Effects of Four Modes of Group Communication on the Outcomes of Software Requirements Determination

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Journal of Management Information Systems / Summer 1998, Vol. 15, No. 1, pp. 99–118.

0742–1222 / 1998 $9.50 + 0.00.

ABSTRACT: Research on computer-mediated communication and group support systems has focused on the study of a single mode of communication technology in comparison to unsupported face-to-face (FtF) groups. However, as organizations combine traditional FtF meetings with a variety of anytime/anyplace communication technologies to support collaborative work, the need to study these new forms of interaction grows greater. This experiment builds on prior work by comparing the effectiveness of four modes of communication for groups working on the upstream phases of software development: (1) face-to-face, (2) synchronous computer conferencing, (3) asynchronous computer conferencing, and (4) combined FtF and asynchronous computer conferencing. Teams of graduate students determined the requirements for an automated post office as a course assignment over a period of two weeks. The creativity and quality of solutions produced by groups in the combined condition were higher than those in the remaining three communication modes. Combined groups were generally more satisfied with their solutions, although no differences among conditions were found regarding satisfaction with the process used to accomplish work.

KEY WORDS AND PHRASES: computer conferencing, computer-mediated communication, creativity, group support systems, requirements analysis.

ALTHOUGH SOFTWARE IS STILL DEVELOPED BEHIND SCHEDULE and over budget, arguably the most serious shortcoming is that often, when the software is finally delivered, it does not meet users' requirements [2, 3, 5]. As if this were not discouraging enough, heightened competitive pressures in today's global environment dictate that software professionals produce creative and innovative solutions to organizational problems [5, 12, 16].

It is generally agreed, among information systems professionals and researchers alike, that having shared, accurate, and complete software requirements is fundamental for increasing development productivity and meeting users' needs, as work accomplished during these early development stages affects the remainder of the software project [6, 8, 26]. Upstream software development [25]—problem formulation, requirements determination, and software design—provides perhaps the best opportunity to instill creativity into the development process [5], since this is where developers work together with users to "figure out what to build" [17]. Upstream development is essentially a collaborative process of communication [17] among developers and users where knowledge acquisition, knowledge sharing, and knowledge integration must be accomplished [27] to develop a mutually shared understanding of problems and the impact of technical solutions.

Communication during software development in general, and upstream development in particular, is an essential but notably time-consuming activity. It has been suggested by various researchers [6, 20, 23] that, in order to make substantial progress toward increased development productivity and proficiency in determining software requirements, information systems professionals must find ways to increase the effectiveness of communication. Indeed, when summarizing the results of a recent

survey within one large software development company, Kraut and Streeter [20, p. 80] comment, "The challenge in software engineering should not be to devise methods to minimize personal communications, for example, as formal specification languages are intended to do. Rather a goal should be to make interpersonal communication more efficient and effective." These researchers suggest that computerized tools that facilitate distributed meetings, such as computer conferencing [15], are "likely to be useful, by opening up the meetings, making them more efficient, and providing an archive" [20, p. 80].

In the corporate arena, it is becoming increasingly commonplace for teams to "mix and match" interaction media over an extended period of time to accomplish their work. For example, some software development teams use a combination of face-to-face meetings and computer-mediated communication (CMC) [18]. Similarly, Cutosky et al. [7] describe the use of a mixture of collaboration modes (e.g., face-to-face and distributed, synchronous and asynchronous CMC) and technologies (mostly Web-based software tools) that enabled engineering teams to consist of highly skilled specialists from different organizations and different locations. Through a combination of various collaborative modes and tools, the dispersed teams were able to design and prototype a complex device (i.e., an optical seeker used in missiles) in an unprecedented six months.

Given the realities of today's business environment, there is a pressing need to conduct research that reflects the new forms of media that organizations are employing to accomplish complex work [18, 21]. To date, out of the approximately 140 group support system (GSS) experiments [11], only three studies [9, 10, 14] investigated the usefulness of combining computer-mediated communication with other communication media (i.e., face-to-face and telephone) over a period of time.

To address this gap in the GSS and CMC research, this experiment compares combined modes and single modes of communication to support upstream software development. Specifically, it compares groups using a combination of face-to-face (FtF) and asynchronous computer conferencing (CC) with groups using only one communication mode: FtF, asycnhronous CC, or synchronous CC. The outcome variables of interest are the quality as well as the creativity of the groups' requirements definition, and group member satisfaction.

Previous Research

THE CONTENT OF GROUP WORK DIFFERS OVER THE LIFE of the group's problem-solving activity. Chidambaram and Bostrom [4] characterize early group work where group members spend time getting acquainted with one another and work to establish group goals, outline tasks to be accomplished, set priorities, and define member roles. Group work during these early stages does not center on the extensive sharing of information and documents; rather, the focus of the group is on planning their work [13]. After the initial phase, groups often enter an execution phase, where members work individually and then share information and their accomplishments with their group members [13]. During the final phases of group work, groups strive to integrate the work of individual

members in order to complete their tasks and prepare materials for external review.

Compared with CMC, Kiesler and Sproull [19] theorize that face-to-face meetings are a more effective means for defining issues, securing commitment, and decomposing the task—all activities that occur during the initial phase of group work. However, during the middle (execution) phase of group work, groups need to share information quickly and frequently. Kiesler and Sproull [19] speculate that groups can benefit from mechanisms that allow for the quick and frequent transmission of information in a form that will permit other members to interpret and use it. Indeed, participants in both the Eveland and Bikson [9] study and Galegher and Kraut [14] study found CMC to be effective for sharing information. Finally, groups who are in the late stages working to complete their task may find face-to-face communication more effective.

In an earlier study, we compared the effectiveness of groups using different modes of communication (unsupported FtF versus distributed asynchronous computer conferencing) and different problem solving approaches (structured versus unstructured) [24]. All groups worked for two weeks developing the requirements and high-level design for an automated post office. We were particularly interested in the impact that asynchronous computer conferencing (asynchronous-CC) had on requirements determination in terms of the creativity and quality of group solutions and also the satisfaction of groups using this medium. The quality of solutions produced by the asynchronous-CC groups was judged to be marginally higher than that of the unsupported face-to-face (FtF) groups, while the creativity of solutions produced by the asynchronous-CC groups was judged to be significantly higher than that of the FtF groups. The problem-solving approach used did not significantly affect creativity or quality. Both asynchronous-CC and FtF groups were equally satisfied with their solutions; however, FtF groups were marginally more satisfied with the process they used in reaching their solutions.

Research Framework

BUILDING ON OUR PREVIOUS RESEARCH, THE CURRENT STUDY expands the exploration of the effectiveness of various modes of communication for groups working on the upstream portions of software development. The primary research question investigated in this experiment is: Are groups that use a combination of both face-to-face and computer-mediated communication more effective than groups that use a single mode of communication?

Four communication conditions are explored in this experiment: (1) face-to-face (FtF), (2) distributed asynchronous computer conferencing (asynchronous-CC), (3) co-located synchronous computer conferencing (synchronous-CC), and (4) combined communication—a sequence of FtF, asynchronous-CC and FtF (combined). Both the asynchronous-CC and synchronous-CC groups communicated using only a computer conferencing system, however the asynchronous-CC groups were distributed in space and time, while the synchronous-CC groups worked simultaneously within the same room. The FtF groups met twice and group members had no communication with one another between meetings.

The combined communication mode was designed to address the differing needs of

groups involved in the initial phase, the execution phase, and the final phase of group work [4, 19]. The combined groups had an initial face-to-face meeting (initial phase), followed by a two-week period where all communication occurred using a computer conferencing system (execution phase), followed by a final face-to-face meeting (final phase).

Hypotheses on Creativity, Quality, and Satisfaction

Creativity of Group Solution

BASED ON THE FINDINGS OF THE FEW PRIOR STUDIES that allowed groups to combine face-to-face and computer-mediated modes of communication over a period of time, we speculated that groups in the combined condition will exhibit higher levels of creativity than groups in the remaining communication modes. The combined groups will be better able to plan and organize their work and thus experience an improved beginning compared to the asynchronous-CC and synchronous-CC groups. The combined groups will have the benefit of continued communication over the two-week period of the experiment, whereas the FtF groups and the synchronous-CC groups can only communicate during the scheduled meeting times. Thus, we hypothesize that:

1.1. Combined groups will produce more creative solutions than asynchronous-CC groups.

1.2. Combined groups will produce more creative solutions than the synchronous-CC groups.

1.3. Combined groups will produce more creative solutions than FtF groups.

The major finding of our initial study was that the creativity level of the software requirements definitions produced by the distributed asynchronous computer conferencing groups was judged as significantly higher than those produced by the unsupported face-to-face groups. However, because no groups used synchronous computer-mediated communication in the initial study, it was not possible to determine whether the higher creativity ratings for asynchronous-CC groups were in fact associated with asynchronous-CC (versus synchronous-CC) or just with the use of computer conferencing. Therefore, in the current study, we incorporate a synchronous computer conferencing treatment to isolate the factors of time and distance from the use of CMC technology.

Research on minority influence theory [22] and group creativity/innovation [28] (see also [23, 24] for a detailed explanation) indicates that creativity is enhanced when groups are not constrained by time. Similarly, communication among group members is believed to be important for encouraging creativity. Therefore, because of the increased ability of the asynchronous-CC groups to stay connected with group members and the relative lack of time pressures compared with both the synchronous-CC and the FtF groups, and based on the results from our initial study, we hypothesize that:

1.4. Asynchronous-CC groups will produce more creative solutions than synchronous-CC groups.

1.5. Asynchronous-CC groups will produce more creative solutions than FtF groups.

Quality of Group Solution

According to minority influence theory [22], groups exhibiting higher levels of creativity will produce outcomes of higher quality. However, results from our first experiment showed that, although the asynchronous-CC groups were judged to produce significantly more creative solutions than FtF groups, the quality of asynchronous-CC groups' ideas was only marginally better than that of FtF groups. Perhaps this finding is attributable to the need for some face-to-face communication. The literature reviewed on phases of group work indicates that computer-mediated groups striving to reach consensus or commitment may benefit from face-to-face communication at the onset and conclusion of their work. Therefore, we speculate that the groups in the combined mode will produce solutions of higher quality than groups in the remaining communication modes. Thus, we hypothesize that:

2.1. The solution quality of the combined groups will be of higher quality than the asynchronous-CC groups.

2.2. The solution quality of the combined groups will be of higher quality than the synchronous-CC groups.

2.3. The solution quality of the combined groups will be of higher quality than the FtF groups.

Neither the FtF nor the synchronous-CC groups have the benefit of continued communication over time, as do the asynchronous-CC groups. Based on our expectation that the FtF and synchronous-CC groups will produce significantly less creative solutions than asynchronous-CC groups, we expect that the FtF and synchronous-CC groups will also exhibit a lower level of quality, compared with asynchronous-CC groups. Therefore, we hypothesize:

2.4. Asynchronous-CC groups will produce solutions of higher quality than synchronous-CC groups.

2.5. Asynchronous-CC groups will produce solutions of higher quality than FtF groups.

Solution Satisfaction

Solution satisfaction pertains to groups' satisfaction with the outcome that they produced. In our initial study, no significant difference was found between the level of solution satisfaction between asynchronous-CC and FtF groups. With the inclusion of the combined treatment in the current experiment, we speculate that the combined

groups, given the ability to work on their solutions both asynchronously and face-to-face, will be more satisfied with their end-product than groups in the other treatments. Therefore, we hypothesize that:

3.1. Solution satisfaction of the combined groups will be higher than that of asynchronous-CC groups.

3.2. Solution satisfaction of the combined groups will be higher than that of synchronous-CC groups.

3.3. Solution satisfaction of the combined groups will be higher than that of FtF groups.

Process Satisfaction

Process satisfaction is a measure of the satisfaction experienced by groups regarding the method(s) used to accomplish work. Thus, each different mode of communication represents a different process for accomplishing work. In the first experiment, FtF groups were marginally more satisfied with the (face-to-face) process compared with the distributed asynchronous computer-mediated groups. Based on the literature regarding the phases of group work, we expect that the combined treatment will have the best fit in terms of the varying needs of groups as they go through the initial, execution, and final phases of work. Thus, we hypothesize that:

4.1. Process satisfaction of the combined groups will be higher than that of asynchronous-CC groups.

4.2. Process satisfaction of the combined groups will be higher than that of synchronous-CC groups.

4.3. Process satisfaction of the combined groups will be higher than that of FtF groups.

Method

Design

THIS EXPERIMENT USED AN AUGMENTED DESIGN. The asynchronous-CC groups and the FtF groups are the same groups that were included in our initial study [23, 24]. These two conditions were "run" during the time period from Fall 1993 through Fall 1994. Groups in the synchronous-CC and combined conditions were not included in any prior study. These conditions were carried out from Fall 1994 through Fall 1995.

Since the problem-solving approach made "no difference" in our first study, it was decided not to fill in a complete 4 × 2 design. Although the same task, laboratory environment, experimenters, experimental procedures and materials, computer conferencing system, and type and source of subjects were used for all conditions, the fact that groups were not randomly assigned to all of the conditions during the same period

raises some methodological limitations that will be explored in our discussion of the results.

Forty-two groups were included in this study (see Table 1). All groups met face-to-face for training. When working on the actual experimental task, groups in the synchronous, combined, and FtF conditions met twice for two face-to-face sessions, occurring exactly two weeks apart. Groups in the asynchronous condition conducted all work using the conferencing system over a two-week period.

Task

The task used is this experiment was the Automated Post Office (APO).[1] Groups were required to reach consensus on the initial requirements of the APO and to submit these requirements in a formal report at the end of the experiment; each group produced a single report. The report was to cover the functionality of the APO along with implementation considerations. It was also to contain a description of the user interface design. This is a modification of the same task used by Olson et al. [25], with an added emphasis on the design of the user interface. Olson et al. characterize this task as incorporating planning, creativity, decision making, and cognitive conflict [25].

Subjects

Subjects consisted of graduate students in the CIS and IS majors at the New Jersey Institute of Technology (NJIT) and M.B.A. students from Rutgers University. All subjects received course credit for their participation. The majority of subjects had coursework and/or job experience directly relevant to systems design. Group size ranged from four to seven persons for all groups. Subjects were scheduled to meet based on their availability for scheduled sessions.

Technology and Facilitation

All of the computer-mediated groups (synchronous-CC, asynchronous-CC, and combined) communicated using the EIES2 computer conferencing system developed at NJIT. Each computer-mediated group communicated in its own conference set up on EIES2. The conferences were minimally facilitated. The conference facilitator's role was that of a technical assistant, helping groups with equipment problems and answering questions of a technical nature.

Pilot Studies

Prior to conducting this experiment, pilot studies were carried out whereby multiple groups were run in each experimental condition. All experimental procedures and surveys were tested and modified where necessary.

Table 1. Experimental Design

Condition	Number of groups	Time period	Meeting 1	14-day interval	Meeting 2
FtF	10	1993–94	Yes	No interaction	Yes
Asynch-CC	10	1993–94	No	Asynchronous communication	No
Synch-CC	12	1994–95	Yes	No interaction	Yes
Combined	10	1994–95	Yes	Asynchronous communication	Yes

Training

All groups met face-to-face for training and used the same practice problem, called Entertainment for Dutch Visitors [25]. Groups using the computer-conferencing system were trained on the communication features of EIES2 and worked on the conferencing system using the practice problem. Face-to-face groups also worked on the practice problem without using technology. Groups in the combined condition received the same training as the synchronous-CC and asynchronous-CC groups. All training sessions were completed within 1½ hours.

Procedures

After training, groups in the FtF and combined conditions remained for one additional hour to begin work on the APO task. This meeting constituted the first face-to-face session for these groups. At the end of the two-week period, these groups reconvened for a second face-to-face meeting, which lasted up to 2½ hours. These groups were provided with a computer with word processing software for their second meeting. In the interim between session one and two, group members in the FtF condition were permitted to work independently on the APO; however, they were instructed not to communicate with fellow group members during this time.

Groups in the combined condition communicated asynchronously using the computer conferencing system during the two-week interval between the two face-to-face sessions. For the second face-to-face meeting, groups in the combined condition were provided with a computer with word processing software and a terminal to connect to EIES. The groups were instructed that they had 2½ hours to complete the task.

After the training session, synchronous-CC groups remained for their first synchronous meeting, which lasted up to two hours. The synchronous-CC groups were required to conduct all of their work using the computer conferencing system; as in the asynchronous condition, these groups were not permitted to talk or otherwise interact with one another other than by using the conferencing system. Like the FtF groups, these groups were instructed not to communicate with each other regarding any aspect of the APO task between session one and session two. Two weeks after their first meeting, the synchronous-CC groups reconvened for a second meeting,

which lasted up to 2½ hours. Pilot studies revealed that groups in the synchronous-CC treatment required a full hour longer than FtF and combined groups during the second face-to-face meeting. For this reason, synchronous-CC groups were given a full hour longer.

All groups had a leader who volunteered for the role at the end of the training session, sometimes with encouragement from the facilitator. Each leader was responsible for ensuring that his or her group submitted a formal report at the end of the two-week experimental period.

Debriefing

Face-to-face groups were debriefed in a face-to-face session. Computer conferencing groups were debriefed in a face-to-face session if class time was available. Otherwise, these groups were debriefed in a special online conference. All participants in the face-to-face conditions were questioned regarding their adherence to the rules for communication outside the two sessions.

Measures of the Dependent Variables

Background data on subjects were collected via a pre-experiment questionnaire. Self-report data regarding satisfaction with the solution and satisfaction with the process used to reach a solution were collected via a post-experiment questionnaire.

A panel of three expert judges measured the dependent variables of quality of solution and creativity of solution. These judges had academic and/or professional experience in software design. Two of the three judges met in two face-to-face sessions for training and practice on report evaluation. (The remaining judge was unable to attend either meeting and was given training individually.) All groups' formal reports were printed using the same word processing package and aspects of each group's mode of communication were masked. Using a slightly modified rating form from the one used in the initial study, the judges rated each group on various aspects of the design (e.g., functionality and interface), written presentation, and overall quality of the analysis [25]. The level of creativity contained in each group's design was also measured by the panel of judges. According to Amabile, a "product or response is creative to the extent that appropriate observers independently agree it is creative" [1, p. 359]. In addition, there is no agreement as to the appropriate subcategories to use in order to rate creativity. Therefore, we did not provide the expert judges with explicit details. Rather, we instructed them to rate the creativity of each group using the general category of "Creativity of Group Solution."

Results

Experimental Validity

IT WAS CRUCIAL TO THIS EXPERIMENT TO USE ONLY graduate students in courses that were likely to furnish subjects with the requisite knowledge and experience to engage

in a fairly complex software analysis and design task. Because only a few courses cover software analysis and design and only a few sections of these are offered each semester, it was impossible to complete this study as a single experiment in a single year. Although the same experimenters were involved in all conditions, following the same documented procedures and incorporating the same key words and phrases into their training sessions, there is always the danger that the nature or experiences of groups in conditions conducted at different periods of time (i.e., 1993–94 versus 1994–95) could create undesirable variance (see Table 1). For example, although students enrolled in the same courses participated in the study in different semesters, enrollment in the courses varied from one semester to another, with the result that the proportion of subjects from each course was not the same each semester. This means that subjects may not be homogeneous across conditions. Therefore, the similarity or differences among conditions must be explicitly examined.

To address these concerns, we ran a series of statistical analyses. Concerning time, a pattern of significant differences between time periods would indicate that time played a role in influencing outcomes. To examine the comparability of the two time periods, group scores on creativity and quality were averaged by time period for each judge and *t*-tests were run to test for significant differences (Table 2). Our analyses show that judge 2 scored creativity higher in the second time period, while judge 3 scored quality higher in the second time period. These differences, however, do not point to any consistent scoring differences per time period, and thus indicate that the two time periods were not an important factor in influencing results.

Another concern was that of the comparability of subjects within each of the conditions. To analyze subjects across conditions, we compared background data on age, years of employment, gender, and graduate academic major that were collected from the pre-experiment survey. Means per condition and *t*-tests to calculate significance levels are shown in Tables 3 and 4, respectively. *T*-tests indicated that subjects across conditions were significantly different in several respects. Subjects in the synchronous-CC condition were younger than subjects in either the FtF or asynchronous-CC conditions. Subjects in the synchronous-CC and combined conditions had less work experience than their counterparts in other conditions. The asynchronous-CC condition had fewer women than other conditions. Synchronous-CC and combined groups had more information systems majors than did FtF or asynchronous-CC groups.

Given these dissimilarities in subjects, we conducted correlation analyses to ascertain whether these differences correlated with the results of the expert judges in terms of scoring creativity and quality of groups' requirements definitions. The correlation analyses showed no significant correlations between judges' scoring and the background data, indicating that the differences in subjects across conditions were not important in influencing outcomes.

The above analyses add to the validity of our findings. Nevertheless, this study should be considered exploratory rather than definitive because groups were assigned to different conditions at different points in time.

Table 2. Statistics on Judges' Scoring of Creativity and Quality by Time Period

Judge	Time period	Number of groups	Mean	*T*-test
		Creativity		
1	1993–94	20	4.90	0.85
1	1994–95	22	4.82	
2	1993–94	20	3.30	0.02
2	1994–95	22	4.09	
3	1993–94	20	4.60	0.09
3	1994–95	22	5.18	
		Quality		
1	1993–94	20	4.35	0.74
1	1994–95	22	4.50	
2	1993–94	20	3.65	0.18
2	1994–95	22	4.23	
3	1993–94	20	3.90	0.05
3	1994–95	22	4.50	

Table 3. Means for Subject Background Data

	FtF	Asynch-CC	Synch-CC	Combined
Age (years)	28.2	28.6	26.3	27.1
Employment (years)	5.4	5.5	2.5	2.2
Gender (% female)	43	25	37	27
Major (% information systems)	51	61	100	98

Experimental Results

ANOVA analyses were run to test the effects of mode of communication on the dependent variables. All statistical means are calculated using the least-square means calculation. In presenting results, significance levels of 0.05 or better will be considered "statistically significant." Levels between 0.10 and 0.05 indicate findings that suggest a relationship may exist and will be considered "marginally significant." Since this is an exploratory study, such findings are worthy of note for further study.

Table 5 presents the means for the dependent variables. The significance levels of *t*-tests comparing the different communication modes are contained in Table 6. ANOVA results are contained in Table 7 for all dependent variables. The expert judges had a high level of agreement when rating the quality of solution (Cronbach's alpha = 0.82) and the creativity of solution (Cronbach's alpha = 0.81).

Table 4. Significance Levels of *T*-tests for Background Data

	Asynch-CC	Synch-CC	Combined
		Age	
FtF	0.75	0.02	0.23
Asynch-CC	—	0.03	0.19
Synch-CC	—	—	0.37
		Employment	
FtF	0.67	0.00	0.00
Asynch-CC	—	0.00	0.00
Synch-CC	—	—	0.55
		Gender	
FtF	0.04	0.47	0.07
Asynch-CC	—	0.16	0.73
Synch-CC	—	—	0.27
		Major	
FtF	0.27	0.00	0.00
Asynch-CC	—	0.00	0.00
Synch-CC	—	—	0.31

Creativity Measure

The expert judges rated the level of creativity of each group's solution on a scale from one (poor) to seven (excellent). As predicted, the creativity level of solutions for the combined groups was significantly higher than the asynchronous-CC groups. Therefore, hypothesis 1.1 was supported. The combined groups were also rated significantly higher than the synchronous-CC groups, providing support for hypothesis 1.2. Likewise, the combined groups were rated significantly higher than the FtF groups, which supported hypothesis 1.3.

Although the solutions of the asynchronous-CC groups were rated higher in terms of the level of creativity than those of the synchronous-CC groups as expected, the difference was not significant. Therefore, hypothesis 1.4 was not supported. Similarly, although the solutions of the asynchronous-CC groups were also rated higher regarding creativity than the FtF groups, as expected, the difference was not significant. Therefore, there was no support for hypothesis 1.5.

Quality Measure

The expert judges rated the quality of each group's solution on a scale from one (poor) to seven (excellent). Combined groups were rated higher than asynchronous-CC groups, as predicted, and the difference was significant. Therefore, hypothesis 2.1 was supported. The combined groups were rated significantly higher than the synchronous-

Table 5. Least Square Group Means for Dependent Variables

	Combined	Asynch-CC	Synch-CC	FtF
Creativity	5.37	4.43	4.14	4.10
Quality	5.10	4.10	3.83	3.83
Sol. satisf.	4.48	3.77	4.22	3.75
Proc. satisf.	3.86	3.77	3.50	4.22

Table 6. Significance Levels of *T*-tests for Hypotheses

	Creativity		Quality	
	Combined	Asynch-CC	Combined	Asynch-CC
Asynch-CC	0.03		0.03	
Synch-CC	0.00	0.47	0.01	0.54
FtF	0.01	0.43	0.01	0.56

	Solution satisfaction	Process satisfaction
	Combined	Combined
Asynch-CC	0.00	0.82
Synch-CC	0.20	0.38
FtF	0.40	0.40

CC groups, thus supporting hypothesis 2.2. Finally, combined groups were also rated significantly higher than FtF groups, providing support for hypothesis 2.3.

Like the results for creativity, although the asynchronous-CC groups were rated higher than both the synchronous-CC and FtF groups, neither difference was significant. Thus, hypotheses 2.4 and 2.5 were not supported.

Solution Satisfaction Measure

Solution satisfaction data were obtained via subject self-reports from the post-experiment survey and varied on a scale of one (low) to five (high). As anticipated, the combined groups significantly outscored groups in the asynchronous-CC and FtF conditions. Therefore, hypotheses 3.1 and 3.3 were supported. However, combined groups did not rate themselves significantly higher than the synchronous-CC groups. Thus, hypothesis 3.2 was not supported.

Process Satisfaction Measure

Process satisfaction data were also obtained via subject self-reports from the post-experiment survey using a scale of one (low) to five (high). Although we expected that

Table 7. ANOVA Results for Dependent Variables

	Source	*DF*	*SS*	*F*	*Pr > F*
Creativity	Model	3	10.72	4.05	0.01
	Error	38	33.27		
Quality	Model	3	11.16	3.56	0.02
	Error	38	39.74		
Solution satisf.	Model	3	3.9	6.12	0.0017
	Error	38	7.84		
Process satisf.	Model	3	2.87	1.07	0.37
	Error	38	35.55		

the combined groups would be the most satisfied in terms of the process used to reach a solution, none of our hypotheses was supported. Combined groups were only slightly more satisfied than asynchronous-CC groups; therefore, hypothesis 4.1 was unsupported. Similarly, hypothesis 4.2 was not supported, as combined groups were only slightly more satisfied than synchronous-CC groups. Finally, there was no support for hypothesis 4.3, as combined groups were less satisfied than FtF groups.

Discussion and Conclusions

THIS STUDY EXPLORED THE EFFECTS OF DIFFERENT MODES OF COMMUNICATION on groups working on the upstream portions of software development. In particular, this research focused on the usefulness of combining face-to-face and computer-mediated modes of communication. Table 8 contains a summary of empirical findings.

As expected, combined groups were rated highest in terms of creativity and quality, and they judged themselves as more satisfied with their solution than did the asynchronous and FtF groups. Interestingly, although synchronous-CC groups were rated lowest on quality and creativity, they rated themselves as second highest in terms of solution satisfaction. FtF groups, who often are most satisfied, rated themselves as least satisfied with their solutions; these groups were judged second lowest on quality and creativity measures. Although FtF groups were least satisfied with their solution, they were most satisfied with the (FtF) process used to reach a solution. Conversely, although synchronous-CC groups were second highest in terms of solution satisfaction, they were lowest regarding satisfaction with the process. Indeed, working together in a room but being allowed to communicate only via electronic means appeared to be a frustrating experience for subjects in this condition.

This analysis provides empirical evidence supporting the usefulness of face-to-face communication in the initial phase of group work, followed by asynchronous communication during the execution phase of group work, followed by face-to-face communication during the final stages of group work. Combined groups significantly outscored groups using all other communication modes on measures of both creativity and quality. Overall, groups in the combined condition produced superior require-

Table 8. Summary of Empirical Results

Dependent variable	Prediction	Result
Creativity	Combined > Asynch-CC	Supported
	Combined > Synch-CC	Supported
	Combined > FtF	Supported
	Asynch-CC > Synch-CC	Unsupported
	Asynch-CC > FtF	Unsupported
Quality	Combined > Asynch-CC	Supported
	Combined > Synch-CC	Supported
	Combined > FtF	Supported
	Asynch-CC > Synch-CC	Unsupported
	Asynch-CC > FtF	Unsupported
Solution satisfaction	Combined > Asynch-CC	Supported
	Combined > Synch-CC	Unsupported
	Combined > FtF	Supported
Process satisfaction	Combined > Asynch-CC	Unsupported
	Combined > Synch-CC	Unsupported
	Combined > FtF	Unsupported

ments definitions than groups that met only asynchronously and groups that met only synchronously, either face-to-face (with no computer conferencing available) or via computer conferencing (with no talking permitted). These results strongly suggest that combining face-to-face and asynchronous communication in different phases of group work is more effective than restricting groups to only synchronous meetings or asynchronous computer conferencing.

These findings have important implications for the way organizations conduct group work. With the increasing use of asynchronous communication technologies in the corporate environment, our research suggests that the use of a communication mode according to the type of group work at a given point in time can greatly affect the effectiveness of a group's work product. It appears that the group outcome can be positively influenced by mixing modes of communication. Moreover, we speculate that this mixing of communication modes is significant with respect to phases of group work. The current study does not test out this speculation; however, it does offer encouraging support to this idea.

The combined groups in this experiment had FtF meetings at both the beginning and end phases of their work. Are both helpful or necessary to obtain significant advantages over groups working only asynchronously, or could an initial meeting alone suffice? Our informal observations of the behavior of the combined groups during the final meeting suggest that they generally had completed their work asynchronously and would not need this final meeting, but this needs to be systematically tested.

Why Weren't the Creativity Results of the Initial Experiment Replicated?

The results of our previously published study [24], which found that the asynchronous computer conferencing groups produced significantly more creative solutions than FtF groups, were not replicated here. There are several differences between the first and the current analyses. A different set of expert judges was used to rate groups in the current study. Also, the judges' rating form was modified for the current study. Quality was measured using fewer categories and the organization of rating categories was changed on the judges' rating sheet. (For the first study, creativity was the last category; for the current study, it was the first.) Finally, the data set of reports for each analysis is obviously different. The FtF groups and the asynchronous-CC groups in the current analysis are a subset of groups from the initial study, representing about half of the total number of groups from the prior research. However, we speculate that the most important differences can be attributed to the inclusion of the combined condition in the current study. Combined groups were rated so much higher for both creativity and quality that we expect that this caused groups in the other conditions to be seen as similar in the eyes of the judges. In essence, we believe that the combined groups decreased the perceived variance among the other three conditions.

Can Creativity Be Attributed to Computer-Mediated Communication in General, or to Computer-Mediated Communication over Time?

Although it was expected that the level of creativity of asynchronous-CC groups would be greater than that of the synchronous-CC groups, no significant differences were found. These results could be interpreted to indicate that time does not play a significant role in the creativity of groups, and rather that, in general, it is the computer-mediated aspect of communication that accounts for differences in creativity. However, given that results from our initial study concerning creativity were not replicated in the current analysis, any conclusions regarding the importance of time versus computer-mediated communication seem unwarranted. As it stands, we still have no definitive answers in this area.

Limitations

The current analysis compared the effectiveness of four modes of communication. There are, however, many more modes and combinations. In order to more fully explore the impact of computer-mediated communication on group creativity and quality, a series of experiments might be conducted comparing the performance of groups working in the following conditions: (1) synchronous computer conferencing, (2) face-to-face, (3) asynchronous computer conferencing, (4) face-to-face plus phone/fax, (5) face-to-face plus asynchronous computer conferencing, controlled by

group phase, and (6) face-to-face plus asynchronous computer conferencing, with uncontrolled usage (e.g. [10]). (Note that the introduction of "phases" makes this too big a design for one experiment, as we found when we tried to plot it out.)

The current experiment was conducted over a two-year period, and subjects and groups were not randomly assigned to conditions. Although these issues appear to be insignificant, it is impossible to say, with certainty, that they had no effect on the experimental results.

Future Research

There is ample opportunity for future research concerning the relationship between communication mode and group effectiveness. Particular attention should be given to matching communication modes with the phases of group work. Also, continued research is needed concerning the relationship among creativity, outcomes, and communication mode. For instance, we still have no definitive answers on the relationships among creativity, computer-mediated communication, and time. Nor do we have consistent results regarding the impact of asynchronous communication on creativity.

To continue our research in this area, we are presently conducting a new experiment comparing various communication modes using a new Web-based interface to our computer conferencing system. In this new experiment, groups will be randomly assigned to all conditions during the same time period, thus addressing any remaining questions about the validity of results presented here.

Given the increasing prevalence of virtual teams in the workplace, research comparing the effectiveness of different modes of communication will be increasingly important. The use of Web-based systems with multimedia and hypertext links raises many issues concerning the way groups discuss and resolve problems. To what extent will the ability to mix text, audio, and visually based materials change asynchronous computer-mediated communication? How will groups using single communication modes in a closed information environment compare with groups working in the open information environment on the Web? These are only a few of the questions that remain to be addressed.

Acknowledgments: This research was supported by grants from the National Science Foundation program on Coordination Theory and Collaboration Technology (NSF-IRI–9408805), from NJIT (SBR–421090), and from the State of New Jersey Commission on Science and Technology to the Center for Multimedia Research. The opinions expressed do not necessarily represent those of the sponsoring organizations.

Among the many people who have contributed to this program of research, in addition to the coauthors, are George Olsen, Ajaz Rana, Les Roberts, Murray Turoff, and James Whitescarver. We appreciate the helpful comments made by the reviewers. This is a revised and expanded version of a paper presented at the Thirtieth Annual Hawaii International Conference on System Sciences (1997).

NOTE

1. The APO task, survey instruments, and judges' rating form used in this experiment can be found on the Web at **http://eies.njit.edu/hiltz/resources/**.

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