorm recap, idea workspace, and activity workspace. Specifically with respect to the activity workspace, participants were instructed to update their activity status and comment on others' status at least twice during each in-class and out-of-class session.

Participants were given instructions in an incremental fashion. At the beginning of each of the five in-class sessions, participants were given instructions for that particular day and their tasks to be completed before the subsequent in-class session (except for the last in-class session). To eliminate any instructor effect, the researcher was present during all in-class sessions for both sections. Further, the instructions were self-explanatory and were not elaborated by the researcher; however, the researcher did clarify issues if asked. The full set of instructions and procedure is detailed in Appendix F for both the experimental groups and control groups.

As part of the experimental procedure, participants also filled out several surveys at different points in time: after being consented, after training, and the beginning and end of in-class sessions. This is detailed below under data collection.

Data collection

Two primary sources of data collection were used: surveys and system logs. The surveys collected data related to the following aspects: background of participants, technology training, progress reports, idea workspace, group dynamics, and awareness manipulation. The system logs collected data related to the following aspects: task artifacts and awareness artifacts. Each of these data sources is explained below.

Background of participants

After being consented to participate in the experiment, participants' background information was collected to ensure that participants in the experimental and control conditions were similar on various dimensions. These dimensions included gender, age, nationality, academic major, number of years in college, grade point average (GPA), number of credits taken in college, first language, and in case first language was not English, proficiency in English.

Two questions regarding computer use were asked. As the experimental task was specific to a particular content management system, two questions regarding Angel use were also asked. See Appendix G for the computer and Angel use questionnaire.

Participant creativity scores were also obtained using a 30-item creativity scale derived from the ACL as explained in the exploratory experiment. Normalized group creativity scores were calculated with respect to the number of members in each group. For metacognitive abilities, a previously validated 52-item questionnaire [Kumar, 1998] was used.

Technology training

After the two in-class sessions in which participants received training using BRIDGE, three questions were asked regarding the use of BRIDGE to ensure that participants in the experimental and control conditions were similarly familiar with technology. See Appendix H for the technology training questionnaire.

Progress reports

After each of the five synchronous in-class sessions, participants answered the following questions on a Likert scale of 1 (Strongly disagree) to 9 (Strongly agree) related to their level of awareness (LA). These five questions were a proxy into how the groups are progressing over time in terms of maintaining awareness; they have been previously validated in [Convertino et al. 2004; http://cscl.ist.psu.edu/public/projects/awareness/quest.html]:

- LA1: I know what my group members have worked on so far.
- LA2: I know what my group members will work on next time.
- LA3: I could tell what my group members were working on while we were collaborating synchronously.
- LA4: I could tell what my group members were working on while we were collaborating asynchronously.
- LA5: I found it difficult to tell what work my group members had done after being absent from my team workspace for at least a day.

After the first synchronous in-class session, LA4 and LA5 were not administered as the groups had no history of working together on the task. LA2 was not administered after the fifth synchronous in-class session, as it was the final group interaction.

Idea workspace

During the period of critical reflection after groups generated several functional requirements, ideas were to be added to the idea workspace. In order to partially address RQ2-AM1(a) and RQ2-AM1(b), participants were asked three questions at the end of D2. The first question related to the overall consideration of all the functional requirements (FR) group members generated on a Likert scale of 1 (Strongly disagree) to 9 (Strongly agree):

- FR1: My group considered all the functional requirements generated during the brainstorming chat session in Phase I.

The second question related to the percentage of the functional requirements that group members added to the idea workspace on a Likert scale of 1 (10%) to 10 (100%):

- FR2: What percentage (%) of the functional requirements generated during the brainstorming chat session in Phase I was added to the idea workspace?

The third question was open-ended to understand why functional requirements were not added to the idea workspace if that was the case:

- FR3: Were there any functional requirements generated during the brainstorming chat session in Phase I that were not added to the idea workspace? If yes, please list these functional requirements and say why each of them was not added.

In order to partially understand RQ2-AM2(a) and RQ2-AM2(b), participants were asked seven questions at the beginning of D3 by when Phase II should have been completed. The first six questions related to the addition of pros and cons (PC) in the idea workspace a Likert scale of 1 (Strongly disagree) to 9 (Strongly agree):

- PC1: I added as many pro and con comments as I could to the idea workspace in Phase II.
- PC2: Our group added as many pro and con comments as we could to the idea workspace in Phase II.
- PC3: I should have added more pro and con comments to the idea workspace in Phase II.
- PC4: Our group should have added more pro and con comments to the idea workspace in Phase II.

- PC5: The pro and con comments our group added to the idea workspace in Phase II are sufficient to critically evaluate the functional requirements.
- PC6: Based on the pro and con comments our group added to the idea workspace in Phase II, I feel confident about choosing the two most creative functional requirements.

The seventh question was open-ended to understand why or why not the pros and cons were sufficient:

- PC7: Do you think enough pro and con comments were added to the idea workspace in Phase II to critically evaluate the functional requirements? If yes, why do you think the pro and comments were enough? If no, why do you think they were not enough?

Group dynamics

To ensure participants in the experimental and control conditions were similar in terms of group dynamics, six sets of previously validated questionnaires were collected: workload sharing, task interdependence, collective efficacy, satisfaction with communication processes, satisfaction with decision outcomes, and team viability. In addition, a previously validated activity awareness questionnaire was administered. All questionnaire items were randomly presented to the participants.

Awareness manipulation

Groups in the experimental condition were subjected to the awareness manipulation (i.e., awareness mechanisms). Hence, these participants were asked open-ended questions related to their use of the three awareness mechanisms at the end of the experiment. The first question related to the use and consequences of the brainstorm recap (BR) awareness mechanism in order to address RQ2-AM1(b):

- BR1: In Phase I, you were provided with a BRIDGE-generated summary of functional requirements based on your chat log. Was this summary useful? If yes, how was it useful - provide an example.

The second question related to the use and consequences of the ideational summaries (IS) awareness mechanism in order to address RQ2-AM2(b):

- IS1: In Phase II, the idea workspace recommended certain actions (e.g., Consider adding a pro). Were these recommendations useful? If yes, how were they useful - provide an example.

The third and fourth question related to the use and consequences of the structured activity updates (SAU) awareness mechanism in order to address RQ2-AM3(b):

- SAU1: Was the activity workspace useful? If yes, how was it useful - provide an example.
- SAU2: The project instructions asked you to update your status and comment on others' statuses. If you were not instructed to do so, would you have used this tool? Why?

Task artifacts

During the experiment, all interactions with respect to the task artifacts in BRIDGE were logged on the server. This included chat communication, scenarios, storyboards, and the final report. Timestamps of individual contributions were recorded for all task artifacts.

Awareness artifacts

During the experiment, all interactions with respect to the awareness artifacts in BRIDGE were logged on the server. This included the following artifacts: brainstorm recap, idea workspace, and activity workspace. For the brainstorm recap, the Wizard-of-Oz summary of ideas was stored. For the idea workspace, all ideas and associated pros and cons were stored. For the activity workspace, all activity updates and associated comments were stored with timestamps.

Data analysis

A mixed-method approach was used to analyze the various sources of data. The multiple sources of data and analyses helped to triangulate the interpretation of the results. The underlying hypotheses were tested using quantitative analysis. Various statistical analyses were conducted such as two sample t-tests, repeated measures analysis of variance (ANOVA), and analysis of covariance (ANCOVA). Cronbach's alpha was used to test internal consistency reliability of various scaled items. Cohen's Kappa was used to test interrater reliability of judges rating the final solution based on Amabile's [1996] consensual technique. The statistical package used to analyze quantitative data was SPSS.

The open-ended questions and data from the awareness artifacts were analyzed using qualitative analysis. Grounded theory [Strauss and Corbin, 1998] was used to analyze and code such data. The researcher read, summarized, and re-read the data to iteratively refine the coding scheme. The coding package used to analyze qualitative data was QSR NVivo.

To measure quality and creativity of final solution, an objective assessment technique [Ocker, 2005] was used. This technique was enhanced to incorporate subjective assessment of judges' rating of ideas. Details of this technique and all data analysis are further explained under results.

Results

Not all participants responded to all questions. Participants in the experimental groups and control groups were homogenous with respect to gender (male), nationality (American), academic major (information sciences and technology), and first language (English). A series of two-sample t-tests were conducted between the experimental groups and control groups with the dependent variables as age, number of years in college, GPA, and number of credits taken in college. The tests revealed no statistically significant differences between the experimental groups and control groups for the background variables. A two-sample t-test was also conducted between the experimental groups and control groups with the dependent variable as the group creativity scores. The test revealed no statistically significant differences between the experimental groups and control groups for group creativity scores.

A series of two-sample t-tests were conducted between the experimental groups and control groups with the dependent variables as computer use and Angel use. The tests revealed no statistically significant differences between the experimental groups and control groups for these variables.

A two-sample t-test was conducted between the experimental groups and control groups with the dependent variable as technology training. The test revealed no statistically significant differences between the experimental groups and control groups for technology training.

For questionnaires related to group dynamics, internal consistency reliability was checked. The Cronbach's alpha value was high for all variables: workload sharing (0.76), task interdependence (0.72), collective efficacy (0.96), satisfaction with communication processes

(0.95), satisfaction with decision outcomes (0.83), and team viability (0.83). A series of two-sample t-tests were conducted between the experimental groups and control groups with the above dependent variables related to group dynamics. The tests revealed no statistically significant differences between the experimental groups and control groups for these variables.

For the activity awareness questionnaire, the Cronbach's alpha value was high (0.93). A two-sample t-test was conducted between the experimental groups and control groups with the dependent variable as the overall rating on activity awareness. The test revealed no statistically significant differences between the experimental groups and control groups for overall activity awareness.

For the metacognitive abilities questionnaire, the Cronbach's alpha value was high (0.98). A two-sample t-test was conducted between the experimental groups and control groups with the dependent variable as the overall rating on metacognitive abilities. The test revealed no statistically significant differences between the experimental groups and control groups for overall metacognitive abilities. A series of two-sample t-tests were conducted between the experimental groups and control groups with the dependent variables as metacognitive regulation and metacognitive knowledge. The test revealed no statistically significant differences between the experimental groups and control groups for metacognitive regulation. There was a statistically significant difference between the experimental groups and control groups for metacognitive knowledge. The two-sample t-test for equal variances was $t(75) = -2.013$, $p < 0.05$. The means and standard deviations for the experimental and control groups were $M = 55.70$, $S.D. = 7.92$ and $M = 59.61$, $S.D. = 8.66$ respectively.

Awareness mechanisms (AM)

RQ2-AM(a): Experimental groups will generate solutions of higher quality than control groups.

Three independent judges were given a script and rubric to rate quality of each group's final solution (see Appendix I for script and rubric). Total quality (60 points) consisted of two dimensions: artifact quality (30 points) and overall quality (30 points). Each judge was considered an expert in the domain. An interrater reliability analysis using the Kappa statistic was performed to determine consistency among the judges. The interrater reliability for the judges was found to be substantial: Kappa = 0.766, $p < 0.05$.

A series of two-sample t-tests were conducted between the experimental groups and control groups with the dependent variables as total quality, artifact quality, and overall quality. The tests revealed no statistically significant differences between the experimental groups and control groups for total quality, artifact quality, and overall quality.

An analysis of covariance was conducted between the experimental groups and control groups with the dependent variables as total quality, artifact quality, and overall quality, and with covariate as the metacognitive knowledge. The test revealed no statistically significant differences between the experimental groups and control groups for total quality and artifact quality.

There was a statistically significant difference between the experimental groups and control groups on artifact quality after controlling for the effect of metacognitive knowledge: $F (1, 18) = 7.067$, $p < 0.05$. For overall quality, the mean and standard deviation for the experimental and control groups were M = 25.46, S.D. = 2.413 and M = 25.12, S.D. = 1.168 respectively. After running post hoc tests, the significant difference between the experimental groups and control groups was confirmed. The covariate—metacognitive knowledge—was significantly related to the overall quality: $F (1, 18) = 6.907$, $p < 0.05$.

RQ2-AM(b): Experimental groups will generate solutions of higher creativity than control groups.

The same three independent judges who rated quality were given a script and rubric to rate creativity of each group's final solution (see Appendix J for script and rubric). Total creativity (40 points) consisted of two dimensions: artifact creativity (30 points) and overall creativity (10 points). The interrater reliability for the judges was found to be substantial: Kappa $= 0.779$, $p < 0.05$.

A series of two-sample t-tests were conducted between the experimental groups and control groups with the dependent variables as total creativity, artifact creativity, and overall creativity. The tests revealed no statistically significant differences between the experimental groups and control groups for total creativity, artifact creativity, and overall creativity.

An analysis of covariance was conducted between the experimental groups and control groups with the dependent variables as total creativity, artifact creativity, and overall creativity, and with covariate as the metacognitive knowledge. The test revealed no statistically significant differences between the experimental groups and control groups for total creativity, artifact creativity, and overall creativity.

Ocker's [2005] objective assessment technique was used to ascertain the degree of creativity for each group in the experimental and control conditions. Two iterations were done to accurately capture the unique list of ideas. The first iteration produced a unique list of 143 ideas. This iteration resulted in higher than expected levels of creativity for the vast majority of the groups. During the second iteration, similar ideas were consolidated. The second iteration produced a unique list of 120 ideas.

If no more than two groups shared an idea, the idea was categorized as *original*. If three, four, or five groups generated the same idea, the idea was categorized *rare*. If up to ten groups shared the same idea, the idea was categorized as *common*. If more than ten groups generated the same idea, that idea was categorized as *pervasive*. These thresholds were decided subjectively after reviewing the range of idea occurrences. For example, in general, the lease frequent ideas occurred only once or twice while the most frequent occurred in more than half the groups.

Tier rankings in Ocker's method did not seem systematic. It was decided to adopt a quartile ranking system. Tukey's method for finding quartiles was used for categorizing each group based on the percentage of their creative ideas (the addition of original and rare ideas). The percentage of ordinary ideas (the addition of common and pervasive ideas) was not factored in the tier rankings as the percentages of all groups were too similar. Further, it was thought that rankings based on creative ideas would reflect the most creative groups. The tier rankings according to quartiles were the following: 1^{st} tier was assigned to groups with 80% or more creative ideas, 2^{nd} tier was assigned to groups between 75% and 89% (inclusive) creative ideas, 3^{rd} tier was assigned to groups between 70% and 74% (inclusive), and 4^{th} tier was assigned to groups with 69% or less creative ideas. 31% of the experimental groups were categorized as 1^{st} tier, 23% were categorized as 2^{nd} tier, 15% were categorized as 3^{rd} tier, and 31% were categorized as 4^{th} tier. 38% of the control groups were categorized as 1^{st} tier, 13% were categorized as 2^{nd} tier, 38% were categorized as 3^{rd} tier, and 13% were categorized as 4^{th} tier. Tables **5-2 (a)** and **5-2 (b)** shows the creativity ratings based on the objective assessment technique for the experimental groups and control groups respectively.

Table **5-2 (a)**: Creativity ratings using objective assessment technique for the experimental groups.

Group →	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Total unique ideas	13	9	10	16	11	6	9	12	12	12	14	10	12
Original (o)	5	6	5	9	8	0	6	7	5	4	7	3	5
Rare (r)	4	1	3	3	1	2	2	3	3	4	3	4	4
Creative (o+r)	9	7	8	12	9	2	8	10	8	8	10	7	9
Common (c)	3	0	2	2	2	1	0	1	1	3	1	1	1
Pervasive (p)	1	2	0	2	0	3	1	1	3	1	3	2	2
Ordinary (c+p)	4	2	2	4	2	4	1	2	4	4	4	3	3
% Original	38	67	50	56	73	0	67	58	42	33	50	30	42
% Rare	31	11	30	19	9	33	22	25	25	33	21	40	33
% Creative	69	78	80	75	82	33	89	83	67	67	71	70	75
% Ordinary	31	22	20	25	18	67	11	17	33	33	29	30	25
Tier	4th	2nd	1st	2nd	1st	4th	1st	1st	4th	4th	3rd	3rd	2nd

Table **5-2 (b)**: Creativity ratings using objective assessment technique for the control groups.

Group →	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Total unique ideas	8	10	15	8	20	20	10	8
Original (o)	4	3	4	1	7	10	5	3
Rare (r)	1	4	7	5	10	4	3	4
Creative (o+r)	5	7	11	6	17	14	8	7
Common (c)	0	2	2	0	1	4	0	1
Pervasive (p)	3	1	2	2	2	2	2	0
Ordinary (c+p)	3	3	4	2	3	6	2	1
% Original	50	30	27	13	35	50	50	38
% Rare	13	40	47	63	50	20	30	50
% Creative	63	70	73	75	85	70	80	88
% Ordinary	38	30	27	25	15	30	20	13
Tier	4th	3rd	3rd	2nd	1st	3rd	1st	1st

One of the drawbacks of the objective assessment technique is that all ideas are weighted equally. For example, invalid ideas or ideas that are not creative are still factored into the creativity ratings. The underlying assumption of this technique is that creativity is purely determined by the uniqueness of ideas relative to others. This can be a cause for concern in cases where ideas are non-creative but are considered creative because others have not expressed it. To avoid such false positive situations and to enhance the technique by weighing the ideas, the objective assessment technique was supplemented with subjective assessment.

Two judges rated each idea as part of two iterations. During the first iteration, the two judges rated each idea independently on a tertiary rating scale: low creativity, moderate creativity, and high creativity. The agreement rate between the two judges for the first iteration was 54%. Ideas that were rated low creativity by one judge and high creativity by the other judge were categorized as moderately creative. All other disagreements were discussed between the two judges and resolved.

Once the ideas were rated, the tertiary scale was quantified. A low creative idea was assigned a weight of 0.5, a moderate creative idea was assigned a weight of 1.0, and a high creative idea was assigned a weight of 2.0. The rationale for this quantification was that the low creative ideas are worth half the moderately rated ideas but the high creative ideas are worth twice. A tertiary scale was deemed appropriate to minimize subjectivity. Indeed, it is easier to identify low and high creative ideas with the rest of the ideas taken as moderately creative versus a scale with greater range. The objective assessment technique was used again to recalculate creativity ratings by taking weighted averages of each idea into account. The tier rankings according to quartiles were the following: 1st tier was assigned to groups with 82% or more creative ideas, 2nd tier was assigned to groups between 76% and 81% (inclusive) creative ideas, 3rd tier was assigned to groups between 71% and 75% (inclusive), and 4th tier was assigned to groups with 70% or less creative ideas. 31% of the experimental groups were categorized as 1st tier, 31% were categorized as 2nd tier, 15% were categorized as 3rd tier, and 23% were categorized as 4th tier. 25% of the control groups were categorized as 1st tier, 12.5% were categorized as 2nd tier, 37.5% were categorized as 3rd tier, and 25% were categorized as 4th tier. Tables **5-3 (a)** and **5-3 (b)** shows the creativity ratings based on the enhanced technique for the experimental groups and control groups respectively.

Table **5-3 (a)**: Creativity ratings using weighted objective assessment technique for the experimental groups.

Group →	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Total unique ideas	14	14	6	20.5	11	6.5	11	12	14	18.5	17	11.5	15.5
Original (o)	7	10	3	15	5.5	0	7	4	8	14	7.5	3.5	9
Rare (r)	4.5	2	0.5	2.5	2.5	1	4	4.5	3	1	5.5	3	3.5
Creative (o+r)	11.5	12	3.5	17.5	8	1	11	8.5	11	15	13	6.5	12.5
Common (c)	2	0	2.5	2	2.5	0.5	0	0.5	0	2.5	1	2	2
Pervasive (p)	0.5	2	0	1	0.5	5	0	3	3	1	3	3	1
Ordinary (c+p)	2.5	2	2.5	3	3	5.5	0	3.5	3	3.5	4	5	3
% Original	50	71	50	73	50	0	64	33	57	76	44	30	58
% Rare	32	14	8	12	23	15	36	38	21	5	32	26	23
% Creative	82	86	58	85	73	15	100	71	79	81	76	57	81
% Ordinary	18	14	42	15	27	85	0	29	21	19	24	43	19
Tier	1st	1st	4th	1st	3rd	4th	1st	3rd	2nd	2nd	2nd	4th	2nd

Table **5-3 (b)**: Creativity ratings using weighted objective assessment technique for the control groups.

Group →	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Total unique ideas	8.5	7.5	20	11	22	27.5	15	11
Original (o)	4	4	10	0	9.5	16.5	5	5
Rare (r)	2.5	2.5	5	8	7	2.5	5	4
Creative (o+r)	6.	6.5	15	8	16.5	19	10	9
Common (c)	0	1	2	0	0.5	3.5	0	0
Pervasive (p)	2	0	3	3	5	5	5	2
Ordinary (c+p)	2	1	5	3	5.5	8.5	5	2
% Original	47	53	50	0	43	60	33	45
% Rare	29	33	25	73	32	9	33	36
% Creative	76	87	75	73	75	69	67	82
% Ordinary	24	13	25	27	25	31	33	18
Tier	2nd	1st	3rd	3rd	3rd	4th	4th	1st

Based on the weighted objective assessment technique, the percentages of creative groups were compared between the experimental groups and control groups based on tier rankings. Table **5-4** shows this comparison.

Table **5-4**: Comparison of tier ranking percentages between the experimental groups and control groups using weighted objective assessment technique.

	Experimental groups	(Upper/Lower tier)	**Control groups**	(Upper/Lower tier)
1st tier	31%	62%	25%	37.5%
2nd tier	31%		12.5%	
3rd tier	15%	38%	37.5%	61.5%
4th tier	23%		25%	

Discussion

The quantitative analysis reveals that the awareness mechanisms did not have a significant effect on the quality and creativity of the product. These results suggest that awareness mechanisms, in general, do not have an effect on the product of creativity. One explanation is that awareness is itself a process variable that seeks to explicitly support collaborators' activities rather than their output. In other words, the qualitative aspects of work processes rather than the quantitative aspects of work products are most directly influenced by awareness.

The quantitative analysis reveals that the experimental groups produced artifacts of higher quality than the control groups when the effect of metacognitive knowledge was controlled. One explanation is that the awareness mechanisms helped the groups to structure and coordinate their work process, which eventually led to a logical and coherent product, though not necessarily a creative product. Awareness is known to enhance common ground in groups [Convertino et al. 2007; Convertino et al. 2008].

The objective assessment technique in its original form did not reveal any notable differences between the experimental groups and control groups. For example, both the experimental and control conditions had similar percentages for creative groups in tier rankings. However, the enhanced objective assessment technique with weighted measures did reveal notable (but not statistically significant) differences. The percentage of creative groups in the 1st and 2nd tier for the experimental condition was higher than the groups in the control condition. Further, the upper and lower quartile rankings reflected opposite percentage of creative groups for the experimental condition and control condition. This result suggests that awareness mechanisms had a notable effect in the generation of creative ideas during the group process. Experimental groups did produce more creative ideas than the control groups, though this was not necessarily reflected in the final product. This may have been because the most creative ideas were not incorporated as part of the final product.

Brainstorm recap (AM1)

RQ2-AM1(a): Experimental groups will generate more divergent ideas than control groups.

A two-sample t-test was conducted between the experimental groups and control groups with the dependent variables as the number of divergent ideas, that is, the number of functional requirements that were generated in the idea workspace after the brainstorming session in Phase I. The test revealed no statistically significant differences between the experimental groups and control groups for the number of divergent ideas.

A series of two-sample t-tests were conducted between the experimental groups and control groups with the dependent variables as FR1 and FR2, that is, the overall consideration of all the functional requirements. The tests revealed no statistically significant differences between the experimental groups and control groups for both dependent variables.

RQ2-AM1(b): How is the brainstorm recap used and with what consequences?

To address RQ2-AM1(b), responses to FR3 and BR1 were analyzed. With respect to FR3, 40 participants from the experimental condition and 20 participants from the control condition responded to the question. In the experimental condition, 12 participants (30%) clearly answered “yes” and 25 participants (63%) clearly answered “no” (Were there any functional requirements generated during the brainstorming chat session in Phase I that were not added to the idea workspace). In the control condition, 9 participants (45%) clearly answered “yes” and 8 participants (40%) clearly answered "no". Responses to FR3 specific to the open-ended question (If yes, please list these functional requirements and say why each of them was not added) were coded. Table **5-5** shows the resulting six categories with the number of coded references for each category.

Table **5-5**: Reasons why functional requirements were not added.

Why functional requirements were not added	**References**
Redundant	9
Lack_of_time	4
Not_worthy	4
Incomplete	2
Forgotten	1
Non-functional	1

Most participants reported that some functional requirements were not added because they were redundant. This implied consolidating related functional requirements (e.g., "They were too closely related to each other to be added") and removing duplicates (e.g., "Some of the ideas were duplicates of the other ideas"). A moderate amount of participants said that they did not have "enough time" to add the functional requirements to the idea workspace. Participants also indicated that they discarded certain functional requirements because they did not consider them worthy enough (e.g., "These were not nearly as strong as the other ideas we provided"; "Some of them were a bit too simple of a feature"). Few participants cited functional requirements to be incomplete (e.g., "Some ideas were incomplete and were not used"). A couple of participants said they may have forgotten to add functional requirements (e.g., "Only reason why we didn't add any would be we had forgotten them") or that some requirements were not added because they were non-functional (e.g., "Those that were left out were not functional").

With respect to BR1, all 49 participants from the experimental condition responded to the question (In Phase I, you were provided with a BRIDGE-generated summary of functional requirements based on your chat log. Was this summary useful?). 34 participants (69%) found the brainstorm recap useful, 7 participants (14%) found the brainstorm recap somewhat useful, and 8 participants (16%) did not find the brainstorm recap useful. Responses to BR1 specific to the open-ended question (If yes, how was it useful - provide an example) were coded. Table **5-6** shows the resulting fourteen categories with the number of coded references for each category (some participants also responded to why the brainstorm recap was not useful; those codes begin with NU):

Table **5-6**: Usefulness of brainstorm recap.

Why brainstorm recap was useful or not useful	References
Efficiency	14
Summary	8
Recall	6
NU_Incomplete	5
Convergence	4
NU_Artifact	2
Parser	2
NU_Annotations	1
NU_Ineffective	1
NU_Incorrect	1
NU_Context	1
Refresher	1
Reference	1
See_member's_ideas	1

Most participants reported that the brainstorm recap was useful because it saved them time and effort to sift through their group chat log and it provided an organized way of codifying the functional requirements (e.g., "It organized everything for us to find information"). In addition to efficiency, participants reported that they liked the summary aspect of the brainstorm recap (e.g., "I liked being able to review the summaries instead of searching through the chat to find out what we did") and that it helped them recall their own ideas (e.g., "They allowed us to remember what we had previously discussed"). Some participants said that the brainstorm recap helped them to converge on their ideas (e.g., “It helped pull together our ideas”) and parsed the chat log into meaningful components (e.g., “It was useful to have the chat broken into topics and related chat with it”). A couple of participants said that the brainstorm recap refreshed their memory (e.g., “I found it that it helped to refresh me on the topics we brained stormed”) or provided a reference into their previous work (e.g., “It was useful as a reference tool to list the functional requirements”). One participant said that the brainstorm recap helped to “see each others ideas”.

Some participants did not find the brainstorm recap useful. Reasons for this were that the brainstorm recap was incomplete (e.g., “It missed some and we had to go back and look for them anyway”; participants used other artifacts to note down their ideas (e.g., “Had written down all of our ideas in a notebook”); participants annotated the group chat log (e.g., “We already had our requirements with starts ** next to them”); the brainstorm recap was not effective (e.g., It didn’t split things up well and it would have been much easier to go off of a manually created list”), not correct (e.g., “We noticed that some of the functional requirements in the summary were incorrect so we avoided it”), or did not provide enough context (e.g., “I went through the chat log instead because I was more familiar with how the entire chat went and knew where to look for what I was looking for”).

Discussion

The quantitative analysis reveals that the brainstorm recap did not have any significant effect in the number of ideas generated between the experimental groups and control groups. Further, there was no significant effect in their perception regarding how many ideas they considered or did not consider. A reason for this result could be that the brainstorm recap was more useful in affecting the process of codifying ideas rather than the product. In other words, the brainstorm recap helped group members to streamline their process of identifying, summarizing, and capturing their ideas. In fact, the qualitative analysis reveals that the brainstorm recap was used in such a way. For example, members in the experimental groups used the brainstorm recap because it was efficient, it helped them recall ideas, and it provided a summary of their ideas.

The qualitative analysis also reveals that participants thought the brainstorm recap did not entirely capture their ideas due to it being inaccurate, incomplete, and so forth. This seems to suggest that many participants did not use the brainstorm recap, which could explain the lack of any quantitative effects. In their feedback, participants indicated that they primarily used the chat log to codify their ideas in the idea workspace. This is supported by their general consensus that they considered all functional requirements, and that the ones that were not considered were due mainly to redundancy. This shows that participants carefully went through the chat log to codify their ideas and were indeed aware of why they were not considering certain functional requirements. Another reason why the participants may not have used the brainstorm recap thoroughly was that the system purported to be "smart", that is, the system claimed to capture ideas automatically. In such cases, it is plausible that the participants were more critical of what to expect from the system.

Ideational summaries (AM2)

RQ2-AM2(a): Experimental groups will generate more pro and con comments than control groups.

A series of two-sample t-tests were conducted between the experimental groups and control groups with the dependent variables as the number of pros and cons, the number of pros, and the number of cons. The tests revealed no statistically significant differences between the experimental groups and control groups for all three dependent variables.

Two sample t-tests were conducted between the experimental groups and control groups with the dependent variables as PC1, PC2, PC3, PC4, PC5, and PC6. The tests revealed no statistically significant differences between the experimental groups and control groups for PC1, PC2, PC3, and PC6. There was a statistically significant difference between the experimental groups and control groups for PC4 and PC5. The two-sample t-test for equal variances was $t(70) = 2.192$, $p < 0.05$ and $t(72) = -2.027$, $p < 0.05$ respectively. For PC4, the means and standard deviations for the experimental and control groups were M = 5.25, S.D. = 2.125 and M = 4.07, S.D. = 2.372 respectively. For PC5, the means and standard deviations for the experimental and control groups were M = 6.20, S.D. = 1.641 and M = 6.96, S.D. = 1.478 respectively.

RQ2-AM2(b): How are the ideational summaries used and with what consequences?

To address RQ2-AM2(b), responses to PC7 and IS1 were analyzed. With respect to PC7, 45 participants from the experimental condition and 25 participants from the control condition responded to the question. In the experimental condition, 21 participants (47%) clearly answered "yes" and 7 participants (16%) clearly answered "no" (Do you think enough pro and con comments were added to the idea workspace in Phase II to critically evaluate the functional requirements). In the control condition, 18 participants (72%) clearly answered "yes" and 5 participants (20%) clearly answered "no". Responses to PC7 specific to the open-ended question (If yes, why do you think the pro and con comments were enough? If no, why do you think they were not enough?) were coded. Table **5-7** shows the resulting four categories with the number of coded references for each category.

Table **5-7**: Addition of pro and con comments.

Why pro and con comments were or were not enough	References
Reached_limit	24
Unequal_participation	5
Better_analysis	4
Lack_of_time	3

An overwhelming majority of the participants reported that they did not add more pro and con comments because they reached the limit for various reasons (e.g., We feel we can not find any more to put in"; "The pro and con arguments went into great depth and I believe we will be able to move on from there"; "We have more than enough ideas to evaluate them"). Some participants said that more pro and con comments could have been added if everyone in their group participated equally (e.g., "One member of our group has not done anything"). A few participants felt that they could have added more pro and con comments in order to better analyze the ideas (e.g., "We barely had one of two comments for each requirements, which is not enough to fully weigh them"). Lack of time was also cited as a reason for not adding more pro and con comments (e.g., "I think that we need time in class to evaluate these ideas").

With respect to IS1, 48 participants from the experimental condition responded to the question (In Phase II, the idea workspace recommended certain actions. Were these recommendations useful?). Some participants responded to the usefulness of the idea workspace instead of the recommendations in the idea workspace. Regarding the idea workspace, 14 participants (29%) found the idea workspace useful and 1 participant (2%) did not find the idea workspace useful. Regarding the recommendations in the idea workspace, 9 participants (19%) found the recommendations useful, 3 participants (6%) found the recommendations somewhat useful, and 12 participants (25%) did not find the recommendations useful. Responses to IS1 specific to the open-ended question (If yes, how was they useful - provide an example) were coded. Table **5-8** shows the resulting seven categories with the number of coded references for each category (responses regarding the idea workspace begin with IW; responses regarding the recommendations begin with RECS; some participants also responded to why the recommendations were not useful; those codes begin with NU).

Table **5-8**: Usefulness of idea workspace and recommendations in idea workspace.

Why idea workspace/recommendations were or were not useful	References
RECS_NU_Redundant	11
IW_Convergence	8
IW_Organization	6
RECS_Guidance	6
RECS_NU_Quantity	3
RECS_Progress	2
IW_Peer_Evaluation	1

Participants who found the idea workspace useful cited various reasons such as the workspace helped them to converge on (e.g., "They were useful because we could determine off of them which were better and more useful") and organize multiple ideas ("It summarized our functional requirements"). One participant said that it was useful in "gaining knowledge of what the other members thought" about everyone's functional requirements. Participants who found the recommendations in the idea workspace useful reported that they guided the evaluation process (e.g., "They let you know which sections still needed to be worked on") and provided a progress indicator (e.g., "It kept us in track of what we needed and didn't need to add"). Participants who did not find the recommendations in the idea workspace useful reported that they were redundant (e.g., "Some of the suggestions were unneeded"; "I also knew to add another one without being told to do so") and too many (e.g., "I thought they required too much work").

Discussion

The quantitative analysis reveals no statistically significant differences in the number of ideas, pros, and cons generated between the experimental groups and control groups. An unexpected quantitative result was obtained regarding answers to PC4 and PC5 between the experimental groups and control groups. It was expected that the experimental groups would feel more confident than the control groups in having a sufficient amount of pro and con comments in the idea workspace due to the provision of ideational summaries. However, the quantitative analysis reveals that the control groups were more confident. This result can be explained by the fact that the experimental groups did not fully use the ideational summaries, which is corroborated by the qualitative analysis.

The fact that the experimental groups were less confident than the control groups is not necessarily a negative consequence. Having less confidence can encourage group members to reflect more deeply on their decisions, which can possibly lead to more creative outcomes. Such an interpretation is plausible based on analogous empirical results. For example, studies have shown that minority dissent, even when wrong, can stimulate better decisions [Nemeth and Rogers, 1996; Van Dyne and Saavedra, 1996].

The qualitative analysis reveals that experimental groups thought the ideational summaries were redundant and too much in quantity. As a result, these ideational summaries were not used fully by the experimental groups. Consequently, these ideational summaries remained in the idea workspace, as they were not being followed. It is plausible that because these ideational summaries continued to remain in the idea workspace, the experimental groups thought that they did not have a sufficient amount of pro and con comments because the system thinks they should add more. The participants gauged their own confidence based on what the system was recommending (i.e., ideational summaries), even though they thought that they reached their limit of generating more pro and con comments.

Structured activity updates (AM3)

RQ2-AM3(a): Experimental groups will have increased awareness than control groups.

Two sample t-tests were conducted between the experimental groups and control groups with the dependent variables as LA1, LA2, LA3, LA4, and LA5. The tests revealed no statistically significant differences between the experimental groups and control groups for LA2, LA3, LA4, and LA5. There was no statistically significant difference between the experimental groups and control groups for LA1 for the first synchronous in-class session but there were statistically significant differences for the four subsequent sessions. The two-sample t-test for equal variances for the first two synchronous in-class sessions was $t(72) = 2.331$, $p < 0.05$ and $t(69) = 2.079$, $p < 0.05$ respectively. The two-sample t-test for unequal variances for the last two synchronous in-class sessions was $t(72) = 2.162$, $p < 0.05$ and $t(75) = 2.561$, $p < 0.05$ respectively. For the second synchronous in-class session, the means and standard deviations for the experimental and control groups were M = 8.32, S.D. = 0.663 and M = 7.85, S.D. = 1.064 respectively. For the third session, the means and standard deviations for the experimental and control groups were M = 8.39, S.D. = 0.829 and M = 7.88, S.D. = 1.236 respectively. For the fourth session, the means and standard deviations for the experimental and control groups were M = 8.24, S.D. = 1.058 and M = 7.61, S.D. = 1.449 respectively. For the fifth session, the means and standard deviations for the experimental and control groups were M = 8.14, S.D. = 1.155 and M = 7.29, S.D. = 1.782 respectively.

A within-subjects repeated measures ANOVA was conducted for the experimental groups and control groups with the dependent variables as LA1, LA2, LA3, LA4, and LA5 over all the synchronous in-class sessions. Mauchy's test of sphericity was violated for the experimental groups and control groups. For the experimental groups, the test revealed that there were significant differences in LA2 between the four measurement times (four synchronous in-class sessions), $F (1, 44) = 13.713$, $p < 0.001$, though this was a relatively small effect size (eta-squared = 0.238). Pairwise (LSD) comparisons revealed that the mean of the first time measurement was significantly lower than the others ($M = 6.44$, $S.D. = 2.073$). For the control groups, the Greenhouse-Geisser test revealed that there were significant differences in LA2 between the four measurement times (four synchronous in-class sessions), $F (2, 49) = 3.614$, $p < 0.05$, though this was a relatively small effect size (eta-squared = 0.131). Pairwise (LSD) comparisons revealed that the mean of the first time measurement was significantly lower than the second and third time measurements ($M = 6.48$, $S.D. = 2.485$).

RQ2-AM3(b): How are the structured activity updates used and with what consequences?

To address RQ2-AM3(b), specific questions in the following two categories were formulated: use of structured activity updates (AM3-USE) and consequences of structured activity updates (AM3-CONSQ). Three questions are of particular interest in the former category (AM3-USE):

- AM3-USE1: How frequently were the different types of activity updates used?
- AM3-USE2: For what purposes were the activity updates used?
- AM3-USE3: For what purposes were the activity comments used?

AM3-USE1 helps to distill any significant differences in the usage among the ten different types of structured activity updates. AM3-USE2 and AM3-USE3 help to understand the different ways in which activity updates and comments were used.

Two questions are of particular interest in the latter category (AM3-CONSQ):

- AM3-CONSQ1: Did users find the activity updates useful?
- AM3-CONSQ2: Did metacognition affect users' perception of the usefulness of activity updates?

AM3-CONSQ1 directly answers the question of whether or not the activity updates were useful. AM3-CONSQ2 is motivated by the definition of metacognition in that people's metacognitive abilities can affect the extent to which they become aware of and regulate their cognitive activities. Whereas cognition is the act of knowing, metacognition is the ability to reflect upon, understand, and control that knowledge [Schraw and Dennison, 1994]. Metacognition has also been noted as the awareness and control over one's thinking [Brown et al. 1983; Flavell, 1978; Metcalfe and Shimamura, 1994]. Hence, it was thought that metacognitive abilities could play a role in evaluating the use and consequences of awareness mechanisms. It was expected that participants with lower metacognition would find the activity updates more useful than those with higher metacognition because the tool would compensate for their lower metacognitive abilities. Metacognition is only being investigated with respect to the structured activity updates because the awareness design strategy was used continually over time, unlike the brainstorm recap and ideational summaries that were used only at one point in time. Further, metacognition is most directly related to the structured activity updates in the sense that the awareness design strategy provides explicit awareness of collaborators' activities.

With respect to AM3-USE1, for each of the 49 participants, the frequency of using each of the ten different activity updates was counted. The frequency was also categorized by synchronous (in-class sessions) and asynchronous (out-of-class sessions) modes of communication. Activity updates were used a total of 511 times, with nearly half split across synchronous (252) and asynchronous (259) updates. Table **5-9** summarizes these frequencies.

Table **5-9**: Frequency of activity updates.

Activity type	**Total**	**Synchronous**	**Asynchronous**
Working	170	67	103
Planning	99	54	45
Brainstorming	76	62	14
Proofreading	62	9	53
Agreeing	39	26	13
Suggesting	23	15	8
Asking	20	7	13
Summarizing	10	4	6
Disagreeing	6	4	2
Dividing up work	6	4	2

A repeated measures ANOVA was conducted to compute any statistically significant differences between the frequencies of the different types of activity updates. The analysis for unequal variances revealed that there were significant differences in the frequencies between the ten types of activities, $F(1, 48) = 43.071$, $p < 0.001$, though this was a moderate effect size (eta-squared = 0.473). Pairwise comparisons for the top four activities revealed that the mean frequency of "working" was significantly higher than all other types of activity updates; "planning" was significantly different from all except "brainstorming"; "brainstorming" was significantly different than all except "planning" and "proofreading"; and "proofreading" was significantly different than all except "brainstorming". A similar analysis could not be run for the different modes of communication due to sparse data. Though, from Table 4-xx, it is apparent that in the synchronous mode of communication, the three most frequently used activities in rank order were "working", "brainstorming", and "planning"; in the asynchronous mode of communication, the three most frequently used activities were "working", "proofreading", and "planning".

With respect to AM3-USE2, all 49 participants responded to both SAU1 and SAU2. 98 responses were coded with the goal of identifying the different purposes that the activity updates were used for. A total of 37 distinct phrases were identified as specifying a purpose. Table **5-10** shows the resulting nine categories with the number of coded references for each category.

Table **5-10**: Different ways that activity updates were used.

Purpose of activity	**References**
Group member update	13
Status broadcast	8
Asynchronous communication	4
Group progress	4
Group member login	2
Synchronous communication	2
Task coordination	2
Member login frequency	1
Timeline	1

Most participants used the activity updates to update their group members of their work (e.g., “To show my team members what part of the project I was currently working on”) or status (e.g., “Gave a little info on what each member was doing”). Few participants used the activity updates to communicate, asynchronously (e.g., “Allowed me to see what each member of my group was working on while I was not logged on”) and synchronously (e.g., “When different tasks were going on simultaneously, it was helpful to know who was doing what”). Activity updates also provided an index into group progress (e.g., “Informed me about my group’s progress”) or who was logged on (e.g., “I could see who logged in last”). Two participants said that the activity updates helped them to coordinate work (e.g., “I logged on to finish scenario 1, and saw what other work was necessary”). One participant said that the activity updates “showed how often group members were logging in and making additions” while another said that “it was helpful as a timeline”.

With respect to AM3-USE2, the actual comments that users elicited in the structured activity updates tool were coded with the goal of identifying the different purposes that they expressed. The comments were coded at the group level of analysis for each of the 13 groups so as to understand any dependencies among group members that the comments were referring to. Table **5-11** shows the resulting eight categories with the number of coded references (number of groups) for each category.

Table **5-11**: Different ways that activity comments were used.

Purpose of comment	References
Coordination	13
Feedback	13
Encouragement	12
Elaboration	11
Discourse	9
Reminder	7
Fun	5
Metamorphosis	2

"Feedback" was one of the most frequent purposes for a comment where participants provided feedback to group members such as "Nice job of organizing the list". The comments were also heavily used by all groups to coordinate work (e.g., "We will review each other's sections on Wed"), though we distinguish this from "elaboration" that refers to an explication or enhancement of an idea (e.g., "We should come up with a few more asynchronous ideas!").

Twelve of the thirteen groups moderately used the comments to encourage and support each other (e.g., "Keep up the good work"). In nine groups, we noticed that the comments represented a communication discourse similar to a conversation that could have occurred using the chat tool. For example, Greg commented on Katie's status: "Can you think of any more functional requirements"; a few hours later, Ed also commented on Katie's status by following up on Greg's message: "I'm also trying to figure out some more functional requirements".

A small number of comments were used to remind group members of deadlines or responsibilities (e.g., “Make sure to add your pros and cons”). A small number of comments were also used for non-work or “fun” purposes (e.g., “I also like surfing”) and to reflect on social dynamics during the metamorphosis stage of concluding group work (e.g., “I have enjoyed working with you and the other group members on this project”).

With respect to AM3-CONSQ1, of the 49 participants that responded to SAU1, 22 participants (45%) found the structured activity updates useful, 9 participants (18%) found the structured activity updates somewhat useful, and 18 participants (37%) did not find the structured activity updates useful. Some of the participants expanded on why the structured activity updates were not useful. 27 of the 98 participants (28%) that responded to SAU1 and SAU2 expressed that the chat communication tool in BRIDGE served the purpose that was intended by the structured activity updates. Among such responses, following were some typical user quotes: “We communicated what we were doing through the chat function”; “This could have automatically been extracted from a chat and displayed”; “I could just go into the chat logs and find out the specific task of each person”.

With respect to AM3-CONSQ2, all 49 participants responded to the metacognition questionnaire. The 49 participants were separated into two categories based on their responses of whether they found the structured activity updates tool useful or not. Thus, 31 participants were placed in the “useful” category and 18 participants were placed in the “not useful” category. A two-sample t-test was conducted between the two categories of usefulness (useful, not useful) with metacognition as the dependent variable. The analysis for equal variances revealed no statistically significant difference. The 52 items in the metacognition questionnaire were then loaded on two factors based on [Kumar, 1998]: *metacognitive regulation* and *metacognitive knowledge*. Metacognitive regulation denotes planning, information management, monitoring, debugging, and evaluation. Metacognitive knowledge denotes declarative, procedural, and conditional knowledge. The above two-sample t-test for metacognitive regulation as the dependent variable revealed no statistically significant difference. The same two-sample t-test for metacognitive knowledge as the dependent variable revealed a statistically significant difference: $t(47) = -2.137$, $p < 0.05$. The mean metacognitive knowledge rating for participants who found the structured activity updates tool useful (M=58.76) was significantly higher than the participants who did not find the tool useful (M=53.92).

Discussion

The quantitative analysis revealed that in general, the experimental groups were more aware of what their members had worked on than the control groups. This seems to suggest that the structured activity updates were used by group members to understand what their collaborators have been doing in order to contextualize their own activities. The qualitative analysis corroborates such an interpretation. The quantitative analysis also revealed that the experimental groups experienced increased awareness of what their members will work on. A similar, though weaker, relationship was revealed for the control groups. This seems to suggest that the structured activity updates were moderately used by group members to understand what their collaborators will do next.

“Working” was the most frequently used activity, which can be explained by the following two reasons. First, as the structured activity updates tool was meant to provide activity awareness in the context of work, it seems natural that collaborators would be inclined to select the “working” activity to make others aware of their work-related tasks. Second, “working” is a general adjective that seems to encompass some if not all of the other types of activities, which are more specific in their description.

The disparity in frequencies between the different types of activity updates may suggest that the high frequency activities are the ones that collaborators are more inclined to stay aware and make others aware of, and vice versa. For example, collaborators want to stay aware and make others aware of tasks related to "working" and "planning" but not so much so as related to "dividing up work" and "disagreeing". Practically, the high frequency activities are associated with high levels of dependency among group members. Hence, it follows that collaborators feel the need to stay aware and make each other aware of statuses related to "working" and "planning". In fact, this is what activity awareness seeks to provide: what is going on in terms of work and how will the work play out next. As for the low frequency activities, which may be only associated with high levels of dependency at a particular point in time, collaborators are inclined to proactively communicate such activities with others rather than relying on awareness mechanisms. For instance, it seems plausible that collaborators would rather divide up work by discussing it with their group members using chat and then work on their respective parts rather than coordinating the division of labor through awareness mechanisms.

There is also a disparity in frequencies between the synchronous and asynchronous modes of communication. Two activities particularly stand out. "Brainstorming" is skewed toward the synchronous mode of communication while "proofreading" is skewed toward the asynchronous mode of communication. This is not a surprise. Brainstorming is typically a synchronous activity and proofreading is typically an asynchronous activity.

The qualitative analysis reveals that activity updates were used in varying ways. Broadcasting one's activity and staying up to date of what one's group members are doing were expected ways of how activity updates would be used. This is similar to how status updates are used in social networking media. However, activity updates seem to be also used for coordinating work and task dependencies, understanding group progress cumulatively over time, and tracking group member contributions.

The qualitative analysis reveals that comments were used in varying ways to support unplanned, brief, and ad hoc communication. The comment feature in the structured activity updates tool was not only used for the obvious purpose of providing feedback to group members but also served as a secondary mechanism or communication backchannel [Ackerman, 2000] to allow group members to coordinate work, encourage and remind each other, and occasionally discuss non-work topics. Such casual interactions keep individuals informed about each other in social and professional contexts, they reinforce social bonds, and they make the transition to tightly-coupled collaboration easier [Whittaker et al. 1994].

There were mixed feelings toward the usefulness of the structured activity updates tool. Directly asking participants about the usefulness of the tool did not solicit an overwhelming positive response. This may be attributed to the fact that the structured activity updates tool was not integrated with the chat communication tool. Hence, the design required collaborators to expend extra effort to switch between the structured activity updates tool and the chat communication tool in order to make effective use of both. Many participants who did not find the tool useful acknowledged this design shortcoming.

The result that participants with higher metacognitive knowledge found the structured activity updates tool more useful than those with lower metacognitive knowledge seems counter-intuitive. One would expect that the tool would compensate for lower levels of metacognition and thus be more useful to such participants.

According to Flavell [1978], metacognitive knowledge refers to acquired knowledge about cognitive processes, knowledge that can be used to control cognitive processes, as well as knowledge of one's own learning processes. For example, you may be aware that your study session will be more productive if you work in the early morning when everyone is asleep rather than evening when there are many distractions. In this sense, participants with higher levels of metacognitive knowledge can be opportunistic in identifying and leveraging strategies that can help them monitor their progress. In such cases, participants are using their conditional knowledge about when and where it is appropriate to use strategies or in our case, awareness tools, to enhance their collaborative learning experience. Such an explanation would lend support for our result.

On the other hand, metacognitive regulation implies checking the outcomes of incorporating strategies and ensuring that cognitive goals have been met. In this sense, the structured activity updates did not explicitly support a cognitive goal or outcome but rather the process of reaching a particular goal or outcome. The result that there was no significant difference in the levels of metacognitive regulation would be corroborated by such an explanation.

General discussion

In addition to understanding how activity awareness design strategies and mechanisms are used and with what consequences, the main experiment contributes to CSCW literature by suggesting theoretical, design, and empirical implications. On a theoretical level, it is argued that awareness mechanisms should engage users metacognitively. On a design level, various enhancements to the awareness mechanisms are identified based on the main experiment results. On an empirical level, the evaluation of creativity as a process and product is discussed.

Theoretical implications

The dominant approach in CSCW has been to conceptualize awareness mechanisms as engaging users at a cognitive level by making them aware of system-based, event-driven information. For example, knowing where a collaborator's mouse pointer is can indeed facilitate the immediate coordination of manipulating shared artifacts. Such awareness mechanisms rely on detecting and providing short-term informational states at the level of low-level tasks and subtasks that facilitates users' immediate cognitive goals. Although the provision of such system-based, event-driven information is critical, it is limiting to the extent of what people need to and can be aware of. Indeed, awareness mechanisms cannot detect and convey people's intentions. In his critique of awareness being construed as a *passive process* [Dourish, 1997], Schmidt [2002] says that passive awareness is restrictive and it prevents users from engaging in practices to align and integrate their distributed but interdependent activities. Rittenbruch et al. [2007] capitalize on this notion to argue for a more intentionally enriched awareness mechanism where users can explicitly characterize and share their own activities.

In this sense, awareness mechanisms should engage users metacognitively. Awareness mechanisms should seek to help users regulate their cognition and think explicitly about their learning and work goals. By explicitly characterizing and sharing their activity intentions, users can engage in and think about deeper work-related interactions such as coordinating responsibilities, managing dependencies, resolving conflicts, and so forth. This allows collaborators to be cognizant of each other at the level of activities, a higher-order function of shorter and immediate tasks and subtasks that are merely system-based, event-driven nuggets of information.

This theoretical implication is consistent with the result that in general, metacognition plays a role in determining the usefulness of awareness mechanisms. Specifically, people with higher metacognitive knowledge seem to be more strongly oriented toward and are interested in being aware of their collaborators' activity. It follows from this result that capitalizing on and effectively using awareness mechanisms may also be a metacognitive and strategy. This suggests that awareness mechanisms should not just be limited to system-based, event-driven information of what is currently going on in a shared workspace. But also, awareness should be about providing cognizance of activities that need to be internalized and monitored over time such that users are prompted to strategically regulate their cognition and manage their knowledge in order to achieve their overall goals collaboratively. In this sense, awareness is a more a metacognitive process than a cognitive product.

Design implications

The results suggest that an automated summary may not be a viable approach to capture ideas. Participants are adept at codifying ideas during and after the process of generating ideas. A possible design enhancement is to consider allowing participants to themselves codify ideas from their chat log, which can then be used as an auxiliary artifact to identify, summarize, and capture ideas. This enhancement would be similar to the initial design mock-up shown in Figure **4-1**.

The results suggest that the ideational summaries were redundant and too much in quantity. A possible design enhancement to mitigate this problem is to allow users to remove or flag the ideational summaries from the idea workspace. Removing or flagging the ideational summaries will allow participants to manually configure which ideational are important. At the same time, the results clearly indicate that the pre-defined heuristics for generating the ideational summaries need to be revised. In particular, the data shows that participants are adept at initially populating ideas with pro and con comments on their own. In this case, for example, ideational summaries prompting participants to add pro or con comments to ideas that do not yet have any associated pro or con comments are not required.

Several studies in CSCW have investigated the use of status updates in collaborative contexts. For example, Tickertape [Fitzpatrick et al. 1998] is a lightweight awareness tool to facilitate social interaction between co-workers. The Notification Collage [Greenberg and Rounding, 2001] is a full-fledged groupware system that incorporates the notion of activity indicators through a variety of media such as digital photos and video. The Community Bar [McEwan and Greenberg, 2005] extends the Notification Collage by supporting communities to foster and maintain ad hoc interaction.

While there are some similar attributes between the structured activity updates and other systems, there are also significant differences. Primarily, the structured activity updates focused on longer-term activities as intentionally broadcasted by users in the context of fully distributed work, not social settings. For example, Smale and Greenberg [2005] studied status updates in instant messenger clients. Though their study context is not collaborative work, it is interesting to note that some of their communication categories of status updates are similar to the results from the main experiment. In their categorization scheme, "fun" is a type of status update that overlaps with how the structured activity updates were used. Particular to the study context of the main experiment, Smale and Greenberg note that people use status updates to broadcast information without involving chat conversation. This supports the feasibility of recruiting status updates for distributed collaborative work as a natural extrapolation from their original intended use in social networking media.

Perhaps the most related work to the structured activity updates is the study by Rittenbruch, Viller, and Mansfield [2007]. In presenting their model of intentionally enriched awareness, Rittenbruch et al. review and critique prior accounts of awareness as ignoring the ways that actors deliberately present themselves and their activity to collaborators. Rittenbruch et al. locate intentionally enriched awareness as lying between mere perception of appearances and events, and public communication and explanation of one's activity.

Rittenbruch et al. focus on notifications of interest and availability for specific activities such as playing a computer game, or going for a coffee. They developed a tool to configure activity-specific polling and notification, enabling users not only to signal their own availability and interest, but to coordinate carrying out the activity with other like-minded users. This tool was used by users who were co-located. Rittenbruch et al. categorized the status notifications as activity indicators and activity inducements. Activity indicator notifications act as invitations to announce that certain activities are about to commence and that fellow users are invited to jointly participate. Activity inducement notifications are statements to convey that people are already engaged in activities.

The different purposes for which the structured activity updates were used in the main experiment are much broader and deeper than the two general categorizations of activity indicators or activity notifications as identified by Rittenbruch et al. For example, nine different ways of how activity updates were used were identified. The structured activity updates allowed the investigation of how users coordinated specific types of activities. Further, the activity comments feature was encouraging to the effect of acting as a communication backchannel in distributed work contexts.

A design enhancement to the structured activity updates tool is to integrate it with chat. This can have at least two consequences. First, people will be more likely to update their activities because an integrated tool provides a single interface for interaction, whether it is for frequent and structured chat communication or ephemeral and ad hoc activity updates. Second, people will be more likely to notice and enhance their awareness of collaborators' activities through a unified interface. Rittenbruch et al. [2007] alluded to a similar integrated design in their discussion of notification and communication as interleaved processes. Their results show that status notifications were more efficient for coordination of activities when compared to using instant messaging, though chat would be preferred for negotiating joint activities.

A design issue to consider in the structured activity updates is the level of structure imposed by the pre-defined activity templates. The design of structured updates was motivated by the Coordinator [Winograd and Flores, 1986], a large-scale electronic communication system that enlists participants in a coding procedure by using pre-defined speech acts aimed at making implicit intent explicit. The premise of this procedure was that explicitly identified speech acts are clear, unambiguous, and preferred, as people tend to be vague as to their own intent and that of others [Suchman, 1994]. In the structured activity updates, users were not allowed to specify ad hoc activity updates. By allowing such flexibility in the design of the tool, it remains to be empirically determined if structured activity updates are preferred over unstructured activity updates and under what circumstances. Further, future studies can explore the generative nature of the pre-defined activity templates by investigating a broader range of speech acts than the ones that were provided.

Empirical implications

In Chapter 1, the type of creativity was characterized as a process and product, implying both novelty and usefulness. The exploratory experiment used an integrated theoretical framework to qualitatively understand the process of creativity. Regarding the product of creativity from a quantitative perspective, novelty was assessed by the objective assessment technique and usefulness was assessed by the consensual technique. The objective assessment technique was enhanced using weighted measures based on the extrapolation of the consensual technique to assess novelty. The weighted objective assessment technique advances our understanding of how to better measure novelty in a creative process. At the same time, there is much room for enhancing the technique.

In the objective assessment technique, in general, determining which ideas should comprise the cumulative unique list was a significant factor in the outcome of the results. The smaller the number of ideas in the list, the lower the percentage of creativity was found among the groups. The greater the number of ides resulted in artificially high levels of creativity among the groups. One way to mitigate for this problem is to trim the number of ideas to get a consistent number for each group. This would control for the productivity of each group in terms of generating ideas. This approach would avoid normalization issues as stated above.

For accuracy, the list was subjectively but logically scrutinized ensuring that each idea was unique, coherent, and aligned with the requirements of the overall task. For example, the idea “professor blogs” and “blogs” were considered to be the same idea. This was decided because the two share the same core concept. On the contrary, there were cases where two apparently related ideas were assessed as distinct. For example, “calendar text message reminders” and “calendar reminders” were categorized as distinct ideas as it was decided that the additional detail provided by the first idea (text message) significantly changed the core concept.

The validity of an idea was also taken into account. Groups were tasked with generating new functional requirements for a course management system. Therefore, each group’s suggestion was judged as to whether or not it can be deemed a functional requirement. The coherency of each idea was also taken into account. Ideas such as “better grade book” or “better chat client” were deemed invalid in comparison to ideas such as “course grade simulator” or “chat rooms for each class”. Such ideas lacked the needed level of detail to be considered coherent.

Another factor that can affect the outcome of the results is the weights being assigned during the assessment of each idea. A tertiary ranking scale was used to rate each idea. Expanding the range in this scale can lead to different results, though the effect of subjectivity may increase. Eventually, the reliability of the weighted objective assessment technique needs to be calculated by iteratively asking independent experts to rate the ideas. Further, the objective assessment technique—in its original and enhanced form—needs to be validated against creativity benchmarks. Unfortunately, no such benchmark exists currently. One approach is to calculate correlations of novelty rankings using the objective assessment technique and the weighted objective assessment technique against usefulness ratings as assessed by the consensual technique. Differences in correlations can provide insight into which metrics for assessment novelty are better. Of course, the assumption is that novelty and usefulness are highly correlated.

Conclusion

This chapter addresses the second research question (RQ2) posed in this dissertation: How are these awareness mechanisms used and with what consequences? Awareness mechanisms, in general, were used in different ways during collaborative work. Feedback from participants suggests that the design of the awareness mechanisms can be enhanced to better support creativity. The data analysis further reveals that awareness mechanisms, in general, do not affect creativity as a product-oriented measure. There are some significant effects on creativity as a process-oriented measure. This may be because activity awareness is itself a metacognitive process and strategy.

Chapter 6

Follow-up analysis

In this chapter, a follow-up analysis to the main experiment is presented. The main experiment focused on the aggregate analysis of all groups in both the control and experimental conditions. As a result, the aggregate analysis did not consider the process of creativity as the primary focus was directed toward establishing product-oriented interpretations. In this chapter, four groups are systematically identified from the main experiment and their chat transcripts qualitatively analyzed to interpret the process of creativity.

Details of follow-up analysis

Four groups from the main experiment were identified for follow-up analysis. The goal was to compare and contrast extreme cases in terms of their creativity. A high and low creative group was identified from the control and experimental condition. High and low creative groups were assessed using a combination of the judges creativity rating of the group's final solution (consensual technique) and the weighted objective assessment technique. In the control condition, group 2 (control high group) was identified as the high creative group and group 3 (control low group) was identified as the low creative group. In the experimental condition, group 8 (experimental high group) was identified as the high creative group and group 5 (experimental low group) was identified as the low creative group.

Each group's chat transcripts were analyzed using qualitative analysis. Unlike the breakdown analysis using a theoretical coding scheme in the exploratory experiment, Grounded theory was used to analyze and code the chat transcripts. The goal of the follow-up analysis was to identify themes that were deemed as significant variables between the four cases above and beyond the themes in the theoretical coding scheme that was used in the exploratory experiment. For example, one of the themes that emerged from the analysis was the different ways in which the low and high creative groups advocated ideas. The analysis showed that members of low creative groups advocated for the ideas they had purposed whereas members in the high creative groups advocated on the best ideas regardless of whether it was theirs or not.

Results

Three major themes emerged from the qualitative analysis with respect to the process of creativity in the four groups. These themes are discussed below with examples from the chat transcripts.

Off-topic conversations

The low creative groups were outliers in terms of the amount of conversation that took place. The control low group was a high outlier with over 10,000 words, much of which was extraneous conversation. The experimental low group, on the other hand, was a low outlier with a total conversation of only 3,200 words, almost none of which was off-topic. In contrast, the two high groups had conversation lengths around the average of all the four groups (6,500 words). Table **6-1** shows the length of the chat transcripts for each of the four groups and the percentage of off-topic conversation.

Table **6-1**: Length of chat transcripts and percentage of off-topic conversation.

Groups	Length of chat transcript	Percentage of off-topic conversation
Experimental low	3,279 words	0%
Experimental high	6,103 words	0.14%
Control low	10,520 words	8.06%
Control high	5,019 words	1.8%

Following is an example of an off-topic conversation that occurred in the control high group:

nichols:	was it 301?
joe:	same, and I almost lost points because I was forgetting to enter it
joe:	yep
jeff:	yep, with reddy
joe:	let's not talk about reddy -.-
stephen:	haha
nichols:	yeah....that class was......(censor)
nichols:	so.....
jeff:	class wasnt that bad, but lets not get off track

In the above chat excerpt, the conversation pulled off-topic by an initial on-topic discussion of an attendance pin idea as a functional requirement to enhance Angel. One of the group members (jeff) quickly brought the conversation back on-topic.

Convergent discussion

The percentage of conversation during the idea converging process varied greatly among the four groups. The two low creative groups spent less than 10% of their total conversation on convergent conversation (2% in the control low group and 8.7% in the experimental low group). The two high groups devoted over 10% (10.4% in the control high group and 20.8% in the experimental high group).

There was a discernable pattern in how the low and high creative groups selected ideas during convergence. The low creative groups seemed to choose ideas that they "liked". The high creative groups, on the other hand, seemed to choose ideas more systematically based on the pros and cons of each idea. The high creative groups also demonstrated greater amounts of reflection on ideas.

For example, the control low group showed an almost complete lack of reflection as indicated in the following chat excerpt:

alex:	i liked the PDF idea we had
phil:	what story would we make for that
alex:	i could make somethiing up
greg:	well there's our two

On the other hand, the control high group reflected deeply on the ideas by explaining them in more detail:

kevin:	calendar and rss can be put into one
laurie:	kevin, can you give an example of combining the 2?
anthony:	i agree the more i think about it, that would be more like expanding the purpose of angel

Idea advocating

To better understand how the four groups functioned, the group member who initially suggested an idea was compared with the group member who advocated the most for that idea toward the end. A clear difference was found between the high and low creative groups. For the low creative groups, the person who suggested the idea toward the end was the same person who initially contributed the idea. The high creative groups, on the other hand, had a different model. The original person who suggested the idea was different than the final advocator.

Following is an example of a chat excerpt from the control low group. In the beginning of the conversation, Nick strongly suggests an idea to synchronize Angel with Outlook:

nick:	I feel it imperative to add a function to sync angel with Microsoft Outlook. This way you can download tasks and calanders your professors put up!

As convergent discussion begins, Nick brings up his idea again but is met with opposition:

nick:	ok i really like the Sync Angel Calendars and Tasks with Outlook
tim:	ok but what if students dont use outlook
tim:	i dont like outlook
nick:	Outlook is a key tool in bridging between various items like Ipod, Cell Phone

At the end of convergent discussion, the group finally decides to accept the Outlook idea. This may be because Nick advocated for it so strongly or he just wore out the other group members:

nick:	the idea would almost be like a 2 parter. if angel calendar was more heavilly used than teachers would be forced to actually put their schedules on it... positng exams, homeworks, readings...
tim:	ok cool

On the other hand, the idea advocating process was different in high creative groups. Following is a chat excerpt from the control high group. During brainstorming, Ned suggests a cell phone access idea:

ned:	so it would be nice to able to access AngelX on cell phones to look at the calendar function and grade functions

At the beginning of the convergent discussion, Jeff first suggests Ned's cell phone idea. The idea is accepted by the group after each member positively contributes to the idea:

jeff:	anyone got an idea of which 2 we want to use?
jeff:	i like the cell phone idea

Discussion

The three themes identified through the follow-up analysis highlight major differences in how low and high creative groups function. The amount of off-topic conversation suggests that there may be a “sweet spot” in the amount of extraneous conversation. It is plausible that too much extraneous conversation will keep a group from operating at peek productivity. On the other hand, it is also plausible that the complete lack of extraneous conversation may also limit productivity. For example, groups do require social grounding before they start to function optimally.

Regarding convergent discussion, the follow-up analysis indicates that the high creative groups exhibited more critical evaluation in choosing the final ideas. The low creative groups may have picked ideas they “liked” or were partial to their own ideas. The high creative groups seemed to pick ideas based on evidence such as the number of pros and cons. Regarding idea advocating, a similar pattern was observed where group members who initially brainstormed ideas were the final advocators of their ideas in the low creative groups. Whereas in the high creative groups, members were more critical of each other’s ideas and selected ideas through a consensual process.

No major differences were observed between the groups in the control and experimental condition. This is not a surprise given the small sample size. A comprehensive qualitative analysis of all groups from both the control and experimental conditions can possibly reveal the effects of the awareness mechanisms.

Conclusion

This chapter compares and contrasts extreme cases through a follow-up analysis of four groups from the main experiment. In some ways, the analysis reveals that low and high creative groups are different from each other in terms of the amount and nature of off-topic and convergent discussion, and how ideas are advocated within a group. The main experiment illustrated how low and high creative groups are different quantitatively whereas this follow-up analysis sheds some light on the qualitative differences.

Chapter 7

Conclusion

In this chapter, overall conclusions are drawn based on the research in this dissertation. The results from the exploratory and main experiments are summarized. The significance and impact of this research is specified with respect to theoretical, design, and empirical contributions. Short-term and long-term future research plans are explicated.

Summary of results

Investigating how creativity can be supported through awareness in distributed collaboration, this research is conducted through five phases. These phases explore different aspects of investigating the feasibility, effectiveness, and consequences of supporting creativity in distributed collaboration.

The first phase (Chapter 2) is a survey of creativity literature to speculate how computer-supported awareness, and in particular activity awareness, can support creativity in distributed collaboration. Based on this literature review, an analytical result was the development of an integrated theoretical framework to understand the process of creativity.

The second phase (Chapter 3) is an exploratory experiment that identifies breakdowns in creativity in distributed collaboration. The following points summarize the results:

- *Minority ideas are under-considered*. During upstream stages of collaborative work, dissenting opinions were buried by majority opinion holders. As a result, minority ideas were under-considered, never reflected on fully, and/or were not incorporated.
- *Novel ideas are easily lost*. During upstream stages of collaborative work, the novel ideas generated and narrowed down by group members in prior interactions did not

fully carry over to subsequent interactions, were not readily available for review, and/or were not incorporated. As a result, novel ideas were easily lost, either for part of the group interaction, or for the entire duration of the activity.

- *There is a lack of critical evaluation of perspectives*. The different ideas that group members generated were not reflected on comprehensively. As a result, group members hastily converged on decisions.
- *Reflexivity is weak during convergence*. There was a lack of shared understanding and common ground between group members, especially during the downstream stages of collaborative work. As a result, group members were not cognizant of each other's contributions.

The third phase (Chapter 4) is the design and prototyping of novel activity awareness strategies and mechanisms to support creativity. The following three activity awareness mechanisms were developed as prototypes:

- *Brainstorm recap*. The brainstorm recap captures novel ideas during divergent thinking and presents a summary to group members for reflection during convergent thinking.
- *Ideational summaries*. The ideational summaries prompt group members to critically reflect on and evaluate different perspectives of group members.
- *Structured activity updates*. The structured activity updates allow group members to develop shared understanding by specifying their work statuses and commenting on others' work statuses.

The fourth phase (Chapter 5) is a main experiment that studies the effectiveness and consequences of using the three activity awareness mechanisms. The following points summarize the results:

- The activity awareness mechanisms did not statistically affect the overall quality of the final product. However, groups with activity awareness mechanisms did produce statistically higher quality intermediate artifacts than the groups without activity awareness mechanisms.
- The activity awareness mechanisms did not statistically affect the overall creativity of the final product.
- Groups with activity awareness support were more likely to be among the most creative than groups without activity awareness support. 62% of the groups with activity awareness support were ranked in the upper tier of being creative versus 37.5% of the groups without activity awareness support.
- The brainstorm recap did not statistically affect the number of ideas generated by groups.
- Most participants reported that the brainstorm recap was useful because it saved them time and effort to sift through their group chat log and it provided an organized way of codifying their ideas.
- The ideational summaries did not statistically affect the number of pro and con comments generated by groups.
- Groups with the ideational summaries were statistically less confident in having a sufficient amount of pro and con comments than groups without ideational summaries.
- Most participants reported that the ideational summaries were not useful because they were redundant and too much in quantity.
- The structured activity updates statistically increased awareness of group members in regards to what they had worked on. Further, the structured activity updates statistically increased awareness of group members over time in regards to what they

will do next, a relationship that was stronger for the groups with structured activity updates than groups without structured activity updates.

- The ten structured activity updates were used with statistically different frequencies, and in particular, "working on" was statistically the most frequently used activity update.
- The ten structured activity updates were used with statistically different frequencies during synchronous and asynchronous modes of communication. "Brainstorming" was statistically the most frequently used activity update in the synchronous mode of communication while "proofreading" was statistically the most frequently used activity update in the asynchronous mode of communication.
- Most participants reported that the structured activity updates were used in varying ways, in particular to update their group members of their work status.
- Most participants reported that comments were used in varying ways, in particular for brief and ad hoc communication related to providing encouragement and feedback in addition to coordinating and elaborating on work.
- Group members with higher metacognitive knowledge found the structured activity updates statistically more useful than group members with lower metacognitive knowledge.

The fifth phase (Chapter 6) validates findings from the main experiment (Study 2). Using a sample of four groups from the main experiment, this follow-up analysis compares and contrasts extreme cases in terms of their creativity.

Contributions and intellectual merit

This dissertation will contribute to the basic science of creativity, to the design science of supporting creative activity, and to the empirical science of measuring creativity.

Theory

The application of creativity theories from the social sciences in HCI and CSCW contexts improves our general understanding of creative collaboration. As a result of the exploratory experiment, the breakdowns that were identified in distributed collaboration contribute to our existing theoretical comprehension of variables that inhibit and enhance creativity in face-to-face contexts. As a result of the main experiment, the general relationship between metacognitive knowledge and awareness suggests that metacognition is a person variable that should be accounted for in studies of creativity.

Design

The prototypes of awareness mechanisms broaden the science of design by developing new tools for supporting creativity. The three activity awareness mechanisms advance the breadth of existing creativity support tools. The awareness mechanisms also inform designers of creativity support tools regarding how these mechanisms can be integrated with existing collaborative tools. As a result of the main experiment, the structured activity updates in particular advance our understanding of design tradeoffs and consequences regarding status broadcast tools in social networking media.

Evaluation

The extension of existing evaluation metrics and frameworks advances our ability to measure creativity using both quantitative and qualitative methods. The weighted objective assessment technique provides a more accurate insight into ranking creative groups. The integrated theoretical framework provides a structured coding scheme of understanding the process of creativity. The breakdown analysis demonstrates the use of this theoretical framework as an effective way of identifying instances of computer support opportunities in collaborative contexts.

Benefits and broader impact

The benefits and broader impact of this dissertation is to enhance the process and product of creative collaboration. Creativity continues to be studied in the social sciences with the increasing consensus that it can be evoked and harnessed through various socio-technical interventions. This dissertation advances this body of research by investigating computer-supported tools that can be used by group members in distributed settings to support their creative work. Though the scope of this dissertation is constrained a specific type of collaboration, it is expected that the results can be extrapolated to other contexts. For example, the results are most directly applicable to partially distributed groups and settings that may not be exclusively focused on scientific work.

The research in this dissertation is of interest to scholars interested in the implications of information technology for supporting creativity. Scholars interested in understanding, evoking, and enhancing the integrity of human activity in contexts of human-computer interaction can consider the role of computer-supported awareness in their own research investigations to engage everyday people in long-term creative and collaborative endeavors. The results in this dissertation are also valuable to the general audience of user experience practitioners, designers, and researchers in collaborative or social networking media interested in supporting networks of people engaged in everyday creativity using information technology.

Dissemination

Various aspects of this dissertation have been published in several professional venues such as research magazines, conferences, and journals. Following is a chronological list of major publications at the time of this writing:

- **Farooq et al. [2005]**: This conference publication, entitled *"Supporting Creativity in Distributed Scientific Communities"*, presents the integrated theoretical framework used to analyze breakdowns in the process of creativity in the exploratory experiment.
- **Farooq [2006]**: This magazine publication, entitled *"Eureka! Past, present, and future of creativity research in HCI"*, is a brief opinion piece on the status and trajectory of creativity research in HCI.
- **Farooq [2007]**: This conference publication, entitled *"Supporting creativity: Investigating the role of computer-supported awareness in distributed collaboration"*, is a symposium presentation on the overall research in this dissertation.
- **Farooq et al. [2007]**: This conference publication, entitled *"Supporting creativity with awareness in distributed collaboration"*, presents the exploratory experiment and initial design mock-ups for the activity awareness strategies and mechanisms.

- **Farooq et al. [2008]**: This journal publication, entitled *"Designing for creativity in computer supported cooperative work"*, is an extended version of Farooq et al. [2005], focusing on the design of creativity support tools in collaboratories.

Future work

The research in this dissertation focused on a small, yet important, problem of supporting breakdowns in creativity using the specific approach of computer-supported awareness for small groups in distributed settings. The investigation and results from this dissertation provide groundwork for further research into supporting creativity broadly in multiple contexts.

An immediate research goal relates to the redesign of activity awareness strategies and mechanisms. The results suggest some major design revisions to the proposed awareness tools. For example, in the case of ideational summaries, the pre-defined heuristics need to be reconfigured and the interface needs to be more noticeable and less intrusive. Some minor design revisions are also required. In the case of structured activity updates, integrating the tool with the primary communication channel such as chat is a feasible next step.

The main experiment was set up as a control group study. Based on redesign of the awareness mechanisms, it would be appropriate to consider a more complicated experimental design in order to compare the effects of the awareness mechanisms on creativity. One possible design is to add another experimental condition to the existing set up. The new experimental condition would incorporate a human facilitator to provide awareness instead of the awareness mechanisms. For example, the human facilitator could apprise group members of different social influences, an aspect that ideational summaries were seeking to provide. This new experimental condition would constitute the strongest manipulation and the control group would constitute the weakest manipulation. Therefore, differences in effects of the awareness mechanisms could be understood more in depth in regards to their specific role in supporting creativity.

Given the nature of the second research question, the main experiment investigated how the awareness mechanisms were used and with what consequences. The main experiment was therefore design to be conducted in a controlled environment in a highly structured manner. For example, subjects were asked to use the awareness mechanisms in certain ways. This research stimulates a future empirical investigation that would be a field study. A viable study site could be a group of researchers across academic institutions that are collaborating on writing a technical write-up over several weeks in a distributed setting. Such a study would investigate the results in this dissertation in a naturalistic context.

The result that metacognitive abilities affect perceived usefulness of awareness mechanisms is worthy of further investigation. This result was based on one study and is limited to one factor of metacognition (metacognitive knowledge). Future studies should investigate how and when metacognition, and both factors of metacognitive regulation and knowledge, have an effect on awareness and if this effect can be controlled. Further, studies should attempt to relate metacognition to group dynamics and performance (e.g., how does metacognition affect group performance at different group stages). Researchers and designers interested in supporting awareness should incorporate metacognition as a variable in their empirical studies.

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Appendix A

Instructions and procedure for exploratory experiment

Overview

As part of a team, you will be working remotely with two partners to write an insightful opinion piece related to information and computer science education, specifically on teaching programming to information and computer science majors. You will be using a collaborative environment called BRIDGE (Basic Resources for Integrated Distributed Group Environments) to work with your team partners.

Overall task

With your team partners, you are to write a short, two-page (approximately 1000 words) technical opinion piece on how to teach and introduce software programming to new students. You will develop your opinion piece based on existing papers that talk about teaching programming to information and computer science majors. Your work will be judged based on the novelty and effectiveness of your approach, essentially on how creative your opinion piece is.

To get an idea of what is expected of you, you may expand, critique, or base your opinion piece on the paper by Ralph Westfall that appeared in Communications of the ACM: "Hello, World Considered Harmful" (http://citeseer.ist.psu.edu/750438.html). You are also encouraged to find other relevant papers on your own and use them for this task.

Ready to begin

To start off, you should read Westfall's paper to get an idea of what is expected of your team.

You should only use BRIDGE to collaborate with your team partners. Please do not contact them face-to-face or via email.

You will also get two emails from the research investigator during the one-week period asking for a brief progress report. Please reply to these emails individually.

Remember, the task is open-ended, so there is no right or wrong answer. Your team's final opinion piece is going to be judged on how creative it is. Good luck!

Appendix B

Progress update email

As part of the collaborative task you are doing with your partners, can you briefly provide (in 2-3 sentences) a summary of the work you have done so far. If you have not made any progress, please mention what you plan to do in the next two days.

Please reply individually to this message today. Thank you.

Appendix C

Semi-structured interview questions

- Were you aware of what your group members were doing?
- Was it easy to find what your group members worked on in the collaborative space?
- Did you get to know your group members better over time?
- Did you communicate well with your group members?
- Were the communication tools sufficient for the shared task?
- As time went on, did you and your group members become more productive at the task?
- Did you plan adequately for the task?
- Did you contribute equally to the project as your group members?
- Did you trust your group members in doing what they said that they would do?
- Can you identify events of creativity during the collaboration?
- Was there enough information sharing with respect to the overall goals?
- Was there shared understanding with respect to the overall goals?
- Were there conflicts and how did you resolve them?

Appendix D

Coded examples based on the integrated theoretical framework

Coding categories	Example
Social influences	
Groupthink	Jay: We should stick with programming that means coding; Marie: Ok; Hasan: Ok.
Normalization	Judy: Maybe we can do something with the animation idea.
Majority influence	Ahmed: I think the debate is a good idea; Judy: It's not the assignment {debate idea}; Chris: Thanks Judy for elaborating the {animation} ideas.
Polarization	{None}
Minority dissent	Marie: Programming is like cooking, its difficult to talk in the abstract; Jay: Yes, I agree; Hasan: That's not true…We are trying to teach the concept of a language.
Information sharing	
Common information pooling	Marie: In the Hello World paper, he is obviously talking about teaching OO to students with procedural language.
Unique information pooling	Sam: I was also thinking maybe we can propose to start not with programming techniques but something more data-driven, like ajax or web services.
Shared understanding	
Reflexivity: reflection	Ahmed: I think the assignment is sufficiently amorphous.
Reflexivity: planning	Sam: We can make an outline of this and then everyone can contribute to any section.
Reflexivity: action/adaptation	Wendy: I can do "Introduction" and "Why start teaching object-oriented language".
Divergent thinking	
Generation of multiple perspectives	Jay: We should identify some problems faced by the students.
Reflection of multiple perspectives	Marie: Do you have any ideas about what problem we can address?
Unique information pooling	Sam: You can't appreciate what's good about OO before some procedural programming.
Convergent thinking	
Critical evaluation of perspectives	Jay: I don't think algorithm {the idea of teaching programming using algorithms} is appropriate, because in CS, there is another course on algorithms.
Perspective implementation	Sam: I liked your diagram and I followed up on it in the brainstorming space.

Appendix E

Wizard of Oz script

You are required to identify functional requirements from chat logs that were generated during brainstorming sessions by virtual teams as part of their collaborative work. You will be given a hard copy of the chat log for each team. Read through the entire chat log. As you're reading through each chat log, do the following:

- Underline each functional requirement. If you think a particular requirement may or may not be a functional requirement (i.e., you are not sure), put a question mark next to it.
- For each functional requirement you underline, highlight the chat utterances around that functional requirement (before and after) that provide context for that functional requirement. The context should include chat utterances that led the group to elicit and discuss that functional requirement.
- You may have to iterate over these steps by re-reading and reviewing the chat log, and in particular, the functional requirements with a question mark next to them. Ensure that each functional requirement you identify is distinct from the others for each team.

Appendix F

Instructions and procedure for main experiment

(Note: Text highlighted in light gray is the part of the instructions that was given to only the experimental groups.)

Day 1 instructions

Overview

You and your group peers are work-at-home employees of a high-tech startup company of 49 people with creative ideas for a new and improved integrated product: “AngelX: Next Generation ANGEL”. With the AngelX project, your group has the opportunity to enhance and re-engineer the basic offerings and operations of the existing ANGEL course management system.

The company president has selected your distributed group to spearhead this project. You have been asked by the president to prepare a report exploring new services that AngelX could offer in the future.

It is an honor being selected to work on the initial stages of this innovative project. Therefore, your group’s success on this project will ensure your future with the company.

Required tools

You will be using a collaborative environment called BRIDGE to work with your group members. Because you are a work-at-home employee, you are part of a “virtual team”. You are only allowed to communicate and collaborate with your group members using BRIDGE. You are NOT allowed to interact with your group members in any other way for this project. For example, you may not talk with your group members face-to-face or contact them via email.

Duration

This project will last two-and-a-half weeks during which you will have five classes. You will work on this project as part of both in-class activities and out-of-class participation. There are four main project phases. Below are the details of Phase I. Details of Phases II, III, and IV will be provided along the course of the project.

Phase I: Generation of alternatives

The outcome of this phase is to brainstorm several enhancements to the existing ANGEL course management system. Each enhancement should be expressed as a functional requirement. A functional requirement captures what the AngelX should do in order to support what users are currently unable to do with the system (assume that the users are undergraduate students just like yourself).

For example, a functional requirement for AngelX is to “access documents from ANGEL on a cell phone”. (This is important in cases where you don’t have access to a computer and want to read a course syllabus on your phone while walking to class.)

What to do and how to do it:

(Task 'a')

Using the chat functionality in BRIDGE, brainstorm several enhancements to ANGEL as functional requirements. The more functional requirements you discuss, the better (brainstorm at least seven!).

(Task 'b')

While doing Task 'a', update your activity status in the "Activity Workspace" at least twice. You are also required to comment on your group members' activity updates at least twice. The more activity updates and comments you have, the better.

(Task 'c')

Continue your brainstorming session by logging in to BRIDGE at least twice after today's class but before next class. This may be done asynchronously (different time), that is, you may contribute your ideas by posting chat content in BRIDGE at your own time when other group members are not present. The goal is to establish functional requirements that cover a reasonable set of functionality for AngelX without too much overlap. You don't need to put these functional requirements in any document – the instructor will monitor the chat content.

While doing Task 'c' (that is, every time you log in to BRIDGE outside of class), update your activity status in the "Activity Workspace" at least twice. You are also required to comment on your group members' activity updates at least twice. The more activity updates and comments you have, the better.

Phase II: Period of critical reflection and evaluation of alternatives

The outcome of this phase is to reflect on and evaluate all the functional requirements that you brainstormed in Phase I.

Phase III: Consensus reaching

The outcome of this phase is to reach consensus on functional requirements that are most creative in terms of providing novel enhancements to ANGEL, thus making AngelX a popular and valuable market product.

Phase IV: Implementation

The overall outcome of this phase is a formal report describing your group's enhancements to ANGEL.

Day 2 instructions

Phase II: Period of critical reflection and evaluation of alternatives

The outcome of this phase is to reflect on and evaluate all the functional requirements that you brainstormed in Phase I. Your group will make pro and con comments on each of the functional requirements. Pro comments are comments in support of a functional requirement; con comments are comments critiquing aspects of a functional requirement. Pro and con comments may be related to usability goals, user experience goals, data requirements, context of use, and/or user demographics.

For example, a functional requirement for AngelX is to "access documents from ANGEL on a cell phone". Pro comments can be:

+ Easy to learn as users already know how to use cell phones

+ Provides good utility for users to look at course syllabus before class

+ Quick and efficient access to ANGEL documents

Con comments can be:

- Frustrating to use with phone keypad

- Information on cell phone will be limited because of small screen real estate

- Data capacity on cell phone might not support large ANGEL documents

What to do and how to do it:

(Task 'a')

In BRIDGE, add all the functional requirements your group brainstormed in Phase I to the "Idea Workspace" by clicking "Add new idea". Each functional requirement should be expressed succinctly in a consistent manner (e.g., AngelX should provide access to documents on a cell phone).

Using the chat functionality to coordinate, take turns adding functional requirements as multiple people editing the "Idea Workspace" at the same time can result in conflicts and even deletion of functional requirements. Each functional requirement should be owned by one group member. Each group member should add his/her functional requirement to the "Idea Workspace".

Hint:

Based on your group's chat log, BRIDGE has automatically generated a summary of the functional requirements your group brainstormed during the in-class activity (Wednesday, February 13) in Phase I. This summary is available in an uneditable object called "Summary:

Phase I". At your discretion, refer to this BRIDGE-generated summary to add functional requirements to the "Idea Workspace". Note that the summary may not be accurate and BRIDGE may not have captured all the functional requirements from the chat log (especially if you logged in after class and added more functional requirements).

(Task 'b')

Using the chat functionality in BRIDGE, brainstorm pro and con comments for each functional requirement. Add these pro and con comments to the "Idea Workspace". The more pro and con comments you add, the better.

Using the chat functionality to coordinate, take turns adding pro and con comments as multiple people editing the "Idea Workspace" at the same time can result in conflicts and even deletion of pro and con comments. Each pro or con comment should be owned by one group member. Each group member should add his/her pro and con comment to the "Idea Workspace".

(Task 'c')

While doing Tasks 'a' and 'b', update your activity status in the "Activity Workspace" at least twice. You are also required to comment on your group members' activity updates at least twice. The more activity updates and comments you have, the better.

(Task 'd')

Continue adding pro and con comments to the "Idea Workspace" by logging in to BRIDGE at least once after today's class but before next class. This may be done asynchronously (different time), that is, you may contribute your ideas by posting chat content in BRIDGE at your own time when other group members are not present. The goal is to add multiple pros and cons that represent distinct comments for each functional requirement of AngelX that you brainstormed in Phase I.

While doing Task ‘d’ (that is, every time you log in to BRIDGE outside of class), update your activity status in the “Activity Workspace” at least twice. You are also required to comment on your group members’ activity updates at least twice. The more activity updates and comments you have, the better.

Day 3 instructions

Phase III: Consensus reaching

The outcome of this phase is to reach consensus on two functional requirements out of the several ones you added to the “Idea workspace” in BRIDGE. Your group will select the two functional requirements that are most creative in terms of providing novel enhancements to ANGEL, thus making AngelX a popular and valuable market product. Based on these two functional requirements, you will begin to articulate design scenarios.

What to do and how to do it:

(Task ‘a’)

Based on your group’s pro and con comments in the “Idea workspace”, use the chat functionality in BRIDGE to converge on the two most creative functional requirements. Make sure you discuss the reasons for choosing the two functional requirements over the others with your group members in your chat communication. It is likely that this task will generate more pro and con comments for certain functional requirements. If so, add these pro and con comments to the “Idea workspace”.

(Task ‘b’)

While doing Task 'a', update your activity status in the "Activity Workspace" at least twice. You are also required to comment on your group members' activity updates at least twice. The more activity updates and comments you have, the better.

(Task 'c')

Once your group has decided on the two most creative functional requirements, write a design scenario for each of the two functional requirements. Each design scenario will envision how users will use AngelX with respect to its associated functional requirement. Use the chat functionality in BRIDGE to brainstorm each design scenario with your group members.

Each scenario should tell a rich narrative in a step-by-step fashion. Remember to include the main constructs of scenarios in the narrative: user(s), technology, need for using the technology, interaction with the technology, context, user experience, and consequence of using the technology. Each scenario should be between 150-250 words (note: you can check the word count using Microsoft Word).

(Task 'd')

Continue to develop each scenario by logging in to BRIDGE at least twice after today's class but before next class. This may be done asynchronously (different time), that is, you may contribute your ideas by posting chat content in BRIDGE at your own time when other group members are not present.

Before next class, both functional requirements and their associated scenarios should be written in the BRIDGE text objects "Scenario 1" and "Scenario 2" respectively.

While doing Task 'd' (that is, every time you log in to BRIDGE outside of class), update your activity status in the "Activity Workspace" at least twice. You are also required to comment on your group members' activity updates at least twice. The more activity updates and comments you have, the better.

Day 4 instructions

Phase IV: Implementation

The outcome of this phase is the formal report describing your group's enhancements to ANGEL. At the beginning of this project, you were asked by the company president to prepare a report exploring new services that AngelX could offer in the future. The report should be between 1,500 to 2,000 words (diagrams are not part of the word count).

Your group has two more classes and the time in-between to finish this phase and the project. Decide with your group members how to proceed and manage time.

What to do and how to do it:

(Task 'a')

If you have not finished Phase III (two scenarios and two storyboards), please do so.

(Task 'b')

The formal report should be written in the BRIDGE text object "Report". The report consists of the following sections:

- *Introduction*: This section should provide information about your group (e.g., team number, names of group members, major contributions of each group member to the project) and provide an overview of the report.
- *Functional requirements*: This section should describe the two functional requirements in detail and why your group chose these two specific functional requirements among the several other ones that were brainstormed.
- *Scenarios*: This section should provide the two scenarios and describe them. Say how each scenario is associated with its respective functional requirement. Explain how

each scenario is persuasive and realistic in terms of providing creative enhancements to ANGEL.

- *Storyboards*: This section should describe how each storyboard exemplifies its respective scenario. (Note: You don't need to embed the storyboards in the report, just refer to each storyboard as "Storyboard 1" and "Storyboard 2".)
- *Conclusion*: This section should describe the advantages and disadvantages of your overall AngelX system (functional requirements, scenarios, and storyboards). Mention major considerations and concerns that would feed into the next phase of actually implementing AngelX.

(Task 'c')

While doing Task 'a' and Task 'b' (that is, every time you log in to BRIDGE in class and outside of class), update your activity status in the "Activity Workspace" at least twice. You are also required to comment on your group members' activity updates at least twice. The more activity updates and comments you have, the better.

Day 5 instructions

(Groups worked to complete their final report.)

Appendix G

Computer and Angel use questionnaire

- How many hours do you spend daily on a computer?
- How many years have you been using computers?
- During semester work, how many hours do you spend weekly on Angel?
- How many months have you been using Angel?

Appendix H

Technology training questionnaire

- I was able to use BRIDGE to complete the in-class activities assigned to me.
- I can use all the tools (e.g., chat, idea workspace) provided to me in BRIDGE.
- I need more time to learn how to use BRIDGE for doing collaborative group work.

Appendix I

Script and rubric for quality rating

The report comprises an introduction, two functional requirements that represent enhancements to Angel, two scenarios (one for each functional requirement), two storyboards (one for each scenario), and a conclusion. Please rate quality (Q) of the report on the following dimensions and associated scales (0 = low, 10 = high):

Artifact quality:

- Q1: Do the functional requirements represent enhancements to ANGEL? (0-10)
- Q2: Do the scenarios follow a logical and coherent flow of events? (0-10)
- Q3: Do the storyboards illustrate and exemplify the scenarios? (0-10)

What is the *overall quality* of the report on the following dimensions:

- Q4a: Feasibility of implementing the functional requirements (0-10)
- Q4b: Success of the product if marketed (0-10)
- Q4c: Written quality of the report (0-10)

Appendix J

Script and rubric for creativity rating

The report comprises an introduction, two functional requirements that represent enhancements to Angel, two scenarios (one for each functional requirement), two storyboards (one for each scenario), and a conclusion. Please rate creativity (C) of the report on the following dimensions and associated scales (0 = low, 10 = high):

Artifact creativity:

- C1: Do both functional requirements represent novel and useful enhancements to ANGEL? (0-10)
- C2: Are both scenarios persuasive and realistic? (0-10)
- C3: Are both storyboards persuasive and realistic? (0-10)

Overall creativity:

- C4: What is the overall creativity of the report? (0-10)

VITA

Umer Farooq

Umer Farooq received a Bachelor of Science (B.S.) in Computer Science from the National University of Computer and Emerging Sciences (NUCES; Islamabad, Pakistan)—formerly known as Foundation for Advancement of Science and Technology (FAST)—in December 2000. He received a Master of Science (M.S.) in Computer Science with a focus in Human Computer Interaction from Virginia Tech (Blacksburg, VA USA) in December 2002. He started his Doctor of Philosophy (Ph.D.) in Computer Science from Virginia Tech in January 2003 but transferred to The Pennsylvania State University (University Park, PA USA) to continue work on his Ph.D. in August 2003. He has completed the requirements for a Ph.D. in Information Sciences and Technology from The Pennsylvania State University in August 2008.

The goal of Farooq's interdisciplinary research is to understand, support, and enhance user experience in social contexts in the areas of cooperative work, collaborative learning, and community informatics. Farooq has published his research in several professional venues such as Computer Supported Cooperative Work, Computer Supported Collaborative Learning, Behaviour and Information Technology, Information Processing and Management, International Journal of Human Computer Studies, and Internet Computing. As a co-principal investigator, Farooq is the recipient of an NSF SGER (Small Grants for Exploratory Research) grant on investigating requirements for supporting scientific creativity in collaboratories: NSF-IIS-0749172 (January 1 – December 31, 2008; $83,826). More information can be found at http://umerfarooq.info.