Distributed Cognition: an alternative framework for analysing and explaining collaborative working

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ABSTRACT

This paper examines the theoretical and practical problems that arise from attempts to develop formal characterisations and explanations of many work activities; in particular, collaborative activities. We argue that even seemingly discrete individual activities occur in, and frequently draw upon a complex network of factors: individual, social and organisational. Similarly, organisational and social constraints and practices impact upon individual, cognitive processes and the realisation of these in specific tasks. Any adequate characterisation of work activities therefore requires the analysis and synthesis of information from these, traditionally separate sources. We argue that existing frameworks, emanating separately from the respective disciplines (cognitive, social and organisational) do not present an adequate means of studying the dynamics of collaborative activity in situ. An alternative framework, advocated in this paper, is distributed cognition. Its theoretical basis is outlined together with examples of applied studies of computer-mediated work activities in different organisational settings.

1. INTRODUCTION

The operation, flow and conduct of work activity is of interest to a number of different groups of researchers: for example, cognitive, social and organisational psychologists, sociologists and anthropologists. Each of these diverse groups or disciplines has attempted to construct theories and frameworks that are designed to offer a formal characterisation of these activities. Such characterisations are a necessary prerequisite for the design and operation of computer systems and software that are intended to support these activities; in particular, collaborative working. However, each discipline usually focuses on a particular level of analysis and description, pertinent to that discipline, and frequently neglects to incorporate the research and theoretical perspectives emanating from other relevant levels. We argue that an adequate characterisation of most work activities requires the analysis and synthesis of information from these traditionally separate levels or sources. Existing frameworks however, developed separately from the respective disciplines (cognitive, social and organisational) do not present an adequate means of studying the dynamics of collaborative activity in situ. On the one hand they assume a decontextualised model of the actors while on the other they neglect the cognitive capabilities of these actors. An alternative framework is required, therefore, that is capable of capturing cognitive activities as embodied and situated within the context in

which they occur: social and organisational. One approach to this problem comes from recent attempts to develop a unifying framework that integrates various perspectives (technical, cognitive and social context) through Activity Theory; see, for example, Kuutti and Bannon (1993). A further candidate framework, examined in the present paper, is that of distributed cognition (Hutchins and Kausen, 1992; Hutchins, 1995).
We begin by examining the characteristics of many work activities and the different levels of analysis required to explore and explain the conduct of these activities. These discussions form the basis for a critical examination of current frameworks designed to capture this area of research. We argue that a particular, framework, distributed cognition, offers a viable alternative means of representing the social and cognitive aspects of activity within an organisational setting. Examples of the application of this framework to work activities in different organisational settings are provided and the advantages and disadvantages of this approach are assessed.

2. THE COGNITIVE PERSPECTIVE: INDIVIDUAL ACTIONS AND ACTIVITIES

A common requirement of many work activities is that of interweaving a number of different tasks within a given time period. Each of these tasks serves a particular goal and while the hierarchical nature of actions and activities allows for inter-relations between goals at different levels of description (see, for example, Vallacher & Wegner, 1985) many of these tasks will be functionally independent. Any given action or activity is associated with a particular duration; minutes, hours or days. The longer the duration the more likely it becomes that other actions and activities will have to be performed during this period. Moreover, individual actions themselves will often require the enactment of both pre-requisite, enabling and subsequent actions. Finally, each of these 'additional' actions can vary in its interrupt value - priority, personal or social importance, urgency etc.

Consider, for example, the task of word-processing a particular report; the 'main' task. This task may require the execution of a number of pre-requisite actions (e.g. finding a particular reference) or identify other, enabling actions (e.g. finding out when the last post is, if the report has to be mailed). During the performance of the main task additional actions may have to be carried out. These other actions may be related to the main task (e.g. letting the intended recipient of the report know the expected time of completion/ arrival) or they may be unrelated (e.g. responding to someone entering your office). As noted above these additional actions will vary also in their interrupt value. The person entering your office, for example, may be a member of senior management (social/personal importance) who requires a summary of a recent meeting before 3pm (urgency).

Task execution also requires, in many instances, interactions with different artefacts. A common feature of many artefacts is the need to 'wait' for the completion of one operation before proceeding onto the next phase of a task; for example, waiting for a printing operation to cease while word-processing. There is a tendency in such situations to try and fill this 'empty space' - particularly when it is extended - with some other activity; for example, telephoning someone to arrange a sporting venue. This tendency can produce several difficulties with respect to the main task: (i) remembering to continue with the next phase of this task and avoiding distraction by other actions related to the interposed activity and (ii) remembering your place in the resumed task. Similar forms of interrupt or intrusion can arise also during the execution of an extended task (hours or days) when there is a high likelihood that other, pre-arranged or unplanned but necessary committments will have to be satisfied during this time period e.g. a meeting or the arrival of a fax. More often than not an individual's work involves continuous switching between activities that are embedded within each other, rather than performing and completing tasks in a serial manner. Any one of these activities moreover can, and is likely to implicate other persons; for example, through the interaction of individual and collective routine work activities, by direct requests from one person to another, and by the interdependence of apparently individual work tasks; for further discussion of these and related issues see, for example, Norman (1988).

The above discussion implies that work activities are rarely straightforward 'individual' actions, as conceived in the conventional cognitive sense. Instead, it suggests that they are fragmented by virtue of both their interwoven nature and the fact that they are situated within an intricate network of social interaction. We suggest that by electing to adopt the individual user performing isolated tasks as the primary unit of analysis many designers and researchers within human-computer-interaction (HCI) have failed to recognise or accommodate the importance of these characteristics of work activity. Indeed, various forms of hierarchical and cognitive task analyses have been developed in which human computer interactions are divided into separate tasks (e.g. printing a document) which in turn are broken down into smaller and smaller task components or units. The prime motivation behind the use of this methodology has been the development of prescriptive rules that will enable the user to perform his or her individual tasks more efficiently in a context-free environment. Efficiency here might be defined either in terms of being able to perform individual actions faster by using fewer keystrokes and mouse clicks or by reducing the risk of error production.

Cognitively-derived methods, such as those described above, are often able to provide certain information about the problems experienced by individual users when trying to carry out certain kinds of tasks with unsuitable or awkward-to-use interfaces (e.g. Card, Moran &Newell, 1980; Gray, John & Atwood, 1992; Shepherd, 1989). However, the lack of consideration that is generally given to the problem of how these individual-based tasks are performed in situ has led to the design of many computer-based systems that are unable to easily support the kinds of interleaving and sharing of everyday tasks that generally occurs between people and between people and machines (Bannon & Harper, 1991). It is scarcely surprising therefore that unwieldy computer systems continue to be developed and that these systems are often totally inappropriate for the work practices in which they have been implemented (Cypher, 1986). Such a glaring omission, however, has not gone unnoticed within the research community. Indeed, in the last few years the caricature of HCI notions of isolated 'users' and 'tasks' has become a popular form of critique both in the social sciences and among disillusioned persons within the HCI community itself (e.g. Anderson, Luff and Moran, 1991; Bannon, 1991; Luff and Heath, 1993; Suchman, 1987) .

3. SOCIAL AND ORGANIZATIONAL PERSPECTIVES

As well as exposing the weaknesses of cognitive approaches to HCI, social scientists have stepped in and offered alternative frameworks and methodological tools. Most notable, has been the seminal work of Winograd and Flores (1986) and Suchman (1987) who have provided radically different orientations for the study of HCI and introduced new ideas of how to think about the design of computer systems. In addition, alternative frameworks based on Activity Theory, originating in soviet psychology, have been applied to interface design (Bødker, 1989) . In each case, the fundamental starting point has been the context in which user's actions and interactions with computers are situated.

With the emergence of the new field of CSCW in the mid-to-late 80's, the problem of how computer systems should be designed to support groups of people communicating and working together came to the forefront of research on system design. Cognitive psychologists, however, were left behind. Simply, the cognitive models and task analytic tools developed in HCI were unable to be applied in this context because of the constraints that follow from their inherent individual-based focus. Sociologists and anthropologists attempted to fill this lacuna and thus began to make their mark in this area of research. Inspired by the influence of Suchman's work in the HCI community, a number of social scientists started to conduct ethnographic studies of technology-mediated collaborative work. Based on detailed analyses of the working practices, important aspects of the work activities and the social interactions were described. For example, a series of ethnographic studies of control centres were carried out in the London Underground (Heath and Luff, 1991) , American airports (Goodwin and Goodwin, 1992; Suchman and Trigg, 1991; Suchman, 1993) and air traffic control (Bentley et al., 1992) . The main findings of these studies have shown how informal working practices, such as inadvertent overhearing of each other's conversation in the workplace and a flexible division of labour, are instrumental to the coordination of work and the co-management of unexpected events.

Several sociologists also have attempted to go beyond providing socially-oriented accounts of the 'practical reasoning' engaged in by members of a workplace and started to prescribe specific design guidelines (Heath and Luff, 1991) and to develop prototypes of systems (Bentley et al., 1992) . There is, however, considerable tension as to whether sociology, and in particular the branch of ethnomethodology, can or should be translated into design prescriptions. For example, Button (1993) discusses the problem of how sociologically-generated analytic categories, that are constructed in ethnographic studies, may be of little relevance to the practical problems of designing systems. Furthermore, while interesting and important findings have been generated from sociological studies on CSCW, many such researchers are largely dismissive of the study of computational aspects of people working together with computers (but see Anderson et al, 1991). Reasons given for this exclusive attitude include the sceptical supposition that cognitive characterizations tend to conceal rather than illuminate practical reasoning (e.g. Heath and Luff, 1993).

Organizational approaches to CSCW also have marginalized the role of cognition in their analyses, insofar as they have tended to focus on developing models of user-centred design, implementation and evaluation methods. One notable exception to this trend is Orlikowski (1992) who recognizes the equal importance of cognitive and organizational elements in her analysis of the changes in work practices and social interaction brought about through the introduction of a new CSCW system.

The predominant research agenda for studying collaborative work and CSCW, therefore, is currently phrased in terms of social and organizational concerns. While this seems appropriate for the study of the social interactions of people working together with computer systems the omission of cognitive aspects in these analyses is, we propose, a grave mistake. Given that much work activity is inherently cognitive (e.g. people need to think, solve problems, predict, make decisions and so on) it is argued that there needs to be an understanding of how work activities are performed at this level of analysis in order to design computer systems that can support both cognitive activities and social interactions. The problem, however, is how one might start to analyse the cognitive activities of people in their working environment rather than the workings of the isolated mind of a single individual. To this end, the alternative approach of distributed cognition is proposed.

4. THE DISTRIBUTED COGNITION APPROACH

Distributed cognition is a theoretical and methodological framework that is currently being developed by Hutchins and his colleagues at the University of California, San Diego (Flor and Hutchins, 1992; Halverson 1992; Hutchins and Klausen, 1992; Hutchins, in press) to explain cognitive activities as embodied and situated within the work settings in which they occur. By explicitly adopting this broad focus the distributed cognition approach provides a theoretical and methodological framework for analysing complex, socially distributed work activities of which a diversity of technological artefacts and other tools are an indispensable part. The applied aim of distributed cognition is to contribute to system design and implementation. This entails going into the workplace and spending time determining and analysing the problems with the existing technology and work practices and then suggesting recommendations as to what needs to be preserved and what systems and work practices need to be redesigned to support and improve the collaboration and coordination of work activities.

The central unit of analysis is the functional system , which essentially is a collection of individuals and artefacts and their relations to each other in a particular work practice. For example, functional systems that have been studied, include ship navigation, aviation flight decks, air traffic control, hospital wards, engineering offices and computer programmer teams. The main goal is to account for how the distributed structures, which make up the functional system, are coordinated by analyzing the various contributions of the environment in which the work activity takes place, the representational media (e.g. instruments, displays, manuals, navigation charts), the interactions of individuals with each other and their interactional use of artefacts.

Within this framework, cognitive activities are viewed as computations which take place via the '... propagation of representational state across media...' (Hutchins, in press). The media here refer to both internal (e.g. individual memories) and external representations (including both computer and paper-based displays). The states of the representations refer to how the various information and knowledge resources are transformed during the work activities. For example, the information displayed by a computer system will transform its state in response to an operator keying in a command. Likewise, the representational state of one or more individual's understanding of an activity can change when information about that activity is transmitted by another person. To analyse how the various representational states are simultaneously coordinated for any given activity, attention is focused on the interactions that take place between the representational media.

The way knowledge is propagated across the different representational states is characterized in terms of various communicative pathways. These include talk, non-verbal communication, the transformation of information between different modes (e.g. verbal message to a keyed input), the switching between different modes of operation and the construction of a new representation by mental computation in combination with external representations. At another level, the pathways are conceptualized as coordinated sequences of action that are continuously interrupted by the demands of an ever-changing environment. In addition, activities are characterized with respect to their adaptation over time in response to new demands in the environment.

An example provided by Hutchins of a well coordinated, distributed cognitive activity is the navigation of a ship. Rather than asking questions such as who is responsible for steering the ship or attempting to break down the individual tasks each member of the team is required to carry out, the analysis focuses on the nature of the distributed activities during the navigation of the ship. In other words the focus is on the way in which knowledge is transmitted between the team members and on how information is propagated through and across the artefacts. For example, the activity of taking a bearing on a ship, which is required for navigation when moving near land, involves coordinating a combination of events and media that are socially distributed (amongst people), technologically distributed (between people and artefacts) and temporally distributed (across time). To take a bearing, one member of the ship navigation team initially has to find landmarks on the shore. This person stands on the wings of the ship and measures the bearings of the landmarks using an alidade, which is a special telescopic sighting device.

In terms of distributed cognition, these activities are characterized as the assembling of various representational states. These include remembering the name and description of the landmark (mental coordination of representational states) and coordinating these with an external sighting of the landmark using the alidade to line up the landmark with a particular setting (technologically-mediated coordination of representational states). The next stage of the activity involves the bearer reporting his readings over a telephone circuit to the bearing timer-recorder who is located in the pilothouse (socially distributed and technologically-mediated coordination of representational states). The bearing timer-recorder then writes the reported bearings in a log book (technologically-mediated coordination of representational states). This information is then propagated to the plotter either by the bearing timer-recorder verbally communicating the information (socially distributed coordination of representational states) or by the plotter reading from the log book (mental coordination of external and internal representational states). He then plots this information on the paper chart by using various instruments (technologically mediated coordination of representational states).

This relatively simple example illustrates how information and knowledge is transformed through mental, social, external and technological representational states. By themselves, the various activities do not amount to much, but when coordinated in the correct sequential order they '... constitute the computation of the ship's position... ' (Hutchins, 1992, p. 2) in the world. Moreover, the '...properties of this computational system are determined as much by the nature of the representational media and the pattern of interconnection among representations as they are by the cognitive properties of the individual actors...' (Hutchins, 1992, p. 2).

A general assumption of distributed cognition is that functional systems comprising of more than one individual have cognitive properties that differ from those of the individuals that participate in those systems. Related to this is the property that the knowledge possessed by the members of a functional system is both highly variable and redundant. On the one hand, individuals working together on a collaborative task are likely to possess different kinds of knowledge and so will engage in interactions that will allow them to pool the various resources to accomplish their tasks. On the other hand, much knowledge is shared between different individuals. A central question that distributed cognition is concerned with, therefore, is the mapping out of the ontology of shared and individual knowledge and the means by which it is communicated, adapted and used in distributed cognitive activities.

Another important property is the distribution of access to information in the functional system. Having shared access, together with shared knowledge, enables the coordination of expectations to emerge which in turn form the basis of coordinated actions. Without access to either of these it would be much more difficult, if not impossible, for distributed actions to be coordinated. Nevertheless, while many distributed work activities are able to maintain a high level of coordination, especially in closed systems like navigation and aviation, inevitably situations arise in which access to the shared knowledge is disrupted or a mismatch between shared expectations develops. If undetected, breakdowns can occur in the functional system whereby inappropriate actions may be carried out or critical actions not carried out at the appropriate time. If, on the other hand, one member or more of the group becomes aware of an anomaly then they will tend to attempt to realign their expectations and shared knowledge of which actions each should be taking at that point in time. This is achieved through engaging in various forms of intersubjective and explicit communication.

The above points are illustrated in the following example. In a detailed analysis of a few seconds of video of a captain and a first officer (F/O) flying a plane Hutchins and Klausen (1992) describe what happens when an expectation about a routine action that should have been carried out is violated. Having received a message from Air Traffic Control the F/O expects, as is normal procedure, the captain to say something. When the captain fails to do so the F/O is uncertain what to do. He reacts by glancing at the captain.

The captain, however, does nothing initially. After a couple of seconds though, he returns the glance, as if to say, "I am answering the question you posed by looking at me without saying anything." The F/O then responds by explicitly asking the captain for the information which would have been normally spoken aloud, without having to be requested.

In identifying the processes, properties and breakdowns that occur in functional systems, the focus is very much on the dynamic aspects of activity (i.e. the means by which knowledge is propagated and transmitted through the functional system) rather than static entities (e.g. the power and role structures within an organization). The initial method employed to delineate the propagation of representational states, is to describe in increasing detail the seemingly trivial and usually taken for granted aspects of actions and interactions. The reason for reiterating through more detailed descriptions of the data, is that it is often discovered that the subtle changes in actions and interactions of the group play a crucial role in the coordination and collaboration of work activities - as illustrated in the above example. If, by contrast, a more conventional task analysis had been applied to this situation it is very doubtful whether the significance of such 'pregnant' moments would or could be revealed using such an approach.

This form of micro-level analysis appears to be well suited for the identification of the multiples causes and knock-on effects of breakdowns in collaborative working. Rather than attempting to isolate single or primary causes of breakdowns it explicitly acknowledges that incidents occur through multiple interacting failures (see also, Reason, 1990). Moreover, it has been observed that it is often the 'trivial kitchen mishaps' as opposed to any major system failures that give rise to accidents (Perrow 1984).

4.1 Informing system design

The utility of distributed cognition as an applied tool for informing the design of computing systems for collaborative work lies primarily in analysing how new systems might fit into or disrupt current working practices. Initially it identifies both the problems and efficacies of how the group work with existing technologies. Based on this analysis, subsequent implications may be conjectured both at general and more specific levels. For example, improvements to the design of aircraft cockpits have been outlined in terms of how to go about designing new systems in the face of the technological evolution of furthering automation (Norman 1990) . At a more specifical level, requirements have been outlined for the technical support of software maintenance teams (Flor and Hutchins, 1992).

To illustrate how distributed cognition can be used to analyze collaborative working in 'open' organizations introducing new technologies, and where the coordination of distributed working activities is an integral part of the work practice, two examples carried out by the authors are presented below.

4.2 The coordination of computer-mediated work in engineering practice

In a study of how networking technology has changed the working practices of an engineering company various breakdowns in the distributed work activities were identified, together with the mechanisms by which the group had adapted their working practices to overcome them (Rogers 1992; in press) . One example that the engineers discovered was a technical incompatibility between the networking software installed on the different computers connected to the network. This had the effect of preventing the default file locking mechanism from being operative. The function of this mechanism is intended to prevent users from accessing the same file from a shared server at the same time and trying to create changes to it. The reason for this is that the file will corrupt in such a state. Clearly having such a mechanism is vital to the control of the sharing of files. The non-availability of this feature , however, meant that the engineering group had to develop a new working procedure to circumvent the possibility of an active file clash occurring.

The problem confronting the design group, therefore, was deciding how to coordinate the sharing of files across the network. Given that the engineers need to work on the same files for much of their work, the probability of more than one of them needing to work on the same file at any time was great. It was highly likely, therefore, that active file clashes would occur. The group were well aware of this risk. To resolve the dilemma, the senior project manager, responsible for the organization of the group's work, had decided to implement a temporary low-tech solution. This was to place a whiteboard in the working area, with the intention that the engineers sign up the file they were currently working on. The idea was to establish a simple and efficient routine: before making a file active each engineer should first look at the whiteboard to check if it was already in active use. If not, then the engineer should erase the file number which currently was under their name and replace it with the new file number. In this way an up-to-date record of all active files would be readily available to everyone in the working area.

What appeared as a straightforward procedure, that should have been easy to assimilate as an acceptable and implementable procedure within the engineering group, was in actual practice difficult to maintain consistently. On several occasions, the engineers failed to sign up the file they were working on. This tended to happen when an engineer needed to make a file active for only a brief period of time. An assumption here was that a record was unnecessary when a file was going to be active for only a brief period of time.

The distributed cognition analysis revealed that part of the problem was that the procedure of signing up an active file was extraneous to the work activities. Hence, when the engineers perceived that the action of signing up or publicly announcing active file use was not a risk they often refrained from using it. At the same time, they were only too aware that such 'productive laziness' is what leads to active file clashes. It is this contradiction that had an unstabilizing effect on the group's ability to coordinate their work activities. A detailed analysis of the events that led up to an active file clash further revealed that subtle differences in the interpretations of what each other expected the other to do or knew was the current state of affairs led to inappropriate actions being carried out.

It could be argued that the active file clash problem was a 'one-off' caused by a temporary software bug and that, in general, networking systems can be designed to prevent the users from having to carry out this type of extraneous procedure to coordinate their work. The analysis showed, however, that there are always situations emerging in the everyday working activities where the members of the group are required to carry out additional tasks, which invariably will mean developing new coordination procedures. For example, in the same study, another problem that arose was the failure of a shared plotter connected to the network to print off plans due to some fault in the network connections or the files being sent (Rogers, 1992). The effect was to prevent all other files being sent to the plotter from being printed. In order to solve the problem, it required initially that the engineers recognized that there was a problem (i.e. that it was the network and not someone else inadvertently walking off with the printed plans), identify the possible causes and propose possible solutions. In doing so, it emerged that sometimes the problem could be solved by one person resending or recreating the problematic file from their workstation or PC whilst on other occasions it required rebooting part of or the whole network. The first remedial action had no effect on anyone else connected to the network whilst the second would kill some or all processes connected to the network and also meant involving the project and/or system managers to carry it out. Adopting the first procedure, therefore, was obviously the easiest and did not require the person who had identified the plotter problem having to coordinate with any one else. The second procedure, however, required the engineers to negotiate with each other as to when it would be possible to reboot the system. In addition, it meant disrupting the other engineer's work.

What tended to happen in practice was that an engineer, on recognizing that one of their files had got stuck, would follow the first procedure and repeat it several times until it became obvious that it was not working. Much, much time would be wasted by adopting this alternative, but the cost of following the second option, in terms of disrupting the other users, meant that it was always preferable to try the simple option and be absolutely certain that the second procedure was necessary.

A further problem with trying to establish a collaborative troubleshooting procedure was the transmission of knowledge between the engineers. Critical knowledge, about the state of the network, often failed to be passed on at the 'window of opportunity' to the other's who were engaged in the troubleshooting, either because there was a misunderstanding, a lack of awareness or a distraction. As a consequence, considerable time was wasted managing the network problem. In contrast to the establishment of the signing up procedure, therefore, the development of a coordinated troubleshooting procedure for an ill-defined problem, was very protracted and not able to be easily articulated. This meant that it was difficult for the group to synchronize their awareness of the problem as it emerged and subsequently coordinate their actions in the most efficient way.

So, what are the implications of these coordination and interactional problems? Moreover, is it possible to design future CSCW systems that can overcome them whilst still being able to facilitate collaborative working? An obvious solution to such 'teething problems' is to have a system manager or a group of support staff in charge of the network, who would manage and oversee them as and when they arise. Collaborative software could also be developed that would automate many of the coordination procedures. Indeed, various co-authoring tools are currently being developed that provide instant updates of the status of files such as who has contributed to them, without the users having to input any information. But perhaps, the most significant implication of the analysis was to highlight and elucidate a fundamental problem that computer systems, designed to support collaboration, are up against when introduced into established working practices: namely what happens when individuals that work together are required to coordinate their work even more in order to use the new collaborative system or groupware.

4.3 The coordination of activity in a hospital department

The second example comes from an ongoing study of work activity and communication in the Radiology Department of a large district hospital (Symon, Ellis, Long, & Hughes, in prep.). The hospital as a whole is concerned with a perceived need to introduce computer systems on a hospital-wide basis for the recording and transmission of information on patients and work-flow. Present systems tend to be department-specific. Studies conducted thus far illustrate the importance, for the eventual success of future technological innovations, of conducting a detailed multi-levelled analysis of existing work practices (Symon et al, 1996).

Within radiology, a particular focus of interest is that of the form and function of the 'Request Form' (RF). It has been suggested, by system analysts, that the information relayed on this form might be conveyed via an internal hospital-wide computer system. The Request Form is currently intended to serve at least three main functions: (i) to convey a request for examination (internally or externally generated), (ii) to transmit sufficient information about the patient to enable the appropriate examination to take place (by a radiographer , usually) and (iii) to retain a record of the results of that examination (supplied by a radiologist). In practice the prime function of the form, from the perspective of departmental members, is permissory - a kind of 'passport' for examination. Again, in practice, function (ii) is often frustrated by the provision of only fragmentary information (staff frequently have to obtain further information) while function (iii) may be omitted or by-passed. The actual usage of the request form is considered below with respect to a particular sub-group within the department - the Mobile Unit - and the implications of this for further technological developments are considered.

The Mobile Unit is formed exclusively from departmental radiographers. It is a very fluid group of persons comprising, at any one time, departmental radiographers who rotate (on a department-wide basis) on a monthly basis. Rotation is based on individuals and not stable sub-groups of personnel. The only permanent member of staff is the Unit Manager - a senior radiographer. The fluidity of the group is further emphasised by the inclusion of other non-mobile radiographers on an ad-hoc and temporary basis when either the department is relatively 'quiet' and/or the Unit is particularly busy. Unit practices therefore tend to be implicitly maintained by all radiographers in the department.

The primary function of the Mobile Unit is to provide a service to all in-patients who are unable to come to the department. Request forms are usually seen only at the point of contact with the patient - in a ward, theatre etc. They do not, therefore, serve the intended function of a 'request' for service (this is usually conveyed via a telephone message); their practical 'passport' function is thus emphasised within this group; no request form, no delivery of service. Many important decisions however have to be, and are made prior to receipt of this form; for example, prioritisation of attendance, selection of radiographer, provision of correct number of films, equipment etc. These decisions are typically made from a brief synopsis of the (telephoned) request: gender of patient, ward/theatre identification, type of examination and time request received/time required. Such decisions are also influenced by the requirements of other, concurrently active or anticipated requests for service and by individual preferences and expertise.

Our studies of this Unit reveal the use of a variety of different media for conveying and recording information necessary for the smooth working of the Unit. Individuals work in an apparently relatively autonomous fashion: one person on each request returning to the department to develop a film and/or to collect their next 'job'. However they need access to information not only about an individual request but also on the location of equipment in the hospital (it is too heavy to carry around everywhere), the identity of other active members of the Unit and about the current location of these other members. The latter allow them to assess, among other things, the availability of other staff and of the nearest equipment, and the correct status of a request, when reaching a decision on which request to attend to. This information is displayed on four charts near incoming requests: (i) equipment position; (ii) current staff and location; (iii) & (iv) theatre lists (these constitute extended (hours) temporal commitments).

The department has a specialised computer system for entering patient details, type of examination etc. This system is only used by the Mobile Unit on completion of an examination. Other members of the department use it continually from patient entry to completion. The Mobile Unit are unable to do the same because (a) the request form is not available until they reach the ward (i.e. details not present) and (b) time constraints in responding to requests. It is possible however, that the introduction of a hospital-wide computer system would enable requests from wards etc. (with Requent Form information) to be entered directly at source and be sent to the Mobile Unit. Other forms of information (location of staff, equipment, urgency of call etc.) could, in principle be contained in this. Alternately the request could be transferred into a more specialised local system and the necessary extra information added there. Any such changes however would have to take account of the fact that current practices utilise different media and different representations within a single medium (e.g. paper charts, lists etc) in order to allow the assimilation and transfer of knowledge vital to the group at a glance. A database that failed to capture the richness of current practices would have a critical impact on group efficiency and understanding of the current status and anticipation of potential breakdowns. One of the main observations from the present study is that information cannot be considered solely in terms of discrete content units but that it is interactive and iterative. The support of effective work practices is dependent on recognition of this and on the maintenance of 'tacit' knowledge and understanding within both Unit and Departmental radiographers. Furthermore, it is possible that attempts to incorporate both practices and knowledge into a formalised data-base may constrain the necessary flexibility of response that the Unit requires.

5. CONCLUSIONS

The distributed cognition approach attempts to overcome the limitations of existing single-disciplined frameworks, for studying collaborative working, by traversing conventional disciplinary boundaries. In particular, it is intended to explain socially distributed, cognitive work activities that are mediated by the rich assortment of technological artefacts found in the workplace. The unit of analysis adopted is the collection of individuals and artefacts in the work setting. The focus of the analysis is on the relations and interactions between the individuals and the artefacts. An important part of the analysis, therefore, is accounting for how the various structures are coordinated.

The two studies summarized here present an outline of the functional role of shared representations in the coordination of interdependent activities. They illustrate how a variety of media and representations within a single medium can be instrumental in providing shared moment-to-moment knowledge of the whereabouts of the members of a group together with the availability of shared tools and resources. In the hospital setting, access to such knowledge was considered necessary to enable decisions to be made concerning incoming requests for services from other parts of the hospital. In the engineering setting, the difficulties encountered by the group members of being able to maintain and transmit important information about the current representational states of the various media in the work setting was discussed.

An important implication from these empirical studies, for the design of computer systems to support collaborative working, is how the introduction of new technology will change existing work practices - especially the extent to which the coordination of interdependent work activities might be disrupted. A main concern, within this context, is how the form and variety of media in which information is currently represented might be transformed. From a traditional cognitive perspective, this problem is usually conceived of in terms of optimising the display of independent 'bits' of information for individual users. From a sociological perspective, the emphasis has been on the need to preserve certain kinds of physical interactions with information resources in the work place because of their important social role of allowing others in the workplace to know at a glance what each other is doing (e.g. Bentley et al, 1992; Luff et al, 1993). From a distributed cognition perspective, however, the aim is to support the interactive nature of information, as used cognitively and socially. By interactive, it is meant that external representations used in situ are interpreted in coordination with the implicitly shared and individual knowledge of current events and work practices. Hence the focus, in the theoretical analysis, on mapping out the ontology of shared and individual knowledge and the means by which it is represented, accessed, communicated, adapted and used in work activities. Therefore, implications for the design of information resources (computerized or other) are couched in terms of providing support for the many interleaving forms of social and cognitive interactions.

Accounting for social and cognitive interactions is by no means easy. Some orthodox researchers would even consider this kind of interdisciplinarity as an impossible or unacceptable objective because of perceived irreconcilable and incommensurate theoretical positions (e.g. Potter and Wetherell, 1987). However, it is important to stress that the approach adopted here is primarily motivated to understand the interaction of collaborative and individual work activities in situ. Hence it is not an attempt to promote a radical paradigm for pure theoretical research but an alternative framework to analyse computer-supported collaborative working.

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