AI & Soc (2006) 20: 169–188
DOI 10.1007/s00146-005-0014-5

ORIGINAL ARTICLE

Renate Fruchter · Humberto E. Cavallin

Developing methods to understand discourse and workspace in distributed computer-mediated interaction

Received: 1 December 2004 / Accepted: 2 June 2005 / Published online: 5 January 2006

Abstract This paper presents ongoing research towards understanding the discourse and workspace in computer-mediated interactions. We present a series of methods developed to study non-collocated computer-mediated interactions. These methods were developed originally to study interactions involving teams composed of architecture, engineering, and construction management students as part of the AEC Global Teamwork course offered at Stanford University in collaboration with universities worldwide since 1993. The methods stress the value of using ethnographic approaches, particularly the role that both discourse and workspace have in developing the communication processes involved in the interactions. We used the AEC Global Teamwork course as a testbed and focused on issues regarding the nature of the communication act in building design projects when mediated by computers. We successfully tested these new methods and present the preliminary results.

Keywords Discourse · Workspace · Distributed teamwork · Computer-mediated interaction

1 Introduction

Recent digital communication technology developments offer groundbreaking advances in geographically distributed collaboration teamwork environments. This real-time distributed collaboration allows people to work together at the same time from different locations on the solution of tasks, as in the case of collocated design processes or management situations (Olson and Olson 2000;

R. Fruchter (✉)
Civil and Environmental Engineering Department, Director of Project Based Learning Laboratory (PBL Lab), Stanford University, Stanford, CA, USA
e-mail: fruchter@stanford.edu · Tel.: +1-650-725-1549 · Fax: +1-650-723-4806

H. E. Cavallin
Escuela de Arquitectura, Universidad de Puerto Rico, Recinto Río Piedras, San Juan, Puerto Rico
e-mail: hcavalli@berkeley.edu

Gutwin and Greenberg 1999). These shared computational workspaces are usually based on hardware and software that enable the sharing of video, audio, data, and software applications. In addition other technologies have been developed based on advanced versions of chat applications, whose original purpose were to enable text-sharing capabilities over the Internet.

Inside these high-tech worlds of collaboration, however, the fluency of communication is often affected by the affordances of the interfaces (Chapanis 1975). Virtual workspaces are often awkward, unnatural, and essentially frustrating compared to collaboration in collocated face-to-face real-time settings. Nevertheless, it is not clear what aspects of the work environment create the frustration in these kinds of collaboration conditions.

However, the problem of producing research that can enable us to answer these kinds of questions, is not a trivial one. Conducting research in non-collocated interaction environments involves an unknown landscape that poses several methodological questions:

– How should the collaborative environment be instrumented to collect and store the data?
– How should the data be analyzed and represented so that the results depict a complete scenario of the situations under investigation?

This paper presents methods we have developed to study non-collocated computer-mediated interactions involving teams composed of architecture, engineering, and construction management (AEC) students as part of the AEC Global Teamwork course offered at Stanford University in collaboration with universities worldwide since 1993. The interactions studied have been part of the project-based learning laboratory (PBL Lab) launched at Stanford, an initiative and vision that was in response to the need to improve and broaden the competence of engineering and architecture students regarding the new work settings in the professional practice (Fruchter 1999).

The particular characteristics of computer-mediated interactions as communication channels, along with the need to improve the communication process of students involved in this course, formed the testbed foundation to pursue a research program focused on the interactions resulting from the PBL global student teams. These methods have been theoretically grounded on the principle of bricks& bits& interaction (BBI) (Fruchter 2001). This principle defines that these activities occur at the intersection of a conceptual space defined by (1) the design of physical spaces, affordances, and limitations of typical preset physical, spatial configurations of workspaces, (2) collaboration technologies, and (3) new ways people behave in communicative events using affordances of IT augmented spaces and content. The BBI principle is based on two hypotheses:

– If we understand the relationship between bricks, bits, and interaction we will be able to

1. design workspaces that better afford communicative events;
2. develop collaboration technologies based on natural idioms that best support the activities people perform;
3. engage people in rich communicative experiences that enable them to immerse in their activity and forget about the technology that mediates the interaction.

– Any new information and collaboration technology will require change and rethinking of:

1. the design and location of spaces in which people work, learn, and play;
2. the content people create in terms of representation, media, interrelation among the different media, the content's evolution over time so that it provides context and sets it in a social communicative perspective.

This research effort investigates the nature of the communication process of the building design process when mediated by computers. The research has investigated both the physical setting of the interactions, the workspace, as well as the psychosocial aspects of the interaction, focusing mainly on the nature of the discourse produced in the communication process.

In pursuing this goal, one of the main challenges has been to understand: (1) how to collect the data in order to capture the richness and dynamics of the interactions, and (2) how to formalize it into models and representations that enable a better understanding. This paper presents the methods we have developed to achieve these goals, by recording, representing, visualizing, and analyzing data from the interactions. It documents the fundamental issues regarding the conceptual communication model we used for these analyses.

2 The project-based learning experience

The PBL experience is an ongoing integrated research and curriculum program coordinated by Stanford University involving undergraduate and graduate students from engineering, architecture, and construction management from Stanford, UC Berkeley, and Georgia Tech, Kansas University in the United States, Strathclyde University in Glasgow, UK, Ljibljana Technical University, Slovenia, Bauhaus University, Weimar Germany, ETH Zurich and FHA in Switzerland, TU Delft in Netherland, KTH Stockholm in Sweden, Aoyama Gakuin University, Tokyo and Stanford Japan Center in Kyoto, Japan. The emphasis of this AEC PBL program is on cross-disciplinary, collaborative, geographically distributed teamwork. The AEC teams work on a building project using Internet based communication technologies to connect the participants, enabling them to interact in geographically distributed shared environments. Each A/E/C team has an owner representative whose responsibility is to set the budget, program, and context limitations as well as approve variances to the project. In addition, each team has an existing site and a users program for the building. Other academics and practitioners interested in the research act as mentors representing each of the three professional areas of expertise. Figure 1a shows a typical final project.

Students are organized in A/E/C teams, whose members interacted remotely with each other from their home universities in their countries of origin. An example of a typical team would have the architect at Berkeley, the structural engineer at Stanford, and the construction manager at TU Delft, Netherlands, and the apprentice at Stanford Japan Center in Kyoto, Japan.

Typically, students use wireless laptops or desktop computers running applications on Microsoft Windows environments (Fig. 1b). For 3D CAD designing tasks students use typical applications such as CAD tools (e.g.,

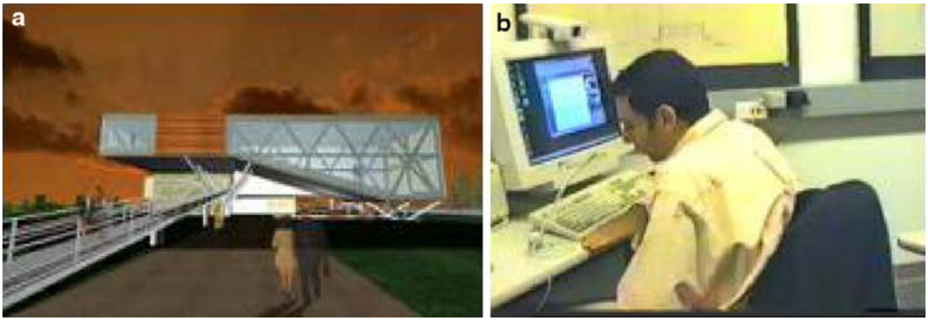

Fig. 1 **a** Typical final AEC project; **b** Typical videoconference setting in PBL Lab

AutoCAD, 3D Studio Max, Form Z), and simulation tools (e.g., SAP2000, RISA), costing and scheduling tools (e.g., MS Project), as well as custom-designed collaboration technologies developed by the PBL Lab research team, at Stanford University (Fruchter 2003a, b). The non-collocated communication tasks are performed by the students using instant messaging, netmeeting exchanging voice, video, and application sharing, as well as sharing design, scheduling, and project cost applications, using web project group workspaces, and web discussion forums.

3 Data collection

To date, 11 generations of students have participated in the PBL experience. Their learning experience has been the environment for the observations of the teamwork tasks faced through the challenges and opportunities established by the course. The traditional methods of collecting information, e.g., participant observations and notes taking, have proven to be insufficient to account for the complexity of interactions involving computer-mediated activities. In order to capture the complexity and richness of the interactions, this research project has used several simultaneous data collection systems—direct observation, video recording, and screen capture.

3.1 Direct observation

Observations are a useful resource to complement the media described below. Notes provided by observers about the interactions give first-hand information that can escape the capabilities of the mechanical media for recording the information. Observation alone however, poses limitations for producing records of the interactions, i.e., certain important aspects of the events that cannot be easily identified by mere observation. Two other information-tracking techniques have been used in our research work to overcome this limitation:

Video recording: Video is a powerful tool for capturing the interactions occurring in the workspace. It was a major source of information mainly for user interactions in the study of the use of the workspace.

Screen capturing: The information regarding the use of electronic interfaces used by the participant is also relevant and critical to understand the nature of the tasks being performed by the participants. The images that appear on the monitor of computers used for the interactions by the participants were recorded directly form the CPUs by a video recorder device. This media has shown to be particularly useful for observing the role of desktop's affordability in the interaction.

The use of video to record computer-mediated interactions has been a regular practice in usability studies. There are several ways of recording the information regarding the screen and user, either by keeping the sources of video independent, or by integrating them via the use of video mixers in real time or as post-production activities. In this study, the information was recorded separately and analyzed on an individual basis. The data produced during the seventh generation of PBL totalled more than 100 h of videotaped interaction. For the purposes of this study, we used about 40 h of the total recording available. The core of the data was captured on a Video-8 system, using a setting as the one shown on Fig. 2.

The video camera is located in a position that enables the capture of most of the workspace area involved during the interaction, allowing the videotaping of the screen, the input devices, as well as the participants in their interactions. An additional monitor hookup (not shown in the figure) was used for capturing information from the computer screen. The use of video has enabled us to register several relevant aspects of the ongoing interactions of the participants.

4 Data analysis

In the development of the methodological approach to the study of the communicative events in computer-mediated non-collocated interaction in building design, one of the aspects considered to be important to stress was the complex nature of the processes involving both communication and the use of the workspace. Traditionally, evaluation of computer-mediated interactions have been studied from perspectives that prioritize the quantitative actions of the

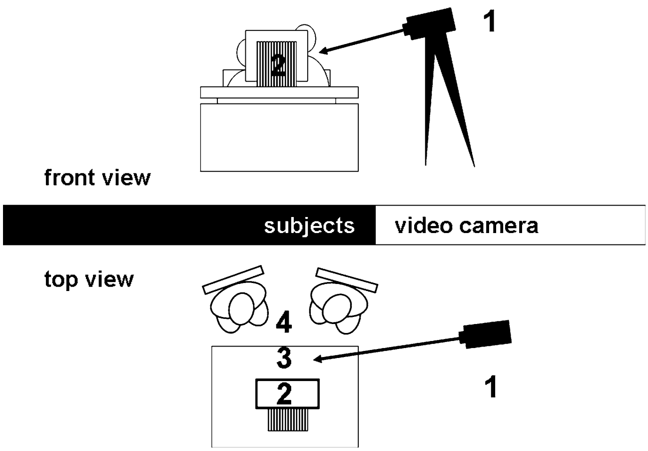

Fig. 2 Setting for data collection: *1* camera, *2* monitor, *3* workspace, and *4* participants

interaction, i.e., time employed in the solving of tasks, shortcomings of the qualitative aspects of the interaction in terms of the content and structure of the communication processes, and use of the workspace. Moreover, either a purely qualitative or a purely quantitative approach will result in giving a partial account of the activities under study. Considering this, our approach is grounded in a methodology that seeks to consolidate both perspectives, bringing a more complete description of the processes involved in computer-mediated teamwork.

The perspective presented in this paper includes two elements traditionally observed by usability studies: the psychosocial processes and the physical objects involved in the interaction. Many of the recent approaches to the study of the use of human–computer interaction have focused on these two aspects for producing explanations about the nature of the activities involved in the interactions and the role of computers as mediators. Some of the studies particularly stress the role of the social components in the interaction's diverse theoretical frameworks, as in the case of the activity theory developed by Vygotsky and Leont'ev (Bodker 1997; Wertsch 1991). This approach used in the social sciences and education has been applied in the field of HCI to the study of computer-mediated task solving.

For the purposes of this research work, the different elements involved in the interactions have been organized into two major categories:

Psychosocial processes: Diverse processes involving both aspects of the individual and the group psychology, take place in a non-collocated interaction. The main resource selected as a way for accessing these processes has been the discourse produced by the participants in the interactions. The verbal activity of the interaction has usually been the object of the study of those concerned with the use of protocol analysis as a means of evaluating computer interfaces. Traditional protocol analysis however, seeks information embedded in the spoken discourse by means of quantitative processing of the verbal data, e.g., repetition of words and topics, without necessarily considering any of the other aspects included in the interaction, e.g., the limitations placed by the tools used in the communicational process. This study of the discourse produced in the interaction, takes into account both the level of the structural aspects of the discourse as well of those concerning meanings.

The nature of the workspace: In addition to the analysis of what is said, this study shows the relevance of extending the analysis beyond the verbal into the characteristics and affordances of the workspace. It is important to include the nature of the relationship between what is said in the context of how that discourse is staged in the physical space as well as the equipments used for communicating.

Finally, it is relevant to consider the psycho-sociology of non-collocated communication both in the asynchronous mode, as in the case of email lists and news groups, as well as synchronous, in the case of chat rooms, MUDs, and avatars (Wallace 1999). The social nature of the work developed in PBL Lab emphasized the understanding of the different actors in the non-collocated interaction as members of a particular community or group. The processes occurring at this psychosocial level can explain aspects of the interaction such as the development of trust, emotional bonding, and style of co-operation.

4.1 Identifying the psychosocial processes

The discourses produced during the interactions were analyzed with the premise that they were more than a mere exchange of verbal information. In the context of the methodology developed for this study, the discourse is analyzed as a constituent element of a bigger structure of events that include others aspects, such as the use of tools and their role on the production of such a discourse. In order to produce a representation of the situation that would keep as much of the richness of the events of the interaction as possible, schemas and procedures were developed for collecting, coding, and representing the analyzed situations.

Two main categories were considered when coding the data:

1. Discourse data: Discourse information corresponding to the different verbal exchanges occurred during meetings. They were transcribed coding not only the purely verbal aspect but also relevant non-verbal aspects, such as gestures, voice intonation, interjections, expressions, and idioms as the speakers used them in the discourse. Interruptions, delays, and pauses also were noted as previously illustrated. All these elements were particularly useful in determining the possible communication intentions and rhetoric strategies by the speakers.
2. Behavioral information: Not all the relevant information produced during the interactions was, as it has been pointed out before, verbal. An important part of the interactions corresponded to aspects that involved body language and the use of the hardware available during the interaction. Some of the issues that were coded in our transcripts regarding these aspects were:

a. Description of the gaze of the speakers: The direction where the gaze of the speaker was pointed provided information about the aspects of the interaction on which the speakers and receivers focused.
b. Notes about the use of software: Describing aspects such as applications used during the meetings, movement of the mouse, location and size of the windows opened, etc.
c. Notes about the use of the hardware: this aspect is very important because it gave clues about the use of the computer and other equipment. Some of the aspects that were tracked were the use of microphone, video camera, and pointing device(s).

Movements of the participants in space: This aspect provided information about the use of the available resource in the environment related with space and hardware. We formalized these observations in diagrammatic representations using an upper view of the participants.

A typical transcript page is shown in Fig. 3. The page is divided into four fields

1. Field (a) was used to mark the time elapsed during the interaction. Timing was extremely valuable information, both when going back to the source of the text and when matching different components of the same interaction. From the experience of this study it is recommended that the time intervals be no longer than 30 s because it makes the identification and retrieval of any particular event in the discourse during the analysis process more accessible.

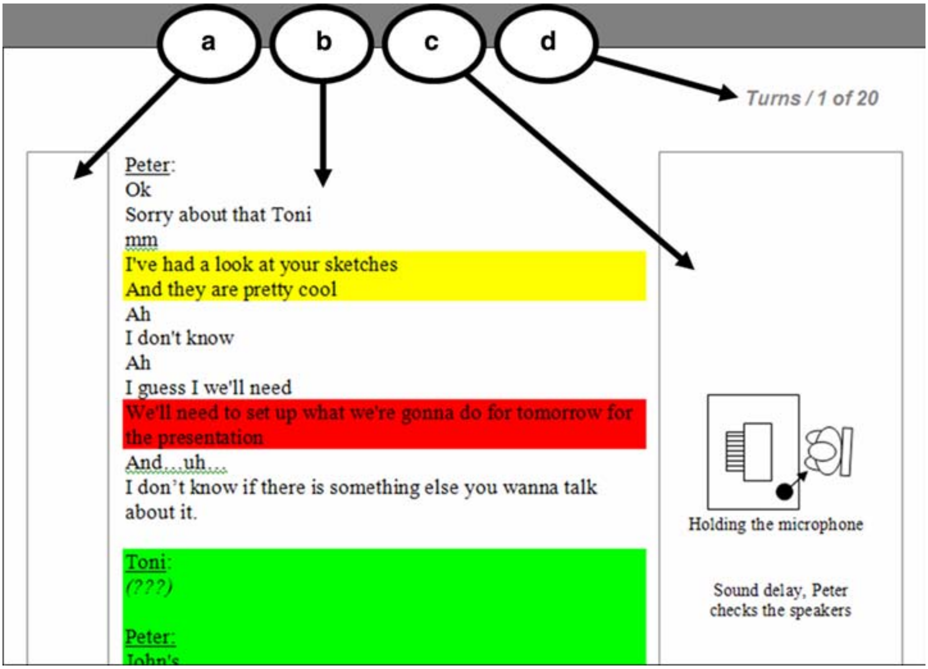

Fig. 3 A typical transcript page included three fields: time stamp **(a)**, verbal discourse transcript (**b**), and general cues (**c**). Header (**d**) containing the information pertaining the particular interaction transcribed

2. Field (b) contains the transcript of the verbal discourse. Each speech turn in the interaction was identified with the name of the speaker.
3. Field (c) provides general cues, such as the description of the gaze of the speakers, notes about the use of objects, notes about the movements of the participants in the space and notes about the use of software and hardware. The use of space was represented by a plan view of the speaker and their position in relation to the computer.
4. Field (d) indicates the name given to the meeting when the tape was identified during the recording, the number of the page, and the number of pages of the transcription.

In analyzing the discourse, the smallest unit of communication for this level of analysis was the turn defined by each intervention produced by any of the speakers in the context of an interaction. This indicates that the conversation takes place through alternate turns among the participants, even though the turns can be incomplete utterances. The turns were grouped and structured into larger units, creating three different levels of aggregation inside the discourse's structure.

1. Topics: the topics correspond to those identifiable themes raised by the speakers during the conversation. Different turns can share a same topic.
2. Episodes: episodes are a series of turns that share some specific functional content in the context of the discourse. These turns in the episode can belong to different kinds of topics.

3. Protocols: protocols point out the existence of patterns in the communication between the participants that happen in the inner structure of the Episodes. A protocol is shaped by a particular series of turns, which produce structures of verbal and/or behavioral actions that can be identified as having a particular purpose in the context of the interaction.

The following example illustrates this distinction. Consider the following text extracted from one of the interactions analyzed:

A1:Ok. That sounds good. So, I'm meeting with *R* at 8:30
B1: Ok...Ok...I...and...Ere...Do you...I don't think...I don't know...I don't think we should make it a videoconference, cause I don't have too much to say of it. What do you think?
A2:I agree. I sent an e-mail to *R* already about that.
B2: Ok...That sounds great...So...Uh...About tomorrow...We have to speak about half-anhour for the final presentation.

The participants produced four turns in this segment, two turns each (A1/A2 and B1/B2). During these four turns three topics were presented: (1) meeting with *R*, (2) the need for having a videoconference, and (3) the presentation for the day after. These three turns belong to an episode that involves a discussion about the planning of a series of meetings.

In this example there is a recurrent strategy employed by B during the interaction consisting of a series of interruptions and interjections that make the transition between the topics. This strategy is called a correction/restart (Goodwin 1981:22) and in this case, because of its recurrence as a strategy for taking over and introducing changes in the topics of the conversation, we consider it as a protocol used by B as a control strategy during the interaction.

Once the different levels of aggregation of the discourse were identified, two kinds of analysis were applied. The first was a variation of the Linkography, a technique developed by Goldschmidt (1998). Linkography is useful to identify characteristics of the verbal interaction as the different topics enclosed by each episode, the connections between topics, and the recurrence of them. Figure 4 shows one of the linkography produced. This technique enables to graphically represent the relationship among the different topics present in the discourse. It is possible to identify in the graphic the recurrence of the topics, represented by the several triangles; the bigger the triangle, the farther the appearance of a topic is from the last time it was mentioned in the interaction. We called intertopical distance, to this distance, defined as the number of occurrences of different topics between appearances of two identical topics.

In order to make this information more visually explicit, we augmented Goldschmidt's linkography method by color-coding the triangles. Use of colors made it possible to identify important parts of the occurrences of topics. For example, those that present more frequent ocurrances (represented visually as a small series of pyramids in Fig. 4) are those topics that constitute the core of the discussion.

A second graphical analysis was applied to the data. This analysis is also based on the intertopical distance (Fig. 5). In the graphic, the horizontal axis enumerates the appearance of the topics during the interaction, and the vertical axis corresponds to the value of the intertopical distance. In this case, the higher

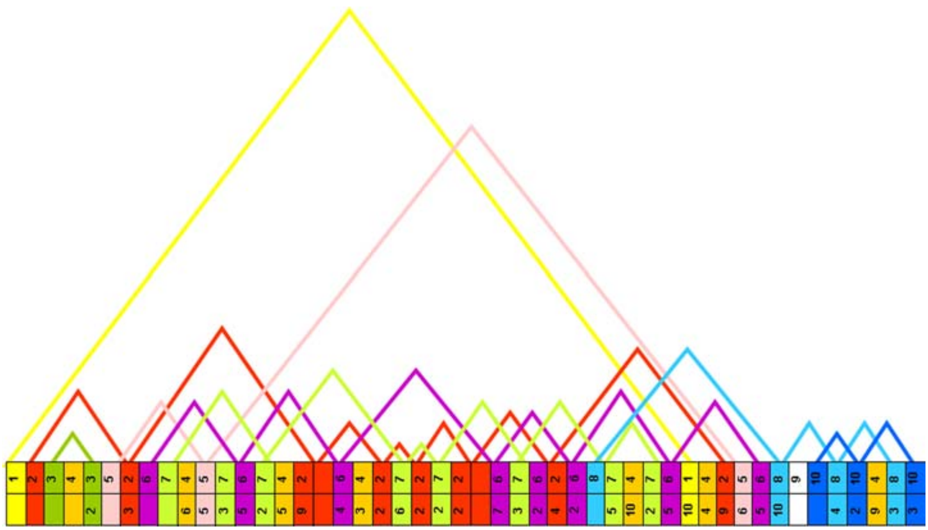

Fig. 4 Linkography representation of a meeting. *Boxes* on the *bottom* correspond to different Topics. The recurrence of the Topics is represented by several *triangles* on *top*. A *different line* type represents each topic

the value represented in the vertical axis of the graphic, the larger the amount of different topics that have occurred between the appearance and reappearance of a particular topic by using the same example we previously selected to show the

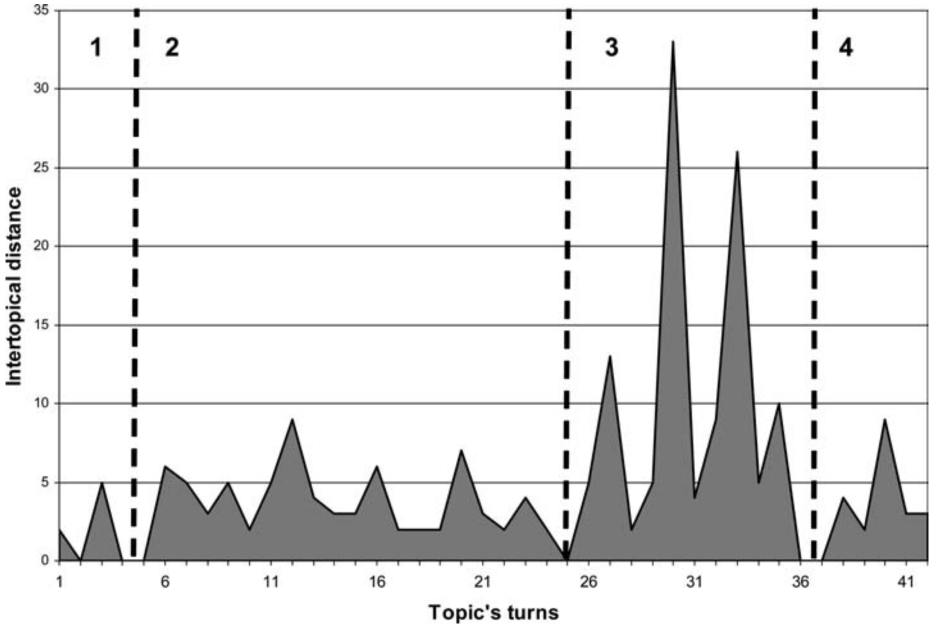

Fig. 5 Intertopical distance in a non-collocated meeting. Based on the graphic analysis, we can identify four different phases in the interaction: *1* greetings, *2* topics and discussion, *3* conclusion, and *4* farewell

use of linkography (Fig. 4) we identified four distinctive phases in Fig. 5. These phases correspond to what we defined previously as episodes in the interaction.

A third method used to represent the verbal interactions and the different episodes contained in them was the bar graph (Fig. 6). These bar graphs consisted of horizontal bands in which the horizontal axis represents the temporal duration of the episodes represented in a proportional scale. This temporal reference is important to establish ratios between the weights of the different episodes in the context of the whole conversation. The readability of these graphics is very straightforward, and enables easy identification of issues as recurrences and proportional relation in the different episodes.

Bar graphs also illustrate a third level of aggregation as mentioned before that is the identification of the communication protocols present in the different episodes. An example is illustrated in the strips pointed out by the arrows in Fig. 6 that represent the protocols used for producing the transition between episodes.

4.2 The workspace

The workspace is a central component of our analysis of computer-mediated communicative events in global teamwork. From the observations made of the interactions, one important aspect in understanding the behavioral patterns of the participants was the study of the workspace in which interactions took place.

Most of the time, the environment was pre-configured, fixed and constrained to the desktop and its immediate surrounding areas, creating a very restricted space for the equipment required for the interaction. Other relevant aspects of the workspace were the affordances of the equipment used, which co-determined the way in which the participants used the space.

In order to represent the use of the physical workspace space, a graphic code was developed to scale to indicate the floor plan, the participants, and the equipment used in the interaction. This graphic representation revealed relevant aspects related to the way in which people use their workspace:

(a) the locations of the monitor,
(b) the placement of the digital video camera used for the videoconferences, and

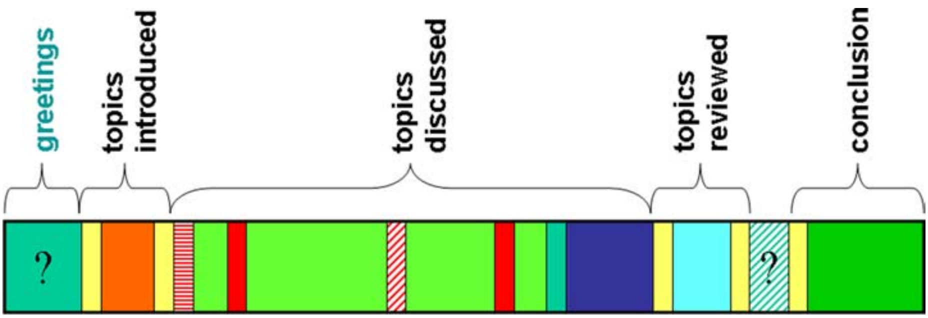

Fig. 6 *Bar* chart of the episodes during an interaction. The *horizontal axis* represents the time of the Episodes. *Each segment* represents different episodes during the interaction. In this case, i.e., the five episodes marked by *arrows* represent episodes involving transition between the different major phases of the interaction

(c) both monitor and video camera placement define preferred locations for participants, narrowing the possibilities for using a certain area of the working space.

5 Applying the data analysis methods

The following examples show three applications of the previously described methods. In these cases, it is possible to see how the combined approach of analysis involving discourse, interaction, and workspace, has enabled us to identify processes and dimensions that would have been almost impossible to determine by using only one of the listed categories of analysis.

5.1 Visibility

Figure 7 shows the movement pattern for three participants—one in Berkeley and two at Stanford—during a video-mediated interaction that took place over an hour. Both non-collocated components—Berkeley and Stanford—of the conference are represented back to back, i.e., the left column of images represent the Berkeley site, and the right column of images represent the Stanford site. It is possible to see that the movements of the single participant on the left side are more confined to a particular area than those of the two people that are sharing a space that defines a cone on the Stanford side. The special movement analysis over time provides an insight into the use, affordances, and limitations of computer-augmented workspaces.

The analysis of the scenario shown in Fig. 7 describes the environmental aspects present in the interaction. An example of it is the analysis of the participants' movements in the space as it was described in the methods for transcript. In this example, the occurrence of the movements was analyzed in time, correlating it to the verbal interaction, and physical in relation to the computer's location. By linking the information about episodes and movements in space, we were able to see an increment in the physical movements of the participants once a second participant arrives. We were also able to see the effect of the location of the video in the use of space camera watching carefully the disposition of the participants in the space. In the cases studied, the presence of the camera forces a diagonal disposition of the participants during most of the interaction.

Figure 8 shows the total amount of movement during the communicative event shown in Fig. 7 as a result of overlapping the vignettes. From this analysis the overall amount of movement occurring in the workspace emerges. Both Berkeley and Stanford sites had the same furniture and hardware configuration (i.e., desktop PC, monitor, keyboard and mouse, microphone) as shown in Fig. 9. The key difference is that at Stanford a second participant joined the meeting (starting at image seven in the series of frames in Fig. 7) and has to share the workspace with the first participant who initiated the interaction.

From the observations we made of the interactions, one important aspect in understanding part of the behavioral patterns of the participants was the study of the workspace used in the interactions. It was reduced in general to the area surrounding the computer, creating a very restricted space for the equipments

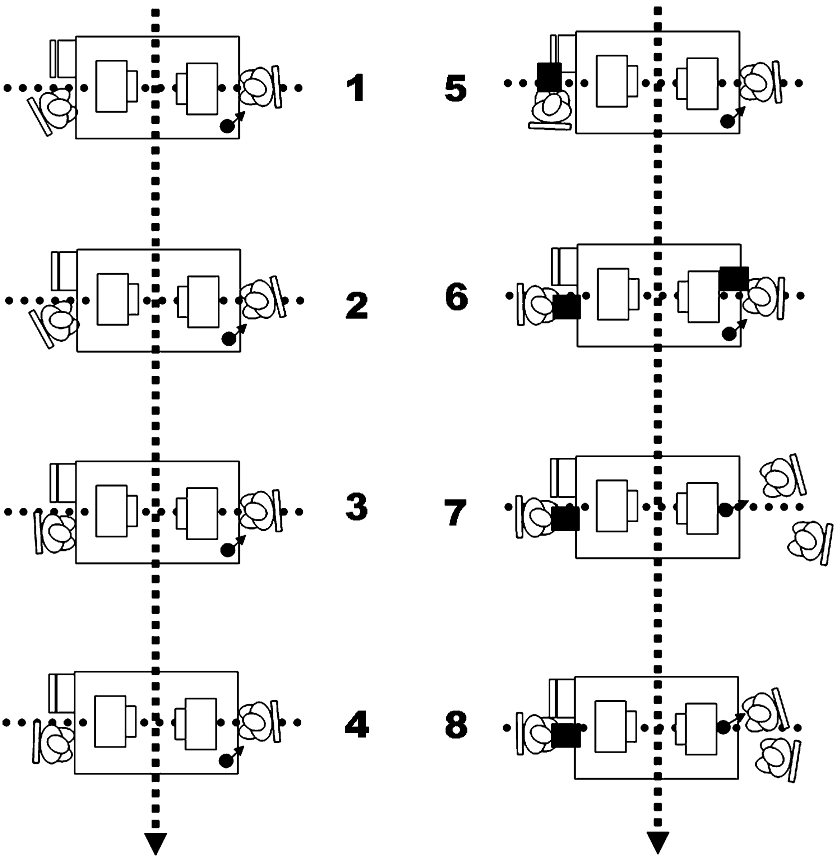

Fig. 7 Series of frames showing movement

required for the interaction. The affordances of the equipments used also determined the way in which the participants used the space. Particularly, two aspects have shown to be very relevant in the way in which people use the workspace: the locations of the monitor and the first Video camera.

Both Monitors and Video cameras define preferred locations for participants that narrow the possibilities for using a certain area in the working space. When analyzing the movements of the participants in relation to the location of the equipment, we can see that the movements are restricted to a triangular area, that we have called Cone of Interaction (COI). Four major areas of the COI have been identified through our studies (see Fig. 9):

1. Command area (A): Is the area in which the person that leads the interaction is located. The position is determined most likely by the use of the input device, and the fixed hardware configuration is usually geared left-handed users.
2. Secondary area (B): this is the area occupied by default by the other person collocated participants involved in the interaction.
3. Pointing device area (p) in this case is the mouse.
4. Microphone area (m) is the location where the microphone is placed.

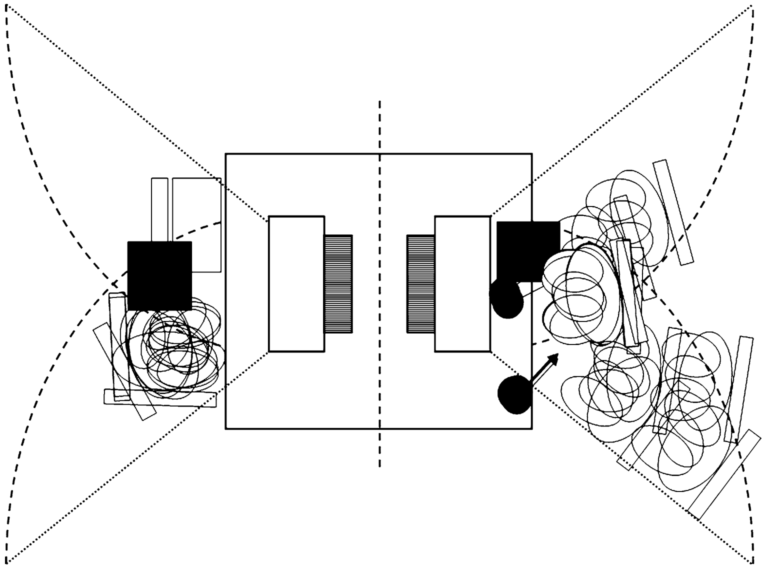

Fig. 8 Representation of total amount of movement

The existence of the COI does not imply that participants necessarily use the whole area provided by the cone during an interaction.

Some other aspects have to be considered in relation to the COI. On one hand, the overlapping of functional areas created by the video camera and the monitor. This overlapping creates three zones in the specific workspace (see Fig. 10):

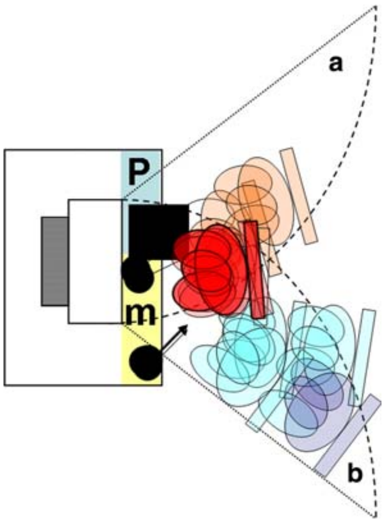

Fig. 9 Four major areas in the cone of interaction (*COI*). Command area (**a**), is the area in which the person that leads the interaction is located, Secondary area (**b**), this is the area occupied by default by the other participant(s) involved in the interaction, Pointing device area (*p*), and Microphone area (*m*)

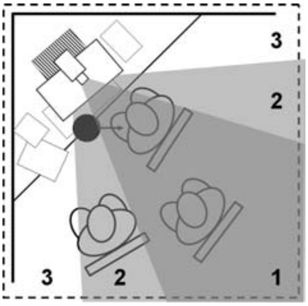

Fig. 10 Plan view showing the different areas of visibility and awareness

- Zone (1) defines the area in which the user of the computer can be aware of the shared digital content on the monitor screen; as well as be visible to the remote participant(s) as he/she can be captured by the lens of the video camera;
- Zone (2) is most problematic of all, because when being in this area the user of the system can be aware of the content on the computer screen, but at the same time be out of the camera range without noticing it, i.e., not visible to the remote participant, therefore creating a visual contact failure during the communicative event.
- Zone (3) is the area in which no visibility or awareness is afforded, for both the user of the computer and for the receiver of the image captured by the video camera.

The COI helps identify which areas of the workspace contribute to a false sense of awareness of the participant in the videoconference interaction, by creating the wrong belief that being in the visibility range of the screen, the actions performed will be transmitted to the non-collocated participant.

5.2 Discourse and workspace analysis

The three representations described in the previous sections show partial information regarding the interaction, i.e., structure of the discourse, movement of the participants in space, use of the workspace. When this partial information is integrated, a richer representation of the interaction emerges. The following example shows some of the conclusions derived from a complex representation of the interaction produced by crossing information resulted from the three interaction analysis perspectives some previously described.

For instance, a data representation was produced based on the analysis of the participants' movements in the space. In this example, we perform a temporal analysis that links movement and discourse in time. The amount of movements performed by the participants was analyzed in relation to their occurrence in time. By correlating movements of the participants to the verbal discourse during the interaction and to the workspace, i.e., the participants' relation to the computer's location, a single graphic representation can depict information about the structure of the episodes and amount and nature of the movements of the participants in space, as shown in Fig. 11.

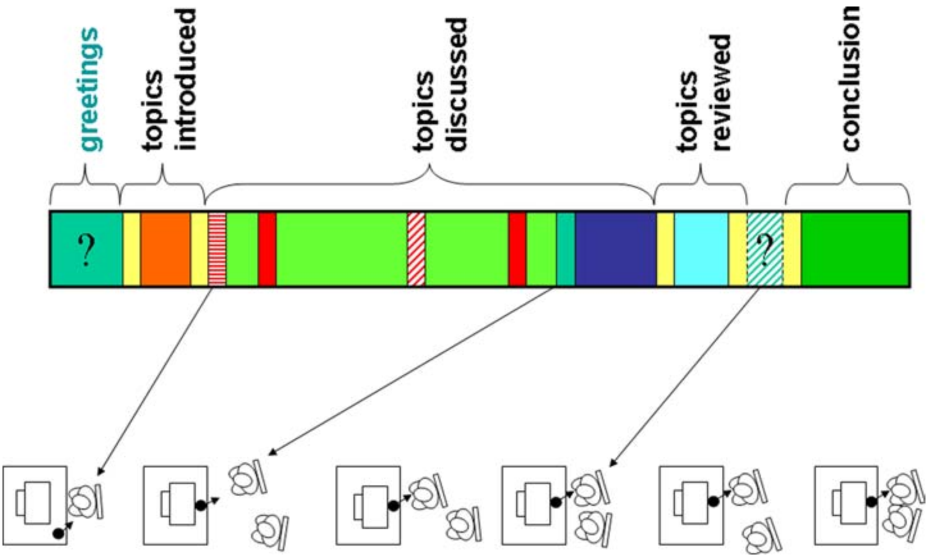

Fig. 11 *Series of interactions* represented in a proportional time scale correlated with top views of the workspace. Second person joins at a certain point during the interaction, and after that we can see that the amount of movement in the space produced by the participants in the two people side increases compared to the situation in which only one person was present

The colored bar on top of Fig. 11 shows a series of interactions represented in a proportional time scale, as was shown on the meta-structure of the episodes. The lower part of Fig. 11 shows plan views of the physical disposition in space of the participants at Stanford during the interaction as it was shown in Fig. 7. As it was pointed out earlier, a second person joins the meeting at a certain point in time, and after that we can see that the amount of movement in the space produced by the participants on the two people side increases compared to the instance when only one person was present. There are eight different spatial situations in approximately one third of the interaction time, in contrast to having only two different spatial situations during the first two-thirds of the interaction. The arrival of the second person represents an increment of almost eight times in the amount of movement.

It seems that the amount of movement of the participants and the contents of the discourse have no correlation, because during more than half of the interaction the movement of the participants was reduced to a minimum. Moreover, the analysis of the series of vignettes represented in Fig. 7 shows that the amount of movement in the one-person side stays almost without any change of movement during the whole interaction.

Correlating the information represented in this graphic with the information provided by the analysis of the COI for the depicted situation, it is possible to correlate the nature of the affordance of both the screen and the workspace in general to the behavior of the participants. After the arrival of the second person, they have to alternate their location in front of the screen in order to be able to address the receiver on the other side of the connection. Also, they alternate their turns on using both microphone and mouse, what results in producing the interaction we can see in the vignettes.

By comparing this physical situation with the nature of the verbal discourse developed during the interaction, it is possible to observe that the workspace creates a condition of unevenness for the couple using the workspace, in which one out of the two exert the control over the communication channel, by means of the position in front of the screen and camera, proximity to the microphone, and use of the mouse. This is determined by the fact that the two participants have to constantly tacitly negotiate the space as a function of their actions during the communicative event. For instance, if one participant is not in control of the mouse but wants to edit a share document on screen he/she will need to move in that position.

5.3 Awareness

An example of the impact of wrong sense of awareness during non-collocated interactions, is an action that we have found often happens when participants are describing information that involves graphical information. We have called it "Faked pointing" (Fp), and it points out to a communication failure situation, in which wrong assumptions about the contents that are transmitted with the interface can lead to misunderstanding and delays in the communication process. Due to its particular characteristics we have decided to analyze it. Consider the following segment extracted from an interaction (Fig. 12):

Let me tell you this...Look this up If I don't give you a scale very soon I will give you the size of one of those rooms So you can work out the scale off of one of those ratios But, I think that this is printed at a scale of 1/32 of an inch in a foot But yeah, the the the...long side is a 116 feet...Um...or actually um...it's actually 116 feet those little offices uh... I'm going to take control for just a second. Uh...ok, right here where the mouse is... These small offices These are the student offices and uh...they are 10 feet by 6 feet

---

The images in Fig. 12 show the "pointing with the hand on screen" gestures of the speaker while describing the graphics on the screen. These gestures, that would be meaningful in a face-to-face interaction, are completely lost in the computer-mediated communication because they fall out of the range of vision of the video camera. What the speaker meant by "long side" and "those little offices" most probably was unknown by the receiver of the information. The

Fig. 12 Fake pointing examples during a videoconference session

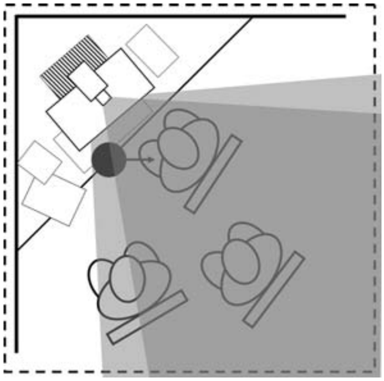

Fig. 13 Re-configuring the workspace to address visibility and awareness affordances

speaker himself notices after a certain point that the information he is aiming to transmit has not been conveyed by his gestures and explanations and decides at the end of the segment to take control of the mouse and use it as a pointer rather than the hand to indicate the described object.

The use of body gestures and its use for conveying the discourse are drastically constrained by the affordances of the video devices in use, and the lack of awareness of this fact by the speaker can lead to important losses in the communication process.

The role of visibility and awareness in videoconference-mediated geographically distributed collaborative, communicative events, seems to be relevant in situations in which the participants are involved in dialogues that imply the exchange of visual information or social issues. The social value that the visual conveyed by the use of video adds to the interaction and resolution of tasks is highly relevant (Veinott and Xiaolan 1999; Rocco 1998).

A better understanding of the role of visibility and awareness in videoconference-mediated teamwork by studying the practices that are involved in the communication process are useful in identifying situations in which the lack of awareness can lead to miscommunication situations. Figure 13 shows how by reconfiguring the workspace, e.g., making small changes in the location of the hardware, part of the problem of the zones of visibility and awareness can be solved. In this case, the camera was located slightly behind the monitor, making the angle of capture and that of visibility to overlap as much as possible.

Another factor to consider is the physical distribution of the workspace. It has to provide space not only for the computer (CPU, monitor, etc.) but also for activities as writing or use of other equipment, all inside of the COI.

Using interfaces that provide enhanced visibility of the participants, as in the case of Ishii's Clear Board[1], could be a better solution to the communication problems we have pointed out in this paper. However, interfaces as the one mentioned have been designed for the participation of two people. In order to develop hardware for multiple participants' interactions, it will be required to

[1] http://www.media.mit.edu/~ishii/CB.html

define new and creative hardware options that will enable to tailor the interfaces to the demands of the activities and natural idioms of users.

6 Conclusions

Computer-mediated interaction between humans involves processes that lie beyond the scope of studying only the technology used in the exchange of data. The complexity of the processes certainly belongs to the realm of complex communication events, in which the computer is only one part of a much larger system involved in the interaction. Once the study of computer-mediated interactions is taken out of the realm of the computer, it is clear to what extent other aspects different than the tool itself are involved in the processes of communication. The interrelation between these different aspects defines the nature of the interactions, and affects both the way in which things are said and what is said.

In order to reconstruct this complexity through research inquiry it is necessary to collect, analyze, and represent information from different domains, e.g., psychology, sociology, and human factors. A major aspect in the communication process analyzed was the verbal discourse produced by the participants. As we illustrated, the words themselves are insufficient to define what occurs during the interaction. In order to better understand such discourse a parallel study of the participants' behaviors was a relevant way to access deeper layers of meaning in the communication event. Behavior in some cases became a predictor of the discourse and in others a negation of the verbal communication itself.

Another important aspect shown by the study is the role that the physical setting plays in the development of the interaction. The processes involved in any communicative action implied much more than what was said in the verbal discourse. Particularly in the case of computer-mediated communication, this study shows how the natures of the interfaces used as well as the affordances provided by the workspaces, define the way in which the interactions occur. The affordabilities defined by the workspace highly determine the way in which the communication process occurs. The spatial quality of the workspace defines the way in which both equipment and people can be allocated within the setting in relationship to computer devices, but also the computer hardware defines the way in which people allocate and use the tools. It becomes an intricate pattern in which equipment, space, and subjects intertwine to define the setting and framework the communication event that defines the interaction.

This complex landscape requires a broad set of fields of knowledge in order to understand and improve computer-mediated communication. As Carroll (2001) emphasizes, future research needs to focus on areas such as usability and human interaction. Furthermore, we stress the need to study elements related to the architecture of the workplaces, and the actions that constrain and connect the immediate environment, i.e., bricks, to the computer interface and hardware, i.e., bits. (Fruchter 2001). This paper presented methods that can be used to extract key elements to analyze the rich nature of the interactions, the processes involved, and the environments in which non-collocated collaboration can take place.

Acknowledgments This study was sponsored by the Project Based Learning Laboratory (PBL Lab), at Stanford, and the Obayshi Corporation sponsored research project.

References

Bodker S (1997) Applying activity theory to video analysis: how to make sense of video data in human-computer interaction. In: Nordi B (ed) Context and consciousness. MIT Press, Cambridge

Carroll JM (2001) Human computer interaction in the new millennium. Addison Wesley, New York

Chapanis A (1975) Interactive human communication. Sci Am 232:36–42

Cooper G, Hine Ch, Rachel J, Woolgar S (1995) Ethnography and human-computer interaction. In: Thomas PJ (ed) The social and interactional dimensions of human-computer interfaces. Press Syndicate and the University of Cambridge, Cambridge

Finn KE, Sellen AJ, Wilbur SB (eds) (1997) Video-mediated communication, Hillsdale. Lawrence Erlbaum Associates, NJ

Fruchter R (1999) Architecture/engineering/construction teamwork: a collaborative design and learning space. J Computing Civil Eng13(4):261–270

Fruchter R (2001) Bricks& bits& interaction, special issue on exploring new frontiers on artificial intelligence. In: Terano T, Nishida T, Akira Namatame, Yukio Ohsawa, Shusaku Tsumoto, Takashi Washio (eds) Lecture notes on artificial intelligence (LNAI), vol 2253. Springer-Verlag, Berlin, pp 35–42

Fruchter R (2003b) Innovation in engaging learning and global teamwork experiences. In: Proceedings of computing in civil engineering conference at ASCE National convention, ed. Ian Flood, Nashville

Fruchter R (2004) Degrees of engagement. Int J AI Soc

Fruchter R, Demian P, Yin Z, Luth G (2003a) Turning A/E/C knowledge into working knowledge. In: Proceedings of computing in civil engineering conference in conjunctions with ASCE National convention, ed. Ian Flood, Nashville

Gallager J, Kraut RE, Egido C (eds) (1990) Intellectual teamwork: the social and technological foundations of cooperative work. Hillsdale, Lawrence Erlbaum Associates, NJ

Goldschmidt G (1990) Linkography: assessing design productivity. In: Trappl R (ed) Cybernetics and systems '90. In: Proceedings of the 10th European meeting on cybernetics and systems research. World Scientific, Singapore, pp 291–298

Goldschmidt G (1998) Contents and structure in design reasoning. Des Issues 14(3):85–100

Goodwin Ch (1981) Conversational organization: interaction between speakers and hearers. Academic Press, New York

Gutwin C, Greenberg S (1999) The effects of workspace awareness support on the usability of real-time distributed groupware. ACM Trans Comput Hum Interact 6(3):243–281

Heath Ch, Luff P (1991) Disembodied conduct: communication through video in a multi-media office environment. In human factors in computing systems conference proceedings on reaching through technology, pp 99–103

Olson GM, Olson JS (2000) Distance matters. HumComput Interac 15:139–178

Veinott E, Xiaolan F (1999) Video helps remote work: speakers who need to negotiate common ground benefit from seeing each other. In: Proceedings of the conference on computer human interaction (CHI '99). Pittsburgh, PA, pp 302–309

Vera HA, Thomas K, West RL, Lai S (1998) Expertise, collaboration and bandwidth. In: Proceedings of the conference on computer human interaction (CHI '98). Los Angles, CA, pp 503–510

Wallace PM (1999) The psychology of the internet. Cambridge University Press, Cambridge

Wertsch JV (1991) Voices of the mind. Harvard University Press, Cambridge