Robertson, T. (2000) Building Bridges: Negotiating the Gap Between Work Practice and Technology Design. *International Journal of Human-Computer Studies*. Academic Press, London, UK, pp. 121-146.

Building Bridges: Negotiating the Gap Between Work Practice and Technology Design

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The underlying premise of this paper is that the defining constraint in the design of technology to enable people in different physical spaces to work together is the essential corporeality of human cognition. Its empirical basis is a long term field study of cooperative design in a small distributed company. The paper is not a descriptive account of the work practices of the designers but instead structures the results of a field study in such a way that they might bridge, or reduce, the gap between the description of the work and the design of technology to support that work. The central conclusion from the field study was that the cooperative design of a software product was enabled and achieved by the work the designers did communicating with each other. The basic argument of this paper is that what needs to be supported, mediated and enabled by CSCW technology used to support cooperative design over distance is the mutual perception, for the actor and others, of the embodied actions of the participants in the process. These actions are considered as classes of cognitive practices that are simultaneously available to perceptions of the actor and others in a shared physical workspace. The public availability of these actions to the perceptions of the participants in a cooperative process enables their communicative functions. A taxonomy of embodied actions is defined that identifies and describes the embodied actions of the designers that enabled a cooperative design process. It is presented as a bridging structure between the field study of cooperative work and the design of technology that might support that work over distance.

1. Introduction

Studies of work practice are increasingly considered to be crucial to the development of technology that successfully fits within its situation of use. The basic argument underlying the focus on work practice is that there are potent relations between an understanding of how work is actually accomplished in context and how effectively new technology can be designed to support it. These relations are somewhat deceptively contained within the 'and' in expressions like 'understanding work *and* designing artefacts'. Discovering how these relations can be constructed between different kinds of work, different groups of people, different work environments, different times and different technologies remains an ongoing area of attention within research fields, such as Human Computer Interaction (HCI) and Computer Supported Cooperative Work (CSCW), that share a concern with designing technology that is appropriate to its use. It has become common for studies of work to end with a section that attempts to identify and bullet list the design implications and recommendations that have emerged from the study. The list then acts as a potential connection that can be generative of relations between the study of social and organisational behaviour and the design of technology that might be useful in the workplace that was studied, or in similar workplaces. At the same time, it has become common for reports about developing prototypes to reciprocate by grounding the prototype in specific design implications and recommendations that have been

identified in studies of work practice. This paper is motivated by an interest in what sorts of artefacts, as well as bullet lists and sections on design implications and recommendations, might be useful in the processes of filling, reducing or bridging the gap between studies of cooperative work and the design of technology that might support similar work in the future.

The empirical basis of this paper is a longitudinal field study of a small distributed company that designs computer based training and multimedia educational software products. But it is not my aim here to provide either a descriptive account of the field study itself or the work practices of the designers who participated in the study (interested readers can find such accounts in Robertson, 1996a, 1996b). In practice, the problem of uncovering and/or grouping the structures and elements within the field study that might be relevant to the design of technology required a layered solution. Basic to this solution was a coherent account of a cooperative design process within a distributed organisation that did justice to its achievement in practice. From this could be developed an approach to the design of CSCW technology to support that practice by structuring the results of a field study of cooperative design in such a way that they might bridge the gap between the description of the work and the design of technology to support that work. It is this latter effort with its motivations and results that will be reported here.

The underlying premise of this paper is that the defining constraint in the design of technology to enable people in different physical spaces to work together is the essential corporeality of human cognition. Human cognition is, by definition, a lived cognition that depends on the kinds of experiences that come from being a body with specific sensorimotor capacities that is always embedded in a physical environment (Varela et al., 1991). And it is a fact of human embodiment that when people are in separate physical environments, interaction between them is not possible without the use of some kind of technology to support or enable that interaction by providing a link, or links, between them that can serve as the basis for the ongoing creation and maintenance of shared meaning. Historically, technologies used for this purpose have included pen and paper, radios, telephones and various means of travel. CSCW technology can be, and has been, used to support remote collaboration because it can convey various kinds of information between arbitrary points (Gaver, 1992, p. 18). As human cognition is always an embodied cognition, then CSCW technology can be used to convey the information, or relevant related information, that enables the social and interactional roles of bodies in shared physical spaces.

Interestingly, it is recent work on user embodiment in virtual spaces that has called for a greater understanding of the social and interactional role of actual bodies (Benford et al., 1995; Bowers et al., 1996a, 1996b). Such an understanding can be grounded in a recognition of acting and perceiving bodies as the material basis of all human action and interaction, including interaction that is made possible by the mediation of technology. A taxonomy is defined here

that attempts a systematic identification and description of the embodied actions of the designers that were observed in video tapes of cooperative design work throughout the design process. The taxonomy is presented as a possible bridging structure that can generate relations between the work practices that ground it and the design of technology that can be used to support the work of cooperative design over distance. The term 'embodied action' is used to name the publicly available, purposeful and meaningful actions that people rely on to interact with others and their environment. Embodied actions are perceptual actions; the actions that enable active and perceiving subjects to immerse themselves spatially and temporally in their lived world. Embodied actions are situated actions (Suchman, 1987) viewed from a perspective that foregrounds the essential corporeality of situated action. They are considered and defined here as classes of cognitive practices that are publicly and simultaneously available to the perception of the actor and others in a shared physical space. These include actions like talking, touching, drawing, looking and moving around in the environment, in order to accomplish whatever the person acting wants to do. It is the public availability of embodied actions that is my interest here because it enables their communicative function. In turn, it is this communicative function that enables people to engage in cooperative activities including, in this case, the cooperative design of a multimedia, educational computer game. Hutchins (1995) argued that the cognitive properties of a group of people working together are not the same as those of an individual. He wrote "the cognitive properties of a group may depend as much on the system of communication between individuals as on the cognitive properties of the individuals themselves" (p. 239). Publicly available embodied action is considered here as a material foundation of that system of communication between individuals. My argument is that this same publicly available material foundation needs to be the focus of technology designed to support cooperative work over distance.

The paper is organised as follows. In the following section the field study is briefly revisited so that its methods and findings can provide a background for the body of the paper and the issues explored within it. For similar reasons, the theoretical motivations, commitments and assumptions that have shaped both the field study and the development of the taxonomy are then described. A taxonomy of embodied actions is presented that includes an account of the categorisation process and is followed by a discussion of how the embodied actions described within it map back to the cooperative design work that was the focus of the field study. Finally the argument is made that relations between a study of work practice and the design of technology that might support it can be developed from a focus on the provision of resources in CSCW applications that enable, mediate or support the public availability, to the actor and others involved in the cooperative process, of the embodied perceptual actions of the participants in that process.

2. The study of work practice: a summary of methods and findings

The field study followed the design of a computer game from the earliest discussion about what it might be through to the production of a working prototype that would be used to raise capital for the project's completion. This is a stage in the development of multimedia software that is determined by the logic of the product and its market context, rather than any formal design model. The company involved had been in existence for over seven years. It has been distributed since it began, with its members working at home and gathering together for a weekly meeting in the home of one of the directors. Computer systems and communication technologies were used to provide crucial infrastructure support as well as communication links between its various members. Over time, these people had developed a range of skills and practices that enabled them to coordinate their work within a distributed work environment. This was an environment where there were major geographical constraints on the time when they could be physically together, and equally major physical and technical constraints on the ease and effectiveness of communication when they were not.

Plowman et al. (1995) reviewed workplace studies from the CSCW literature. They found that the dominant research methodology used was ethnography. They characterised ethnography, in the context of workplace studies, as "research which aims to study work as it occurs, without imposition of specific research questions on the participants, as distinct from the experimental methods which are designed to investigate particular hypotheses" (p. 311). Shapiro (1994) emphasised that it is ethnomethodological ethnography that has dominated CSCW research since Suchman used this approach in *Plans and Situated Action*. Ethnomethodological studies of work practice (e.g. Garfinkel, 1967; Lynch et al., 1983; Suchman, 1987, 1991; Heath and Luff, 1991a, 1991b, 1992, 1993; Bowers et al. 1996a) seek to uncover the spatio-temporal ordering of human action and interaction that is usually, for the participants, nothing other than an unremarkable means to getting their work done. My priorities in this study were to observe and understand how the work of cooperative design evolved over time and how the company members coordinated their work within a distributed workplace. So my methods were derived from ethnographic research traditions (see, for example, Blomberg et al., 1993; Jordan, 1994; and Jordan and Henderson, 1994; for detailed accounts and guidelines for collecting data in the field that is suitable for fine-grained analysis of interaction).

An initial series of workplace interviews provided a broad understanding of the company's market context, how its members organised their work practices and how they defined and structured the various stages in the design and development of their products (Robertson, 1994 reports on these interviews). During the field study itself, I attended weekly meetings over a seven month period, making separate video and audio recordings of relevant meeting activities. Telephone conversations, relating to the product, were audio-taped and the participants made available copies of their meeting notes, research notes, files of various

stages in the developing product and other work-in-progress artefacts. Company members were visited in their homes and contacted by telephone during the times when they were working apart. Detailed transcriptions were made of all the tapes and the various physical artefacts were linked to the particular interaction and/or stage in the design process where they were produced.

During the initial interviews, the designers expressed strong opposition to any kind of process-defined CSCW system. Yet they were keen to continue to incorporate new communications technology into the company's infrastructure because the coordination of complex cooperative work processes required constant effort and extra overhead within the distributed structure of the organisation. While they were working apart they wanted to be able to share the applications they used to design and build their products as well as access to as many options for communication support as they could get. Their most pressing concern, clearly and frequently expressed and observed, was the difficulty in maintaining robust and flexible communication during these times. The essential finding of the study confirmed their concern; it was the work the designers did communicating with each other that enabled and achieved the cooperative design process (Robertson, 1997, 1996a, 1996b). During the field study, it was possible to observe how the company members negotiated and achieved this process without constant access to the communicative resources always implicitly available in same-site workplaces. The company members had to explicitly work at ensuring the steady and robust flow of communication between them because co-presence was not an assumed resource for the organisation of their work. This communicative work enabled them to create and maintain the context for their individual activities and to successfully work together even though they did most of their work in geographically separated workplaces.

The company management encouraged the constant review of the effectiveness of its work practices and the redefinition of these practices when they were not working. Over time, these had evolved to allow the designers to organise their work into the work they did during the weekly meeting and work they did when apart. Meeting time is very limited and highly valued and its primacy is reflected in the organisation of the company's work processes. A pivotal insight in the evolution of this analysis was that the work the company members did when they shared a physical space was not just work that would normally be defined as meeting work, in a same site company, but in fact all the work that they could not do, or did not want to do, while apart. That is, it was the work that, over time, the participants in the cooperative design process had found required the communication resources of shared physical space. A focus on this work potentially offered insights into ways of increasing the support for robust and flexible communication while company members were working apart. At the very least, this support might extend the range of work that they were able to do apart, and so contribute to the flexibility of the company's work practices.

Video recordings had been made of all the work done on the product during the weekly meetings. The perspective of the next viewing of these tapes was simply: what are the designers doing in these meetings? Amongst the talk, laughter and other activities, there was clearly a pattern to each meeting. Individuals reported what they had done while apart. Others would ask questions and each person's work would be discussed by the group. Then another person would report on her work. This process continued until everyone, who had worked on the project through the week, had told the others what she had done. Reporting was always followed by a period of shared designing, where the group worked together on some aspect of the design. Then, towards the end of the meeting, the work for the next week would be negotiated and allocated. From an observer's perspective, it was easy to divide the work of the group into stages such as reporting, discussion, shared design work, negotiation of future work and the allocation of work. This is one level of representation, from one possible perspective, of how the work of cooperative designing was done. Indeed these stages could be broken down further with little effort. For example, reporting usually involved setting the context for the individual work, describing it, and then discussing how it fitted with other people's contributions and the development of the project as a whole.

But the participants in the process did not describe their work with these labels; indeed they did not bother with names for specific stages in their work, as they lived it, at all. Most importantly naming the stages in the design work in this way excludes entirely the work of coordination and negotiation that made the processes they represent possible in the first place. Moreover, this communicative work had been identified by the designers themselves as the work they most wanted supported. The important point for my concerns here is that people did all these kinds of cooperative design work while sitting round a table talking together. At times they moved about the room, entered or left the room and moved various objects around; but there were no formal changes of position, no discernible interactional difficulties and certainly no upheaval when they changed from one kind of work to another. The video tapes were viewed again from the perspective of: what are these people doing when they are reporting, discussing, designing etc? When people were *reporting* their individual work, they talked, sometimes wrote or drew on the whiteboard, or read from their notes, passed objects to each other, showed each other pictures and some would write on pieces of paper. When people were *discussing*, they talked, sometimes wrote or drew on the whiteboard, or read from their notes, passed objects to each other, showed each other pictures and some would write on pieces of paper. When people were *designing* together, they talked, sometimes wrote or drew on the whiteboard, or read from their notes, passed objects to each other, showed each other pictures and some would write on pieces of paper.

Whatever they did was accomplished not just by internal cognitive processes, but by different combinations of their purposeful, embodied actions. This is not a particularly original insight.

It has been recognised by ethnomethodologists, practitioners of interaction analysis (Jordan and Henderson, 1994), CSCW researchers (Benford et al., 1995), exponents of distributed cognition (Hutchins, 1995) and others. But this is why human embodiment is the fundamental consideration for designing CSCW systems to support people working over distance. It is also one reason why situated action (Suchman, 1987), a term defined to "underscore the view that every course of action depends in essential ways upon its material and social circumstances" (p. 50) has become a central and defining concept in the CSCW literature (e.g. Robinson, 1991; Gaver, 1992; Shapiro, 1994; Plowman et al., 1995; Fitzpatrick et al., 1996).

3. Cognition as embodied (inter)action

Greeno and Moore (1993) identified a focus on the structure of interactive relations between people and their environments, including other people, as missing from both the external factors that concerned behaviourism and the theories of symbol manipulation that concerned cognitive science. An emphasis on the role of interaction and context in organising behaviour is common to the collection of theoretical approaches, methods and findings that use 'situated' as the first term in their names (e.g. Suchman, 1987; Haraway, 1991; Greeno et al., 1993; Lave and Wenger, 1996; Clancey, 1997). Newman (1996) defined further convergences between situated approaches including the questions "of how interaction is constituted, and what counts as relevant 'background' to inform an analysis of interaction as the basis for our claims about human knowing and learning" (p. 3). I am not particularly interested, here, in the differences that define particular situated approaches; the fact that all human action is situated is a given in each, just as it is within CSCW research (Fitzpatrick et al., 1996, p. 334). It is the public availability of situated actions that is particularly important here because their communicative function relies on it. Suchman (1987) defined an ethnomethodological view of action that emphasised the publicly availability of both actions and the world in which they are based.

> The basic premise is twofold: first, that what traditional behavioural sciences take to be cognitive phenomena have an essential relationship to a *publicly available*, collaboratively organised world of artefacts and actions, and secondly, that the significance of artefacts and actions, and *the methods by which their significance is conveyed*, have an essential relationship to their particular, concrete circumstances (p 50, my emphasis).

The public availability of anything is dependent on its perceivability. The public availability of both embodied action and the world in which the meaning of an action can be negotiated necessitates a consideration not just of human perception but also its relation to how the significance of artefacts and actions is negotiated and conveyed in practice. In the taxonomy that is defined in this paper I have assumed a phenomenologically-motivated understanding of perception that is derived from the work of Merleau-Ponty (1962, 1968). He presents perception as an active and always interpretive process that moves outwards from the body; perception quite literally connects embodied subjects to their world by finding what is already

meaningful in the environment and using this as the basis for whatever meanings are generated during the process of perception itself. Merleau-Ponty's phenomenology of perception is compatible with the ecological perception of Gibson (1979) and with the focus of situated approaches on the role of interaction and context in organising behaviour. But its experiential commitments make it particularly sympathetic to approaches to the design of technology that are motivated by understanding how that technology is used in practice. The phenomenology of Heidegger has been influential in the development of Participatory Design approaches (e.g Bødker et al., 1991; Ehn and Kyng, 1991; see also Winograd and Flores, 1986, pp. 27-37). Moran and Anderson (1990) stressed the importance of a design paradigm in CSCW that is not technology centred but motivated instead by phenomenology. They argued that by using phenomenology methodologically, designers can gain understanding of the practical activity and commonsense reasoning involved in cooperative work.

3.1. PERCEPTION IN PHYSICAL SPACE

Merleau-Ponty (1962, 1968) provided an experientially-motivated explanation of how our embodied actions enable us to create and maintain shared meaning between people. Central to his account of perception is his insistence that bodies are both physical structures in the world at the same time as they are lived by particular people. He called these two aspects of human embodiment "the body as sensible" (as in available to the senses) and "the body as sentient" (1968, p. 136). These two aspects of embodiment are continually interlinked by the fact that our bodies are perceivable by ourselves and, most importantly, by others. They are not related by an either/or opposition but are instead so profoundly enveloped in each other that they are inseparable in the life of any particular person. But this mutual perception of our body, and others like it, as active forms, enables us to interpret others' actions, just as we shape our own for interpretation by others.

Merleau-Ponty used the term "reversibility" to name the body's presence to itself in physical space as both perceiving and perceived at the same time (1968, pp. 130-155). Put crudely, reversibility is the complex, reciprocal insertion and intertwining of the sensed and the sensing that is the essential condition of our interaction with the world and with others. In a shared physical space a lived body can simultaneously

- see and be seen
- touch and be touched
- make sounds and be heard
- move and reorient its perspective
- cross over these sensory modes. That is, see itself or another being touched or touching, moving, making sounds etc.

The fact that we are able to perceive our own bodily surfaces at the same time as we live our acting bodies enables us to organise our actions (Merleau-Ponty, 1968; Varela et al., 1991). The simultaneous public availability of these actions to the perceptions of others enables them to organise their own actions in relation to ours. In this way group activity is achieved that, in the study of cooperative design, enabled the design process itself (Robertson, 1996a).

I have stressed a phenomenological understanding of perception here because popular understandings of perception, as might be represented on familiar diagrams of uninterpreted sensory data bouncing off the back of the retina, or as input to an information processing brain, cannot support the richness of analysis we need to account for the centrality of public availability to an understanding of situated action. I am also relying on a far more profound meaning than is suggested by more the familiar terms, in the HCI and CSCW literature, of reciprocity and feedback. Reciprocity has been used in the literature to denote the principle "if you can see me, I can see you" while feedback appears to be used to refer to information about the effects of our actions (e.g. Fish et al., 1990, 1992; Cool et al., 1992, p. 26; Sellen, 1992; Bly et al., 1993, p. 45; Tang and Rua, 1994). The usage of reciprocity and feedback assumes causal, linear relations between perception and motor action and these linear relations make them incompatible with situated approaches to understanding human perceptual action. The crucial point about the reversibility of perception is that for any perceptual action individuals can perceive not just that they are perceived but how they are perceived. I want to insist here on an understanding of perception that explicitly rejects causal, linear relations between perception and motor action because I do not want to risk these relations being embedded within CSCW technology. Clancey (1997) argued that the relations between cognitive processes, including perception, conceptualisation and motor action, are not “of the form that input cause output" but are instead nonlinear and codependent processes that he described with the term *structural coupling* (p. 343).

> *Situated cognition is not merely about an agent located in the environment, strongly interactive, or behaving in real time*, but also a claim about the internal mechanism that coordinates sensory motor systems (and how a similar coupling mechanism is the foundation of conceptualisation) (ibid, original emphasis).

This is important for my concerns here because the reversibility of perception is made possible by the material properties of both our bodies and of physical space. The reversibility of perception does not hold in virtual space and cannot be assumed. Instead it needs to be mediated or enabled by the technology.

3.2. EMBODIED ACTION - SUMMARY

The embodied actions that are identified and defined in the taxonomy, assume the phenomenological understanding of perception outlined above. As an active process, perception is always achieved by motor actions - we look around by moving, we touch by

reaching, we stay balanced by moving other parts of our bodies through postural senses. At the same time motor actions, as purposeful actions are achieved by perception. Embodied actions, as they are defined here are always both sensory and motor actions at the same time. Moreover, in any individual, the relations between perception, action and conception have physically evolved together over the specific history of that individuals lifetime (Varela et al., 1991, pp. 172-173; Clancey, 1997, pp. 1-2).

To summarise, before moving into the taxonomy itself, embodied actions are considered here as classes of cognitive practices and depend on a recognition that

- perception and motor action are inseparable in human cognition; that is to say embodied actions are perceptual actions;
- individuals perceive their own actions at the same time as they act them and as others perceive them;
- interaction depends on the public availability of embodied actions to all participants in the interaction, including the actor.

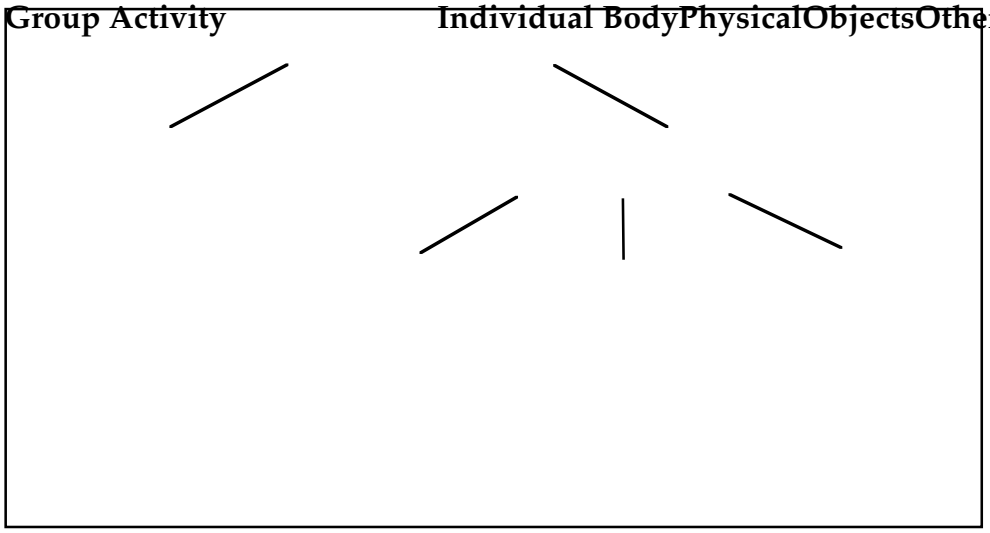
4. Categories in context

The taxonomy developed in this paper is presented as a possible bridging structure between the field study of cooperative work in practice and the design of technology to support remote collaboration. By definition, the design of any technology requires formalisation that, in turn, relies on categorisation and the setting of boundaries. Also by definition, formalisation distances the analysis from its basis in the lived corporeal world. In turn, this distancing is the source of the power of formalisation to structure that world. Lakoff (1987) commented "Categorisation is not a matter to be taken lightly" (p. 5), and Haraway (1991) added "Siting (sighting) boundaries is a risky practice" (p. 200). For those seeking to base the design of technology on the lived experience of those who will use it, formalisation must always be approached with caution so as to ensure that the specificity of this experience is not excluded. The taxonomy developed here is not concerned with any specific stage of the design process because, as already discussed, the study of work practice suggested that this was not an appropriate focus for supporting the work of cooperative design. Instead, in an attempt to tie it explicitly to the lived experience of the designers, the taxonomy defines categories of embodied action that are derived from the observation and analysis of the actions of the designers themselves. I should emphasise that this taxonomy defines categories of embodied actions that can achieve their communicative functions only because, in practice, they are totally open and flexible in how and when people perform and combine them. Both the specificity of the actions and their meanings were always dependent on the situations in which they occurred. This is a critical point for technology designers because it leaves open the possibility that people will evolve different ways to perform these actions, perhaps including ways to perform them in virtual spaces.

The taxonomy of embodied action developed here assumes the reversibility of perception. It recognises that reversibility holds both reflexively to a single body (I can perceive at least some of my own body as the same time as I perceive with my body) and between bodies in a shared space (I can perceive others' embodied actions and they can perceive mine). This recognition is important when considering work that needs to be done in a shared space, whether physical or virtual, and work that does not. It also recognises that individual actions can be done when the actor is alone or when they are in shared space, where the availability of the action for others' perception may or may not contribute to the creation and maintenance of shared meaning. For this reason I have made a fundamental distinction between the activity of the group as a whole and the embodied actions of a single body interacting primarily with physical objects, other bodies, or the workspace. The distinction recognises that the activities of the group were enabled by the individual actions of group members. But the activity of the group is something different from these actions and needs its own categories. This distinction becomes crucial in the design of CSCW technology to support work over distance. Individual participants in a cooperative process will always be acting in their local physical space. Some actions may be enabled by the technology, others will occur within their immediate physical environment. But all would need to be incorporated into the technologically-enabled, shared workspace if they were to be available to contribute to group activity.

4.1. INCLUSION AND EXCLUSION

The structure of the taxonomy is shown in Figure 1. The categories have been defined to correspond to something like the basic level of categorisation proposed by Rosch (Rosch et al., 1976). That level is represented in Figure 1. by the listed elements at the lower level of the taxonomy. The superordinate levels of the taxonomy are in bold text and provide the headings for the definition of the basic categories here. Examples of subordinate categories from the work practices of the designers are also provided for each basic level category but for reasons of space these are not represented on the figure. I have attempted to define the categories at a level where they are most useful to designers of CSCW technology; that is at the level where they can be most generative of relations between the study of work practice and the design of technology and least prescriptive of what those relations might be. This means that I have not broken them down into fine component movements of actions nor made them so broad as to be useless.



These are not mutually exclusive categories in either the temporal or spatial dimensions. Individuals, or the group, were usually doing more than one of them at any one time. People talked at the same time as they looked at something or moved around the workspace. The actions are categorised separately because they are identifiably separate actions that would require different technological solutions if they were to be mutually perceivable over distance. The categories of group activity all require a range of individual actions occurring simultaneously within the workspace. In this sense, they are another way of dividing the same analytic space as that of individual actions. I have already discussed how this dual categorisation is required to account for both the reflexivity of reversibility to a single body and to other bodies within a shared space (Merleau-Ponty, 1968, pp. 130-155) and for the use of technology to connect separate physical spaces. While I would argue that the categorisation accounts for the individual actions and activity of the group in this study, additional categories may be required in other contexts.

The categories emerged from an iterative process of viewing videotapes of group design work, identifying and then grouping the embodied actions of the participants. These were checked against further viewings and redefined. There were many iterations of this process until eventually the categories stabilised into those defined here. This is not to say that the borders between them are absolutely clear or fixed, but they are stable for the data from the study. I should also stress that I do not regard the actions defined here as "natural", in the sense that they correspond to anything that is not culturally and socially produced. But any process of categorisation excludes what is not explicitly included. My judgements about how the categories are organised, as well as what has been included and excluded by the categorisation, have been shaped by my perspective as a CSCW researcher concerned with designing systems that support remote collaboration. My aim is to identify those embodied actions, constitutive

of human interaction, that must be considered in any attempt to provide this support. Actions are distinguished from others because they are identifiably separate actions that would require different technological solutions. Tang (1989) provided a similar justification for the distinction he made between listing, drawing and gesturing. His concern was "intended to highlight different workspace tool implications" (p. 71. Some actions, though not all, are already established in various disciplines that study different forms of interaction, including both HCI and CSCW. I have identified other work I am familiar with, that is relevant to a category, or group of categories.

4.2. A TAXONOMY OF EMBODIED ACTIONS

The major divisions in this taxonomy are

- group activities constituted by individual embodied actions
- individual embodied actions
  - in relation to physical objects
  - in relation to other bodies
  - in relation to the physical workspace

4.2.1. Group activities constituted by individual embodied actions

These actions define shared activity in a shared physical space. All rely on the predictable public availability of the individual actions of the designers for the perception of the all group members, including the actor. In remote collaboration, the shared workspace is not a shared physical space, but one made possible by computer systems and communication technology. This technology needs to provide perceptual resources that can support these activities across the individual workspaces of the participants. This shared workspace does not automatically support the reversibility of perception, but mediates how the embodied actions of the participants are perceived by the actor and by others.

1. Conversing

The literature devoted to the organisation of conversation is huge (e.g. Garfinkel, 1967; Goodwin, 1981; Heath, 1986; Suchman, 1987, Chapter 5; Kendon, 1990). Conversational analysis, a branch of ethnomethodology, has examined the local organisation of human-human conversations in a variety of settings (Heritage, 1984). The premise of conversation analysis is that "face to face interaction incorporates the broadest range of possible resources for communication" (Suchman, 1987, p. 69). A number of principles governing the local sequencing of talk have been proposed including turn taking (Sacks et al., 1974) and repair (Schegloff, 1992). Interaction analysis (Jordan and Henderson, 1994) draws on these traditions among others. As would be expected, the organisation of conversation has been a central concern in CSCW research and product development (e.g. Frohlich and Luff, 1989; Heath and

Luff, 1991a; Suchman and Trigg, 1991; Suchman, 1991; Heath et al., 1995; Plowman et al., 1995; Bowers et al., 1996a). Harrison and Minneman (1995) argued that all the different elements of the design process are "held together by the conversation of the designers" and that supporting social communication is as important as supporting communications about the specific design problem. In my study it was rarely possible to separate conversations that were social and those that focused specifically on design problems. Whatever work the designers did in meetings was accomplished by their talking together. Conversing is the major and essential category in this taxonomy of group activity.

- Maintaining a single conversation involving the whole group
- Maintaining more than one conversation involving different subsets of the group but within the same space (individual involvement can vary over time)

2. Looking at the same thing at the same time

This activity made the design conversation more robust by enabling the inclusion in the conversation of some aspect of what was being looked at. Enabling this activity is the motivating requirement of any shared workspace. Company members identified this activity, while working apart, as the most urgent requirement for CSCW support.

- Looking at a single shared representation, e.g. whiteboard, book or screen
- Looking at a series of shared representations, e.g. the developing prototype on the computer or different pictures in a book (someone holds it up and leafs through it)
- Looking at a number of shared representations at the same time (looking from one to another), e.g. comparing pictures in books with each other and with those on a computer screen
- Looking at something else that is perceivable in, or perceivable from, the shared workspace, e.g. a pile of papers on a desk or a tree outside the window

3. Organising shared communication resources

These are actions or activities that alter some physical aspect of the workspace in order to make communicative resources available as the focus of group activity. This was done most frequently when the group needed to look at something, such as a prototype screen design on a computer or to organise the sequential viewing of files, particularly graphics. If an individual is participating in this activity then the public availability of her actions means that others can utilise this time in other ways. But the activity acts as an indication of what is happening next and how soon it will happen. The rest of the group can use this as a resource to organise themselves appropriately so that the flow of work is maintained.

- Changing what the group is looking at
- Installing graphic files on the computer
- Installing software to enable group viewing

- Cleaning the whiteboard

4. Creating a shared representation

Representations may be physical, or temporal/spatial representations. Bly (1988) suggested that drawing activities are as important to collaborative design work as the resulting artefacts (see also Tang, 1989). The creation of shared representations was used to express ideas, add meaning to the accompanying talk and to summarise work as it was done. Tang and Isaacs (1993) surveyed 76 users of video conferencing systems. They reported that a shared drawing surface was the most commonly requested feature; 68% of the respondents listed it as a desired feature (p. 166). In this study drawing in the air frequently accompanied designers talk and, if considered appropriate, led into drawing on paper or the whiteboard. In remote collaboration, using the shared drawing surface replaces drawing in the air because the latter action cannot be seen by the other participants. This means that physical artefacts are created in remote collaboration that in shared physical space would have simply existed as gestures. How those physical artefacts are then treated by the participants and the technology itself is an important issues for designers of CSCW technology.

- Drawing - in the air, using the actor's body as the background, on paper or the whiteboard using a drawing tool,
- Writing - using a writing tool, on paper or the whiteboard

5. Shared physical use of an object

This activity is distinguished from the others involving various kinds of sharing of objects because more than one individual is in physical contact with the same object in some way at the same time. The shared use of objects became more frequent and central to the conversation as the work progressed. In each case the object was a representation of some part of the developing product, generally a screen design. This activity is seriously compromised, if not impossible in shared drawing systems that impose separate layers for each participant or those that impose locking systems to prevent or place conditions on shared use.

- Performing the same action, e.g. drawing
- Performing different actions, e.g. one person highlighting at the same time as another is drawing

6. Focusing group attention

This activity was generally initiated by one person's actions. But the group, as a group, perceived the action and reoriented its attention. This category enables changes in group focus and is used as a way of structuring the conversation.

- Focusing on a shared object or representation
- Focusing on a speaker

- Focusing on a specific group activity

7. Breaking into smaller groups and reforming

When some aspect of the design work required it, people moved themselves and various objects in the workspace to form into smaller groups. The larger group would reform when this stage of the work was completed. People in different subgroups were peripherally aware of the activities of the other group/s and could participate in these at will. Interaction and movement between groups occurred with minimal overhead.

- To enable smaller groups to work on specific parts of the developing design, e.g. graphics, coding or planning
- To enable a smaller group to work on another project, e.g. one that may be nearing a deadline, while monitoring the progress of the main group.

8. Seizing the moment

Group members took advantage of lulls in the group activity for the opportunistic use of time they were together to do something unplanned. The unplanned activity could include the whole group but was often done when one or more of the others was attending to an interruption, or to other work (including organising shared communication resources). At these times the main activity of the group was interrupted, providing opportunities for this activity. This was a crucial activity both to the maintenance of the group as well as the cooperative design process. Poynton and Lazenby (1992) argued "Chat is economically productive at the most basic level, constituting some of the most skilled work that employees can perform" (p. 16).

- Asking a question about something else to do with work, e.g. technical information
- Used for explicit social interaction, e.g. to discuss movies and tell jokes

9. Doing something else

Individuals occasionally did something other than the group activity, while remaining in the same physical space. Those doing other work are able to be aware of group activity, usually by listening, even if they are not actively participating. Should they wish to participate at any time, they can do so by changing their spatial position and orientation. Perceptual clues for this category include positioning the body to face away from the group and prolonged personal use of a physical object.

- Doing other work, e.g. meeting deadlines on other products
- Disinterest in current group activity
- Personal preference e.g. inability or unwillingness to participate in discussion without fidgeting with something else

4.2.2. Individual Embodied Actions

These have been divided into individual actions performed in relation to objects, other bodies and the workspace. The "in relation to" recognises the indexicality of all embodied actions. Indexicality, in this context, is not used in a narrow linguistic sense, but in the ethnomethodological sense that all actions need to be interpreted within the context they occur (Garfinkel, 1967, pp. 4-7). This is the basis of ethnomethodology's focus on accounting for the "demonstrably rational properties of indexical expressions and indexical actions [that] is an ongoing achievement of the organised achievements of everyday life" (p 34). I should also emphasise that actions defined in relation to objects and other bodies, have an implicit "in relation to" the physical space in which they occur.

4.2.2.1. Embodied Actions in Relation to Physical Objects

In their study of the role of 3-D objects in the design process, Harrison and Minneman (1994) argued that "a common thread that runs through all of the ways that objects were used is the relation of hand and eye" (p. 207). They argued that design conversation is more robust because of the introduction of objects and references to them. Their conclusion about the design contexts in which objects were used was that "the emergent pattern is that there is no pattern" (p.215). The actions in this section are defined from the 'other side' of the relationship to the perspective of these studies. Instead of focusing on the objects in relation to how they were used during the design process, the focus here is the embodied actions of designers in relation to objects during that process.

1. Moving physical objects

Actions within this category make it possible for the designers to take advantage of the motility and immutability of physical objects (Seeley Brown and Duguid, 1994, pp. 21-22). Physical objects, including books, pieces of paper and computer disks are essential resources that the designers can move from place to place, as required by the specific unfolding of the design process.

- Moving a physical object into or out of the shared space. This includes objects selected and brought into shared space from other spaces as well as those moved within the space. Participants may have made a prior decision that the object might, or will be, relevant to future work and should be available.
- Making a physical object explicitly available, as a generator of meaning, during the current activity, e.g. passing it to someone else, putting it somewhere so that it is available or holding it up to be looked at.
- Moving objects within individual workspace (within bodily reach), e.g. clearing a space to write or organising objects so as to be accessible to the individual

2. Producing a private physical representation

These representations may or may not be available for the perception of others during production. Depending on how the work unfolds they may or may not be made available after production via other actions. Whether this action becomes part of group activity depends entirely on its context.

- Drawing - usually on paper
- Writing - usually on paper

3. Highlighting some aspect of an object

Goodwin (1994) identified highlighting as a "general class of cognitive practices that consist of methods used to divide a domain of scrutiny into a figure or ground, so that events relevant to the activity of the moment stand out" (p. 609-610). In this way highlighting shapes "not only one's own perception but also that of others" (p. 610). In highlighting, embodied actions are used to tailor the object, by framing, in some way, some part of it. In the study highlighting was done in relation to representations including those on the whiteboard, in books, on sheets of paper and on computer screens.

- Drawing a line around some part of an object with a pen, e.g. annotation, or by gesture alone
- Masking background of representation, or part of object, with one or more of: hand, arm, paper or other object

4. Personal use of a physical object

This action (like 2) may or may not lead into shared use of the object. It can also be a source of information that is then shared with the group

- Browsing through a book, e.g. searching for something relevant to the moment or just looking through it while it is available
- Working on a computer
- Reading
- Looking at a picture
- Holding object for some, not necessarily obvious, reason
- Touching (including when pointing) to some part of an object

4.2.2.2. Embodied Actions in Relation to Other Bodies

Kendon (1990) argued that "all aspects of behaviour in a situation must be seen at least, potentially, to have a role in the communication process" (p. 27). He observed that participants in interaction do not attend to all aspects of each others' behaviour in the same way, and do not place the same significance on every action. These distinctions make it possible for people to organise their actions in relation to others without having to explicitly

do so. The mutual perception of these actions functions as a way of providing advance information that any one proposing to interact with another has to have (p. 262). Some of these actions are defined within other sections. But those defined here are central to the creation of shared meaning in that they enable the designers' conversation.

1. Emitting signs and monitoring signs

The embodied actions included within this category are those that enable each individual to monitor others' reactions to whatever is happening, as well as the actions that an individual makes that indicate her own. These actions are continually performed by each individual. Their availability for mutual perception is an essential condition for the group activity of conversing. This category enables each individual's decisions about their own actions within the ongoing context of group activity.

- Visual indicators of individual involvement, attention and attitude including body posture, facial expression, direction and intensity of gaze, and changes in any of these as well as other communicative movements like nodding, rolling eyes and gestures.
- Oral/aural indicators of individual involvement, attention and attitude including speech, private mutterings, asides, back channel responses and other sounds.

2. Pretending to be another body

This category is defined to account for enactment that has been identified as a crucial activity in design (Tang, 1989, p. 76; Wulff et al., 1990, p. 242; Robertson, 1996a, pp. 16-18). In this context, it is defined as an action where an individual acts out the behaviour of someone else or animates the behaviour of an object. Enactment enables the individual to make and live within a temporal representation of some process or activity. A person, pretending to be another, makes various changes in their usual embodied actions. In a shared space, these changes shape the perceptions of others so that they are able to interpret the action as enactment and participate in it. As enactment is done through time, only a small part of the enacted process needs to be directly considered at any moment enabling the immersion of the participants in the process. This action was often done at the same time as actions in relation to objects.

- Pretending to be the user
- Pretending to be a character in the game
- Animating the behaviour of some inanimate object or process

4.2.2.3. Embodied Actions in Relation to the Workspace

The workspace includes not just the permanent physical features, such as doors and furniture, but the changing positions of other objects within it (including the bodies of others). These have been considered in previous categories. But the workspace also includes the physical

medium through which actions can be performed and perceived - in this case air. The reversibility of perception (Merleau-Ponty, 1968, pp. 130-155) depends on air as the medium in which people perceive and act. The communicative functions of all of the categories defined here depend on the physical properties of the space where the actions are done. Those in this section are defined specifically in relation to the properties of air that enable the embodied actions of moving through and looking through. Gaver (1992) analysed the differences between the affordances (Gibson, 1979) for action offered by media spaces for collaboration, with those of air (see also Gaver et al., 1995). The categories in this section are defined from the "other side" of Gaver's focus on the medium of interaction. That is, my concern here is the embodied actions of designers in relation to air, as a medium, during the design process.

1. Moving around

Gaver (1992) identified the ability of media spaces to support only static perception as a major interactional constraint. Our perception is seldom static. He argued "Successful systems must *afford* movement" (p. 21).

- To get a better view
- To change bodily alignment to something
- To get an object or put an object somewhere out of immediate reach

2. Pointing at something

The interpretation of what is being pointed at is dependent not just on the act of pointing but on other people being able to perceive what is being pointed at. Pointing is the classic example of an action used to maintain indexicality.

- At an object (including other bodies) somewhere in the workspace, e.g. "have a look in there"
- At something perceivable from within the space, e.g. "the green of that tree"
- As an indicator of direction, e.g. "they live over there"

3. Shifting direction of gaze

Gaver (1992) observed that air is isotropic with respect to light. Isotropism is a term from physics that refers to a material that has characteristics that are the same when measured along any axis (p. 22). Air is the medium through which we look, irrespective of the object or direction of the gaze. The gazer needs to be able to gaze at something and others have to be able to perceive what it is, or that the gazer is just gazing into space which is an indicator of action in itself.

- To look at the current speaker (in order to follow a conversation)
- To look at an object (including other bodies) for some reason
- To look at nothing in particular

4. Moving in or out of the shared space

Individuals would, for a range of reasons, temporarily leave the shared workspace. This category is defined separately to moving around within the workspace because absence from the workspace meant that the individual could not participate in the current group activity, whereas moving round within the workspace contributed to the current group activity. Temporary absences were perceivable, by others, as temporary and the individual's return was assumed.

- To prepare the group lunch
- To meet with a client in another room
- To attend to other responsibilities, including domestic responsibilities
- For no obvious reason

4.3. MAPPING THE EMBODIED ACTIONS OF SHARED DESIGN WORK

Maps of the embodied actions of the designers for two periods of quite different design work are included in Figures 2. and 3[1]. Figure 2. maps a period of design activity when one of the designers, Sarah, told the others about an idea for the game she had developed while working alone through the week. This idea formed the basis for the game that was developed. Figure 3. maps a period later in the design process when the designers were looking together at the first group of graphics that had been prepared.

4.3.1. Reading the maps

In both maps the activity of the group is recorded in the top row. The other rows record the embodied actions of each individual. Unless indicated in their own row, each individual was involved in the activities represented in the group row. Each of the categories defined in taxonomy has been allocated a symbol and/or a line. The legend at the bottom of the maps connects the symbols, lines and categories. Due to space limitations some category names have been shortened in the legend. My first priority was to record that an action occurred; then, when it occurred relative to other actions. Timing of short actions, represented by symbols, is approximate and the duration of the action is not reflected accurately by the length of the symbols used to represent them. A single symbol means that the individual, whose actions are represented in that row, performed the action. A second, identical symbol immediately following may mean that the action continued over time, e.g. browsing through a book, or that it occurred twice, e.g. pointing. Two identical symbols at the same time in the same row mean that the action was performed twice, e.g. using both arms to point at different

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[1] Both figures will require a whole page each and should have arrived as a separate file. They need to be inserted somewhere convenient after section 4.3.1.

things. The central group activity, conversing, continued throughout both segments. The individual embodied action of emitting and monitoring signs was also performed continuously by each group member. Some individual's rows appear empty. This does not mean that they were not doing anything; they were participating in the activity of the group and may have been out of camera range.

4.3.2. Intertwining embodied actions to enable group activity

The design work represented in Figure 2. was a period of intense and excited discussion. Sarah's and Susan's rows are the "busiest" reflecting Sarah's presentation over the first eight minutes and Susan's use of the whiteboard to focus group attention during the remainder of the meeting. Only Trish took personal notes during the meeting and Reg spent much of the segment organising resources for group use, in this case by fetching, installing and searching the CDROM encyclopaedia. He looked round to the group when he had some information to share with them or when something happened that he wanted to attend to. Some patterns of combined actions emerge in the map. Pretending to be another body was intertwined with the creation and use of shared representations. Pointing and highlighting connected the discussion with some aspect of a physical object, including the pictures in Sarah's book and the representations on the whiteboard. The frequent shifting of gaze by the whole group, particularly between the 32nd and 34th minute, which is the period immediately following Sarah's presentation of her idea, reflects the excitement of the discussion and the frequent changes of speakers. In the later stages of the segment, the shifting of gaze by the whole group, reflects the use of the whiteboard for group focus, people looked from the board to the speaker and back. None of these actions were performed in any predetermined sequence, but were performed purposefully and opportunistically by the participants as they worked to create and maintain shared meaning.

Figure 3. maps the embodied actions of the designers through a segment of shared design work that involved an extensive use of pictures, both in books and on the computer screen. Dianne, Jackie and Trish appear to be less busy than the others. However, Trish is out of camera shot for the last 10 minutes so there is no data to map her actions. Much of Sarah's individual activity was moving to see better; though the number of gaze shifts and movements she made indicates that she was among the most active contributors to the discussion and was working intensely at looking at whatever was on display. Gemma and Dorothy are the "busiest" in this segment reflecting the fact that they are the two group members responsible for the visual aspects of the product. At certain points there are clusters of activity that relate in some meaningful way to each other. When someone is holding a book, they are also, usually, highlighting some part of it. Other people are moving so that they can see what is being pointed to. When there are two or more images being looked at, there is constant and widespread gaze shifting. In the last six minutes, both Gemma and Dorothy are especially

active. Both are pointing, looking through books, writing, talking and shifting their gaze frequently. But all the actions are related meaningfully by what is happening at that particular time. In the segment of work mapped in Figure 2., the action was organised by intense discussion, with few objects used. In the work mapped in Figure 3., the conversation was slower, but organised to enable a number of activities including the complex shared use of physical objects. Yet the same embodied actions enabled the work in both segments. Most importantly, throughout the shared design work, people managed all these actions quite unremarkably, moving from one to another seamlessly and opportunistically.

Mapping the embodied actions, defined in the taxonomy, back to the work of cooperative design has demonstrated how the categories are linked to the lived, corporeal world that is their basis. This process shows

- that individuals perform a number of different actions during group work;
- that embodied actions, including both a single individual's actions and actions between individuals, are densely intertwined;
- that in normal work processes, embodied actions always make sense in their context, that is to say, they are purposeful;
- that while certain actions frequently occur together, there are no preordained patterns or rigid sequences of embodied action in lived cognition;
- that individuals do not all perform the same actions at the same time, even though they are involved in the same group activities. The exception to this is when each individual shifts their gaze at around the same time to follow the flow of group activity;
- that different individuals make different contributions to different group activities at different times.

5. Discussion

For designers of CSCW technology, perhaps the most important point to emerge from the analysis is also a very simple one. Irrespective of the specifics of the different segments of work, it was always achieved in the same way. That is, the moment-by-moment accomplishment of a cooperative design process was enabled by the embodied actions of the designers that were publicly available to all the participants acting within the shared physical space. Moreover, the same categories of actions are present in each segment of work. As would be expected, the spread, frequency and combination of the different actions varied, depending on what the specific work was, but people always talked, used physical objects and moved about the workspace. Yet they were able to organise their actions to achieve whatever results they required. The meanings of specific actions and the group activities they enabled were always situated in the context in which they occurred (Suchman, 1987). At the same time, the effects of those actions and activities constituted the ongoing creation and maintenance of that context. This would suggest that technology designed to support

cooperative design over distance might be more effectively directed to supporting the interaction of the designers rather than attempting to structure the design process according to functional categorisations of design work.

Interesting questions then arise about what constitutes those interactions in the first place. How those questions are answered will affect how the communicative work of cooperative design is both perceived and represented. In turn, the representation of work will be used to generate relations between the work itself and the design of technology to support it. The point that needs to be considered is that these representations are not neutral and different technologies will result from different priorities in the process of representation itself. In this research I have utilised theoretical tools and perspectives common to situated approaches because they share a focus on the role of interaction and context in organising behaviour. This has enabled me both to consider and articulate how interaction is constituted in practice (Newman, 1996) and particularly how the system of communication between individuals (Hutchins, 1995) can be represented in a way that might prove useful for technology designers.

The basic argument of this paper is that what needs to be supported, mediated and enabled by CSCW technology used to support cooperative design over distance is the mutual perception, for the actor and others, of the embodied actions of the participants in the process. All the categories of embodied action, defined in the taxonomy, function as communicative actions in shared physical space because physical space enables the reversibility of perception (Merleau-Ponty, 1968). Yet the reversibility of perception, a fact of human embodiment in physical space, is not a fact of virtual spaces. In shared physical space we can predict how our actions are perceived by others because we can perceive them ourselves as we live them. In technology-mediated communication individual participants will always be acting in their local physical space at the same time as they act in virtual space. Self-perception, then, will require not just the assumed resources of the local physical space but the development of perceptual skills and the provision of perceptual resources to enable each individual to perceive their own actions as they appear to other participants. Put another way, a basic principle in the design of CSCW technology to support cooperative work over distance is that the perception by others of any individual's actions needs to be explicitly regarded as part of the same process, or act of perception, as that individual's perception of their own actions. clearly, at this point of time, developing technology to support the reversibility of perception of even one of these actions, with the finesse and flexibility of selection and combination available to people in shared physical space, would be a major achievement in itself. But this does not mean that the provision of perceptual resources people need to organise their own actions in relation to others' actions ought not to be a central focus of technology design.

Technology designed with this aim:

- prioritises the negotiation of shared meaning by the people doing the work, rather than dictating any assumed procedure of the work itself or imposing the organisation of work by embedding inappropriate representations of that work within the technology;
- enhances the resources available for achieving shared meaning over distance by enabling people to organise their actions for the perception of others who, in turn, can organise their responses on the same basis;
- maximises the agency of those using the technology to flexibly organise their work by supporting the actions they utilise to negotiate with others, when they need to, how work is to proceed;
- ensures that the interactions between people are organised and controlled by them, rather than by the technology.

The taxonomy presented here is intended to structure the results of a field study of cooperative work in a way that might bridge the gap between the study of work practice and the design of technology to support that work if it were to be done over distance. Its immediate value may lie in enabling researchers and designers of CSCW systems to recognise the actions that current systems do not support and perhaps cannot support. On one level, this recognition may enable a clearer understanding of what existing technology does, in fact, support in practice. This may make the need for social or organisational solutions to the specific communication problems inherent in working over distance more obvious, more acceptable and the solutions more forthcoming. On another level, it may lead to the development of perceptual resources in virtual space that are compensatory or even analogous to those provided by physical space. The openness of the categories of embodied action defined here, particularly in terms of the flexibility of how particular actions are achieved and how they can be combined in practice, is deliberate. It leaves open the possibility that people can find new ways to exploit the developing perceptual resources of virtual space to ensure the public availability of their own, and others actions as they accomplish a cooperative process.

Acknowledgements

My thanks, again, to the people whose work I have discussed in this paper. This research was partly financed by an Internal Research Grant from the University of Technology, Sydney. The Telstra Fund for Social and Policy Research in Telecommunications supported my extended visit to the Work Practice and Technology Area at Xerox PARC. I am particularly grateful to Lucy Suchman, Susan Newman, Randy Trigg, Jeanette Blomberg and Julian Orr for the opportunity to ‘learn-by-doing-and-hanging-around’ about constructing relations between studies of work practice and the design of technology.

This is a significantly revised and expanded version of a paper that was presented at the ECSCW ‘97 conference, Kluwer Academic Publishers, The Netherlands.

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