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ABSTRACT

The purpose of this exploratory study was to examine student use of a prototype networked collaborative design environment to support or augment learning about engineering design. The theoretical framework is based primarily on Vygotsky's social construction of knowledge and the belief that collaboration and communication are critical components in the development of reasoning and learning. The specific goals of the research were to characterize design activities and practices and to examine the use of multiple communication resources to augment activities in a three-way group collaboration. Three groups of students were asked to solve an engineering design problem using a variety of materials, a prototype computer-supported cooperative work (CSCW) system, consisting of audio/video conferencing, chat box, draw tool, an interactive multimedia database of engineering information and a multimedia database of electronic textbooks. The groups were given tasks analogous to those of a main contractor and two subcontractors, but specific tasks were left ambiguous to force students to negotiate the boundaries of their tasks. Activities were categorized as: orienting; sub-dividing the problem; establishing roles; information seeking; information sharing; monitoring; negotiating understanding; designing; building; and evaluating. Multiple channels of communication were used by students in three ways: increasing the depth of the discussion; increasing the breadth of the discussion; and overcoming technical difficulty. Conclusions suggest that students need multiple representations of design information to effectively move the design process forward. These multiple channels can encourage both monitoring an active participation and can facilitate clarifications, acknowledgements, information sharing, negotiation, and the transmission of design information. Findings are illustrated in two figures. (Contains 33 references.) (MAS)

Communication Resource Use in a Networked Collaborative Design Environment

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Use of Communication Resources in a Networked Collaborative Design Environment

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Abstract

The goal of this exploratory study was to examine student use of a prototype networked collaborative design environment to support or augment learning about engineering design. The theoretical framework is based primarily on Vygotsky's social construction of knowledge and the belief that collaboration and communication are critical components in the development of reasoning and learning. The specific goals of the research are to characterize design activities and practices and to examine the use of multiple communication resources to augment activities in a three-way group collaboration. Conclusions suggest that students need multiple representations of design information to effectively move the design process forward.

Learning, Collaboration, and Communication

There is a growing interest in using the computer to enhance instruction and learning through shared activity, and to engage students in the same intellectual and cultural activities that sustain real-world scientists and engineers in knowledge building (Scardamalia & Bereiter, 1993). A major part of this learning involves engaging the student in sense-making activities: conversations and talk about external representations that use concepts, symbols, models and relationships. Brown, Collins, and Duguid (1989) argue that learning is making sense of some experience, thought, or phenomenon *in context*. Their basic hypothesis is that our representation or understanding of a concept is not abstract and self-sufficient but rather is constructed from the social and physical contexts in which the concept is found and used. Brown et al. have emphasized the importance of implicit knowledge in developing understanding rather than acquiring formal concepts. It is therefore essential to provide students with *authentic experiences* with the concept.

Learning is fundamentally built up through conversations between persons or groups, involving the creation and interpretation of communication (Schegloff & Sacks, 1973; Schegloff, 1991). Learning is established and negotiated through successive turns of action and talk (Goodwin & Heritage, 1986; Schegloff, 1991). Conversations are the means by which people collaboratively construct beliefs and meanings as well as state their differences. The purpose of these conversations is to provide a common ground or mutual knowledge about beliefs and assumptions during conversation (Clark & Brennan, 1991). Therefore, one of the major issues facing designers of communication systems concerns helping one person or group understand the other and create and maintain common ground. Clark and Brennan evaluate several media and the aspects of these media that may affect common ground (Table 1).

Medium	Constraints
Face-to-face	Copresence, visibility, audibility, cotemporality, simultaneity, sequentiality
Telephone	Audibility, cotemporality, simultaneity, sequentiality
Video teleconference	Visibility, audibility, cotemporality, sequentiality, simultaneity
Terminal conference	Cotemporality, sequentiality, reviewability
Answering machines	Reviewability, audibility
Electronic mail	Reviewability, revisability
Letters	Reviewability, revisability

Table 1. Seven media and their associated constraints. (Clark and Brennan, 1991).

This model points out that different media provide different opportunities for coordinating activities and establishing understanding. The communication system used in this study provides many of the characteristics of these media. Video-conferencing primarily supports conversation among participants and allows presentation of objects or artifacts in real time. Chat boxes and video white boards (variations of the terminal conference session) can be received simultaneously or separated by other activities. Electronic messages and other computer records and data can be reviewed and revised, but lack the feeling of being in direct contact with another individual or group. Providing combinations of these resources should afford choices to the user that would otherwise not be available. Extra channels for communication are reassuring and psychologically important (McCarthy & Monk, 1994). Daft and Lengel (1986) note that managers should choose channels which most effectively reduce uncertainty and equivocality for their communication.

Garfinkel (1967), Garfinkel and Sacks (1970), Schegloff and Sacks (1973), and Mehan and Wood (1975) have highlighted the importance of indexical support for meaning negotiation. With indexical support, speakers use the resources of the physical world to establish a common or socially shared meaning. Suchman (1988) studied the ways writing and drawing activities interact with conversation. Such activities can be used to display understanding, facilitate turn taking, and in general serve as appendages to the verbal conversation. Some experimental video systems such as Videodraw have been used to create representations that express ideas (Tang, 1989). Tang also pointed out the importance of gestures and the relationship of gestures to the workspace. Nardi et al. (1993) found that video images of the surgical field helped focus and maintain attention of the surgeons.

Minneman (1991) studied how design emerges from social interactions among individuals and groups as they communicate to establish, maintain, and develop a shared understanding. He observed four practices that participants used to achieve design communication: a) negotiating understanding, b) tailoring communication, c) preserving ambiguity , and d) manipulating mundane representations. Minneman noticed that

> "Talk, gesture, sketching, lists and tables, formal drawings, calculations, video, photographs, and embodiments all show up as contributing to the representational and communicative activity in group designing" (Minneman, 1991, p.147).

These studies suggest that a multi-channel communication system provides more information and better facilitates communication between users. However, several research studies show little or no evidence of a specific benefit of multi-channel communication to outcomes of a problem solving group (Chapanis, 1975; Chalfonte, Fish and Kraut, 1991). Chapanis found that restricting channel capacities had little impact on the outcomes of problem-solving tasks, but did influence the process through which the result was obtained. In educational environments, this distinction can be critical, as students are expected to learn *how* to work together — to learn the process of collaborative design.

Computer-Supported Cooperative Work and Collaborative Learning

Various forms of computer conferencing, coordination tools, and on-line knowledge databases are currently being explored to help augment learning activities (Hiltz, 1988; Newman, 1993; Pea, 1993b; Scardamalia & Bereiter, 1992). Computer-supported cooperative work (CSCW) systems are designed to provide an interface to a shared environment in which users are linked in multiple ways such that they will perceive themselves to be communicating as if they were in the same space (Ellis, Gibbs & Rein, 1991; Greenberg & Bohnet, 1991). Using CSCW systems, collaborators make use of a host of tools such as networked chat and draw systems, file transfer, electronic mail, and audio- and video-conferencing to work together to solve problems. When applied to educational environments, students can communicate with collaborators from institutions worldwide; the students will experience, and have to contend with, cultural, ethnic, knowledge, and other differences as if they were meeting face-to-face.

Advocates of CSCW systems claim that these technologies can be used to support conversations and enhance communication (Hiltz, 1988; Pea, 1992). Even for people involved in face-to-face communication, images, graphics and text can be used to support the process. The use of multiple representations and multiple communication channels provide opportunities for helping one person understand the other (Clark & Wilkes-Gibbs, 1990; Pea, 1993). CSCW systems such as Conferencer (McCarthy & Miles, 1990), Videodraw, (Tang & Minneman, 1991), Groupsketch (Greenberg & Bohnet, 1991) and CoVis (Pea, 1993) encourage the use of multiple channels to establish common ground. These studies also suggest that there is a fit between the media and a particular task or social context. Designers of CSCW systems have to be aware of the complex nature of the communication process and the use of tools and channels to facilitate communication. As designers develop new communication tools, they need to be aware of how the CSCW system fits into existing workspace (McCarthy & Monk, 1994). Finally, designers have to be aware of the ways people experience or perceive these new media for communication.

Learning Collaborative Design in Networked Environments

In an effort to help improve the teaching of concurrent collaborative design and to help students learn to work in a collaborative context, the Interactive Multimedia Group (IMG) and the College of Engineering at Cornell University, have been working on a multi-year project to implement and test a networked multimedia environment. Since Cornell is a member of the National SYNTHESIS Engineering Education Coalition, Cornell students will eventually be able to collaborate not only with each other but also with students at other campuses (Gay & Thomas, 1992).

This paper reports on the results of an exploratory study in which students solved a design problem using a prototype system for collaborative design. Particular attention is paid to which channels students used to conduct which design activities. The results of studies of this type will be used to determine which features or channels support or disrupt a students' ability to understand others and to move work forward. The analysis will be used as part of a foundation for designing future systems to support educational interaction.

The Exploratory Study

For this exploratory study, three groups of students at geographically distinct locations were asked to solve an engineering design problem using a prototype CSCW system. Students were given two hours to design a windmill which would produce two volts of power under the forced air from a hair dryer. The groups were given tasks analogous to those of a main contractor and two subcontractors, but the specific tasks of each group were left ambiguous to force the students to negotiate the boundaries of their tasks. The students were also given a variety of materials to construct their design. These materials included LEGO/DACTA building blocks, strips of balsa wood, parachute cloth, paper drinking cups, and a variety of fastening materials.

The CSCW system consisted of multiple communication technologies and multimedia databases. The communication resources were all three-way, and each channel was active throughout the session. The resources were as follows:

- Audio/Video-conferencing - a three-way, closed circuit video-conferencing system which allowed all groups to see and hear all of the activities in the other groups,
- Chat Box - a terminal conferencing system which allowed students to type messages on their computer and send them to their collaborators; students were also able to sound a beep at the other stations, and
- Draw Tool - another part of the terminal conferencing system which allowed the students to draw a design on one screen and have it appear on the other two.

The multimedia databases included:

- Carousel - an interactive multimedia database of engineering information which contained information on each of the subject areas the students would need to address in their design: gears, structures, aerodynamics, power, and generators, and
- Electronic textbooks - scanned John Wiley and Sons engineering textbooks, which also covered the subject areas that would need to be addressed by the students.

<u>Data Collection</u> Several types of data were collected. Prior to the study, students filled out a questionnaire asking about their experience with computers and group work. During the session, the video signals from the conferencing system were recorded. Each camera was positioned to focus on the main work area and the members of each group. Screens of the chat and draw tools were periodically saved throughout the session. Afterward, students

again filled out a questionnaire: this one focusing on their impressions of the CSCW environment and on working in groups using the system.

Analysis The entire video record was transcribed and entered into a spreadsheet using Gay, Mazur, and Lentini's (1994) methodology. Channel use was also entered into the spreadsheet by time initiated and duration (see Figure 1, Resource by Time). Researchers then analyzed the tapes using a form of interaction analysis (Jorden and Henderson, 1993). The students' activities and interactions were recorded in order to determine common themes and elements. A group of five researchers from various backgrounds (communication, education, psychology, and organizational behavior) examined the tapes and classified subject activity through the use of descriptive verbs. The initial analysis resulted in a list of 150 verbal descriptions of activity, which were eventually grouped into the following 10 activities or task types:

1. *Orienting:* Becoming familiar with the communication and information resources and the building materials, establishing contact with the other groups, and becoming familiar with the environment and the problem which needed to be solved,
2. *Sub-dividing the problem:* Defining the task, setting goals, establishing requirements and setting boundaries,
3. *Establishing roles:* Identifying the individuals and groups responsible for solving each aspect of the problem,
4. *Information seeking:* Asking specific technical questions and looking for information in the databases or from other members of the teams,
5. *Information sharing:* Answering questions, sharing drawings, holding materials up to video cameras so that other groups could see designs, gesturing over the video channel, referring others to information found in database, and reporting on the progress of prototype design,
6. *Monitoring:* Watching communication channels to monitor other groups' progress and understand what they are doing (also including monitoring communications from the chat box and draw space),
7. *Negotiating understanding:* Making sure all parties understood the basic principles being implemented to develop design — explaining design rationale, questioning and justifying decisions,
8. *Designing:* Sketching, visualizing, drawing, and manipulating materials,
9. *Building:* All activity associated with constructing the design including measuring, taping, cutting, and connecting pieces together, and

10. *Evaluating:* Checking at any stage of the process including decisions regarding task, goal, design, and the actual efficacy of any developed artifact, including testing artifacts to see if they performed adequately and met the task requirements, and all trial and error procedures.

The ten categories were also coded into the transcript by time initiated and duration. Cross tabulations of resource use and activities were run on all three groups to determine what activities were occurring on which channels (see Figure 2, Resource Crosstabs). Graphs of resource use over time were constructed. This information was subsequently examined for important interactions and themes of use.

Results

During this analysis it was determined that there was some correlation between activity and resource used, and that this was a critical part of how the students used the system. The multiple channels were used by the students in three ways: increasing the depth of the discussion, increasing the breadth of the discussion, and overcoming technical difficulty. Using multiple channels to increase depth involved using more than one channel to converse about one topic, while using multiple channels to increase breadth involved conversation on multiple topics, with each topic on one channel or a set of channels. Overcoming technical difficulty referred to activities to diagnose and then work around problems with the prototype system.

Throughout the description which follows, the interactions are coded using the following conventions:

1) Chat box interactions are labeled with the number of the group initiating the transaction. Group #1 is Main Assembly, Group #2 is Blades, and Group #3 is Main Assembly. Interactions are repeated verbatim — typographical, spelling, and grammatical errors were part of the original communications.

2) Verbal interactions are labeled with the first letter of the group name, followed by a number to differentiate between the members of the group. For example, speech by the first person in Structures would

be labeled S1, by the second person in Structures S2, etc. Unless noted, the interactions occur between groups.

3) Times are coded in hours, minutes and seconds from the beginning of the design session.

Increasing depth of communication The first theme of the use of multiple channels involved increasing the depth of the discussions between the groups. Increasing the depth of discussion refers to the use of multiple channels to increase the clarity of the discussion and to gain a richer understanding of the subject of the discussion. In the design session, the students used one channel to refer to and elaborate on the activities in the another channel.

The need for depth was reflected by the students struggling to communicate complex material over only one channel. Fifty-two minutes into the session, one of the students in Structures had just finished searching for information in the scanned textbooks. The student then attempted to share that information with the other groups. Earlier attempts to explain the location of information in the database had met with little success, so the student had to explain the material himself.

S1: Okay, I wish there was some way to clip some of this and send it.
M1: Just tell us.
S1: Okay, under the section in gears they're talking about, um, series and gears are moving the energy in a line from one place to another at its less than idea source and destination of the rotating energy should be as close together as possible. That would mean...

Had there been a way to either "cut and paste" the information or to take over the other groups' computer and navigate to that portion of the database, the students would have been able to use it as a common reference point in their discussion about the gearing and propeller size which followed. Not having that channel forced the students to work without as rich an information base, as S1 noted.

The use of multiple channels proved important in activities other than information sharing. Blades group had been discussing how long to make the blades and how many to have in the assembly. At 1:23:05, Main Assembly and Blades engage in designing and subdividing the problem using the audiovisual conferencing and the draw channel:

M3: Blades, do you think... do you see the thing that I drew on the screen there? Do you think that you could make something like that with six or eight blades?
B2: Like, which one? on the screen?
M3: Upper left.
M3 (to M2): Do you see how they did that? They cut a notch half way through and just stuck them together. (intergroup): I think we could do that with like four or five.
B2: Four or five? I don't know if we do four or five if the blades will be still rigid.
M3: Yeah, you just have to make slightly bigger notches.
M3: Um... if you... if they're shorter they'll be... it won't have as much...
B2: All right, we'll make 'em shorter then.
B2: We'll try making them out of balsa wood...[inaudible] be better.

In this example, the representation on the screen served to supplement the mental and physical representations already available to the students. By referring to the image of the Blades, the students were able to create a clearer understanding in their discussion.

During the final twenty-five minutes of the session, the value of using multiple channels to increase the depth of the interaction became very clear. Throughout this time period, Structures and Blades were transmitting their designs to Main Assembly so that they could build the complete windmill. Using the multiple channels for information sharing and designing, Structures and Main Assembly began to build the main tower for the windmill at 1:34:15:

S2: Bill? Okay, Bill do you see the L shaped pieces? Okay, if you take...
M1: Yeah, these? (holds up to camera)
S2: Right, yeah. Okay if you take the L shaped piece and the long piece...
M1: Right here.
S2: Yeah. You put them together like so. You can have them standing up which save a lot on parts.
M1: Put together where?

S2: Huh? Okay, and then um, then you have a base.
M1: Base?
S2: Okay, um make like four of them and...
M1: Wait, how did you put the blue pieces together?
S2: Here, let me draw it. Hang on I'll draw it.

After one and one half minutes, the conversation continued:

S2: This, this right here's the ground. Okay, so you got, um, the bumped side of the L shaped piece connecting to the bottom of the holey piece. I don't know what to call this.
M1: Do you put two of them?
S2: Okay, do you have that?
M1: Right.

The ability to use multiple representations allowed the students to supplement a mental and video representation of the design artifact with a drawing that showed details not immediately obvious from looking at the assembled design. Increasing the depth of the interactions allowed students to more effectively communicate their meanings and create much richer representations of the designs.

Increasing breadth of communication The second way that the groups used multiple communication channels was to increase the breadth of their conversations. Increasing breadth is the use of multiple channels to transfer a greater volume of information. The use of multiple channels to increase breadth proved especially useful when one group member was engaged in a time-consuming activity on one channel. For instance, information sharing on the draw tool required large amounts of time to create a complex drawing. Structures had to do just that at 1:04:00:

M1: Hey, group 3?
S1: Yeah?
M1: Could you guys start drawing out what you're building there in the box?
S1: In the box? Yeah, sure. Let me go to where the box is. You mean the gears, right?
M1: Yeah.

S2: (to S1) Tell you what. You work on the gears, I'll work on the structure.

At this point, the two group members changed places so that S1 could use the computer to draw the gears as requested by Main Assembly. S2 then began to engage in a variety of activities in order to work on the structure, including 3.5 minutes on the audiovisual conferencing system. During that time he was involved in evaluating (80 seconds), designing (80 seconds), information seeking (90 seconds) and monitoring (30 seconds) with Main Assembly and Blades. He would not have been able to spend so much time communicating had S1 needed the channel for his information sharing.

Using the breadth available via multiple channels also became important near the end of the session when the groups had to transmit a great deal of information in very little time. Both Blades and Structures were attempting to transfer the results of their work to Main Assembly so that the final assembly of the windmill could occur. Two members of Main Assembly worked with the two sub-groups, and the third coordinated and worked on the gearbox (transmitted earlier via the draw channel). Both groups continued to use the draw channel as a referent for their other conversations, but also as a substitute when the other sub-group was transmitting over the conferencing system. Breaks in the transmission while one group switched to the draw or chat channel provided an opportunity for the other groups to step in and transmit. For example, at 1:37:45, the Blades group was holding their assembly up to the camera, and Structures was instructing another member of Main Assembly on the construction of the structure.

M2: (to other members of Main Assembly) No, I want to see...
M3: Greg? (S2 in structures) Put it on the board... just draw... where'd you put it?
S2: Okay.
M2 (now speaking to blades): Rotate it to the side, right. A little more...
B1: Can you see better now? Do you want me to take the blades off?
M2 (to M1): Okay so she's got two wheels running...
M1: So you're using this type of wheel, right? (holds it up to the camera)
B1/B2: Right.
B1: Yeah.
M1: Okay, and you're putting three axles through that?
B1: Yeah, one in the middle, two on the side.

M1: Got it, okay. got it, okay.
M1 (to M2): Did you see how that works?
M3: Greg? What else?
S2: Okay, so, um, do you see the four little marks on one side of the... side of the four? (referring to drawn image)
M3: Yeah.

In using the draw tool to communicate while Blades and two members of Main Assembly worked out a part of the design, Structures was able to continue working with the third member of Main Assembly. The sub-groups were able to sub-divide their work and continue to communicate with Main Assembly, switching between the chat tool, draw tool and conferencing system. They were able to increase the "bandwidth" available when they needed to send large amounts of information rapidly.

Overcoming technical difficulty In using multiple channels to overcome technical difficulty, the students used one channel to reiterate what they had attempted to communicate on another. This occurred when they knew that one channel was not working, and then afterward when they perceived problems with the channel (though the problem had been solved). The best examples of this occurred when the audio channel in the Blades group malfunctioned early in the session.

From the beginning of the session the audio in Blades is problematic — there was substantial feedback from the audio-conferencing system. That the feedback will be a problem for the groups became obvious at 0:03:40 when the groups were orienting and beginning to communicate with each other. Structures group initiated the interaction, and then Main Assembly group joined in trying to contact Blades group (Number Two refers to their identification in the chat box).

S1: Number Two, can you hear us?
M1: Number Two are you alive out there, Number Two?
M1: Looks like we don't have Number Two here.
M1: Number Two do you hear us?
S1: Blades are you alive? Hello. Number Two can you hear us?

It was not until monitoring the video channel at 0:03:55 that the Blades group realized the other groups were trying to talk to them. At that point the groups tried to communicate for several more seconds.

B1 (to B2): Wait, wait, they're all looking at...
B1 (to B2): They are talking about something.
B2 (to B1): Yeah, they are. (intergroup) We're number two. We can't hear.
M1: Can't hear you
S1: Can you hear us? Hello. Can you hear us?
B1 (to B1): Can you hear? I can't hear.
M1: Nope.
S1: No, she said no.
M1: All right, communications problems.
B1: Hello?
B1: Can't hear! Can you hear?

When this failed, the groups switched to the chat box, in which the following conversation occurred:

#3: #2 are you there?
#2: we are here
#3: #2 can you talk into your mike?
#2: we tried to talk, can you here? if you do say something

The added channel in this case served as the vehicle for recognizing that the groups were trying to communicate but that there was a technical problem. The students also found a way to continue working without the audio-conferencing by communicating through the chat box.

Several minutes later, the knowledge of an alternate communication method became important as Structures attempted to contact Blades seeking information. It was not clear at that point whether the system was fully functional, and in fact the feedback was still substantial, but the groups were able to complete the interaction using the two channels.

S1: Blades, do you have the hair dryer? Blades? Number Two.
B1: What?

S1: Number Two. Okay. Do you have the hair dryer?
B1: Yeah? Yeah? Can't hear. What?
S1: I'm just curious whether one of our groups has a hairdryer.
B1: Yeah.
B2: Yeah, we do. Yes we do.
S1: Okay, just curious.

In order to make sure Blades received the message, the following Chat Box communication occurred:

#3: we do not have a hair-drier
#2: yes, the torque is no problem
#2: we have the hair drier
#2: are you hearing us?

The groups were able to use the Chat to reinforce the communication in the face of a perceived system breakdown.

Although the feedback problem was solved by 0:20:00, the groups acted as if there was still a problem until almost one hour has elapsed. Around forty minutes into the session another interaction occurred while the groups were sub-dividing the problem. Structures and Main Assembly were discussing how much gearing would be needed. Structures came up with a procedure that involved Blades.

M1: Blades do you have a multimeter?
B2: Yeah, we do. (To B1): Can they hear us?
B1: Can you...
B2: (To B1) Yeah, they can, sorry.
S1: Okay, now Blades could use the multimeter and the windmill that they've assembled and a motor to determine the voltage created by the hair dryer...
M1: Okay, does that sound like a good idea Blades? Did you catch that?
B2: We didn't catch that, what was the idea? No.
S1: Well, we don't have a hair dryer. With the hair dryer arbitrarily one to one or something, try and run the motor. See how many volts you get.

B2: (to B1) I don't think they can hear us. We have to talk into that. (referring to the computer).

Since the members of Blades perceive that the other group might not be able to hear, B1 starts typing on the computer, and the other groups join in as well. The following message is relayed in the Chat box:

#3: Once you have the windmill set up, try spinning the motor at 1:1 gear ratio to see what (small voltage you get out of it...then we'll know what ration to create in group 2.

It is unclear whether the Blades group did not "catch that" because they were not paying attention or because they were simply unable to hear. The groups, however, interpreted it as being similar to earlier exchanges when the technical problems were occurring, and used the redundant channels to overcome the technical difficulties. With the availability of multiple channels, the students were able to continue working on their project despite the technical problems. In fact, they learned to communicate around technical difficulties, a skill which will be useful as they work in collaborative teams in industry.

By using multiple channels, the students in this session were able to overcome technical difficulties, increase the depth of their interactions, and increase the breadth of their conversation.

Conclusions

These findings suggest the need for systems that use multiple modes to support a broad range of communication and design activities for the students. These multiple channels can encourage both monitoring and active participation and can facilitate clarifications, acknowledgments, information sharing, negotiation and the transmission of design information. Specifically multiple channels can be used to:

1) increase the depth of interactions (using informative diagrams or explanatory text as referents for conversations over the audio/video channels);

2) increase the breadth of interactions (engage in multiple communication activities at the same time).

3) overcome technical problems (using chat to convey messages that should have gone through the audio-visual channels);

In this design environment, most of the activities took place around talking about objects, prototype designs and other visual representations of the design. Different representational systems and communication channels worked better for different activities. For example, visual and aural channels encouraged both monitoring and active participation and could clarify and enhance the transmission of design information. Designers and researchers need to consider which activities need to be communicated between students (such as gaze, activity, and position).

There was also a correlation between the use of two or more communication channels, collaboration, and progress on the working design. Combinative interactions and prompts for exchanges advanced the problem-solving for each team as they engaged in making and visualizing their design. Manipulating representations (text, drawings, and prototypes) and talking about the designs created effective design communication practices. Designers of distributed communication programs need to take into account the students' need for multiple representations of content. Students participating in collaborative design over networks need to have options for channel selection.

Students need to have opportunities to work with models, concepts and theories that will allow them to socially construct meaning. In particular, students need to learn to converse, question, construct meaning and use database resources and representations to support their conversations and multi-group collaboration. We need to develop an understanding of how students access sophisticated drawing tools and databases that allow them to augment conversations, express points of view, and compose meanings.

Distributed computing systems provide a unique opportunity for researchers to explore a number of dimensions of communication activity and the ways people support these activities as they interact with not only a computer system but with other people. Such analyses will help us understand how students' "talk" may be accepted, repaired, revised, or contradicted. Researchers can examine broader issues of social presence, tailored communication environments and tools, and the use of multiple representations to support communication for learning.

The construction of these distributed learning environments provides opportunities for students to engage in authentic communities of practice and scientific conversations and discourse. As we continue to analyze the social design practice in the context of networked multimedia environments, we should be able to both make practical recommendations concerning their use for learning and contribute to the development of a new body of theory that will inform the use of multi-group concurrent design and communities of practice as learning environments.

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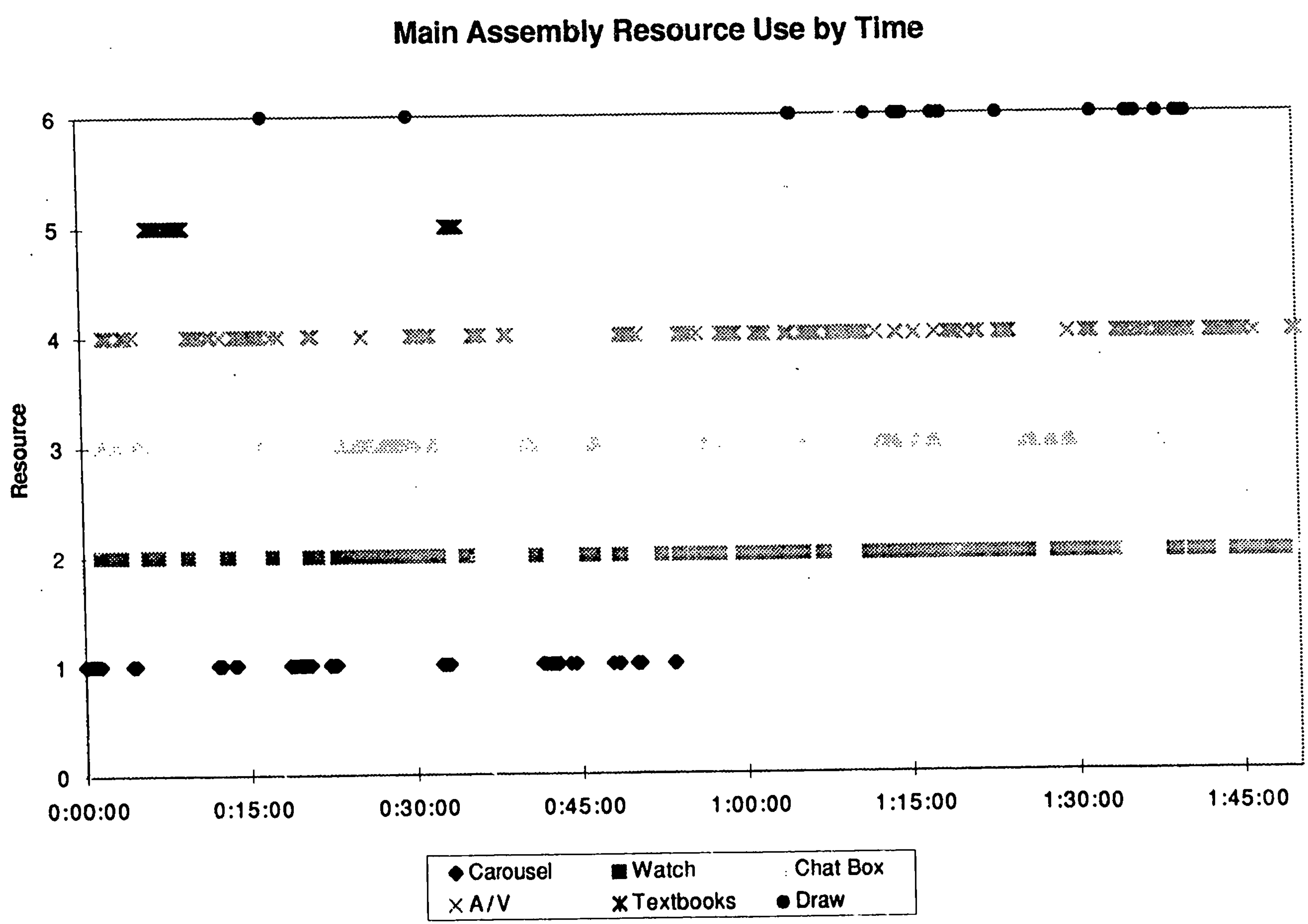

Figure 1
Resource Use by Time, Main Assembly

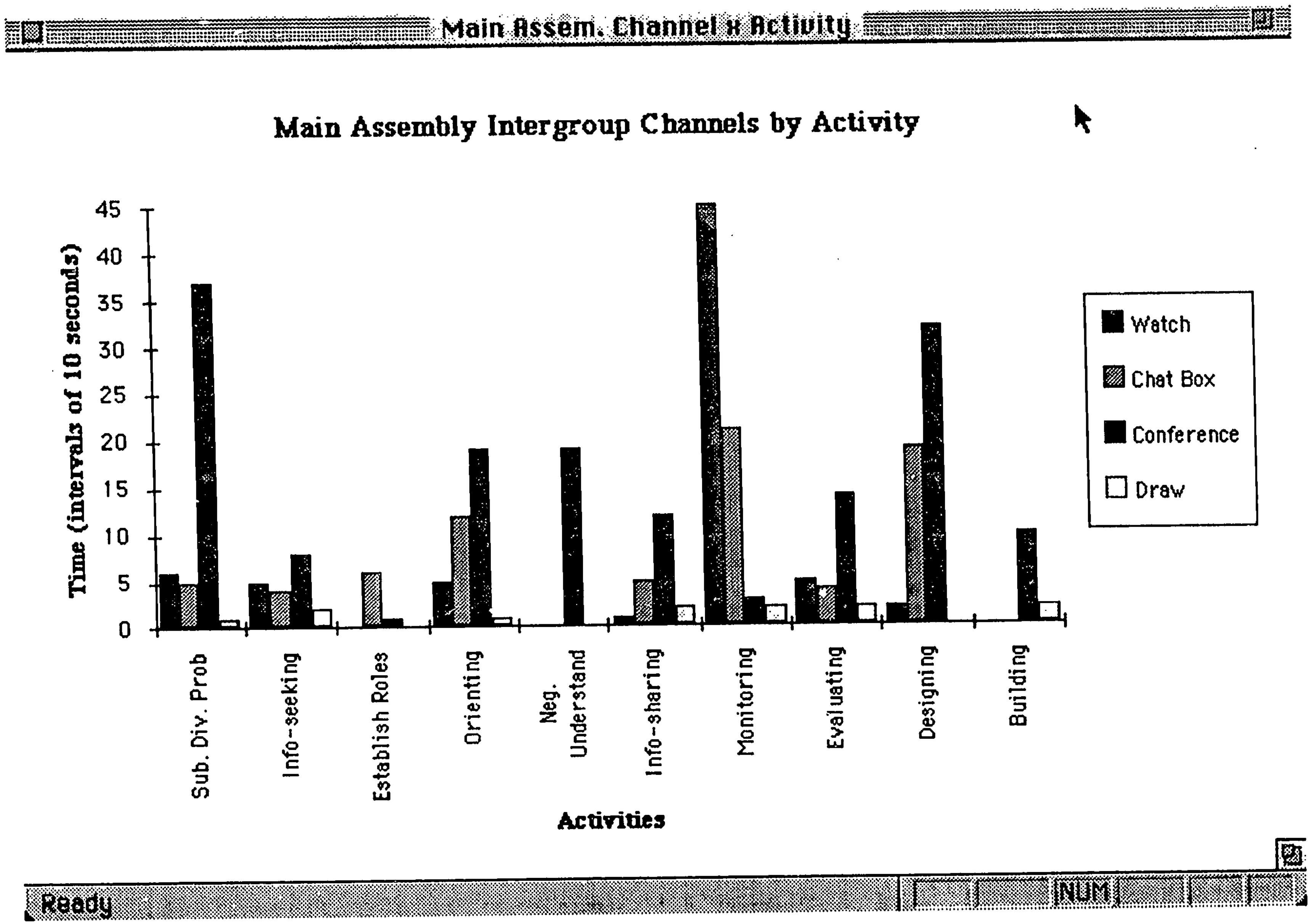

Figure 2
Resource Use by Channel, Main Assembly