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Distributed Cognition and IT support for Knowledge Work in Breakdowns: Match or Mismatch?

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Abstract

Knowledge is instrumental in organisational problem solving and is embedded in organisational processes and routines. We explore the application of IT in breakdowns (forms of interruptions from normal organisational work routines) and illustrate the application of distributed cognition theory (DCT) as a useful lens to explain the exchange of knowledge in breakdowns. DCT also allows for a rich analysis of the role that information technology (IT) can play to foster knowledge exchange in breakdown situations. We use two cases to illustrate that DCT is useful in identifying the matches and mismatches in IT support for exchanging knowledge in breakdowns.

Keywords

Breakdowns, Distributed cognition, knowledge exchange, knowledge work

INTRODUCTION

The importance of Knowledge work in organisational settings is receiving more attention than ever. This is evident from the wide range of literature covering a variety of Knowledge Management (KM) issues ranging from Knowledge definitions (Brown and Duguid, 2000; Cook and Brown, 1999; Davenport and Prusak 1998), to Knowledge Management Systems (KMS) (Alavi and Leidner, 1999 & 2001), Knowledge processes (Davenport and Prusak, 1998; Nonaka & Konno 1989; Nonaka and Takeuchi, 1995), Knowledge Management technology (Marvick, 2001; McDermott, 1999) and Knowledge Management strategies (Hansen et al. 1999). More recently there is an acknowledgement of the intrinsic role of intangible assets and intellectual capital (Daum, 2003; Stacey, 2001). More profound analysis of organisations reveal that it's indeed information and knowledge that form the foundation of intangible assets and that these elements play a crucial role in new economies of current and future business enterprises (Daum, 2003).

While widespread KM literature creates greater appreciation of Knowledge work in organisations, Knowledge Management Systems (KMS) –in particular the use of technology - still do not deliver the expected outcomes (Nevo et al., 2003). Many organisations invest in KMS in an attempt to support the management of knowledge while also facilitating more effective knowledge sharing and problem solving practices (Nevo et al, 2003). However, studies have shown that organisations with KM practices and technologies in place still face the same types of problems than organisations without these elements (KPMG, 2000).

Hansen et al. (1999) describe two approaches to KM namely the codification approach or personalisation approach and claim that the choice of the right approach to KM is critical. Once chosen, a too heavy emphasis on either of the approaches may not reap full benefits. For example, overemphasising of codification may result in information overload, ineffective use of KM systems, duplicate work and reinvention of the wheel (Nevo et al, 2003). Overemphasis on personalisation on the other hand, is costly, may not link the right people, and may not effectively transfer market or technical knowledge to relevant teams and role players (Hansen et al, 1999). Hence, while many organisations have a variety of technologies in place to enable Knowledge work, IT as a vehicle for KM has not lived up to its expectations. The challenge of using IT to enable knowledge work is not merely the codification or circulation of knowledge, or linking people, but to really build an environment that truly supports or promotes knowledge exchange (McDermott, 1999).

The codification approach (Hansen et al., 1999) focuses on explicit knowledge, which is formal, systematic and easily transmitted from one person to another in the form of language (Stacey, 2001). It derives from the process of making ideas and thoughts that are tacit, explicit and storing this knowledge as artefacts (Snowden, 1999). Environmental artefacts or tools are conceptual or material resources that humans employ to extend their own cognitive capabilities (Winsor, 2001). This extension of a human's cognitive capabilities beyond the individual's head into the environment forms the essence of the Distributed Cognition Theory (DCT) (Hollan et

al., 2000; Lakomski, 1999; Wright et al. 2000). According to this theory, cognition is naturally distributed across artefacts, individuals and internal and external representational media and states. These elements are particularly important in breakdown situations since knowledge processes as empirical phenomena come to the foreground during breakdowns. Breakdowns can be described as the unexpected events or situations of non-obviousness that occur in everyday practices and can vary from being less serious, local or systemic (Patriotta, 2004).

In this article we introduce the theory of Distributed Cognition as a useful lens to explain the exchange of knowledge, and we focus in particular on how individuals draw on IT to exchange knowledge during breakdowns. We believe that this theory will provide valuable new insights and perspectives on the design of IT-based KM systems for knowledge exchange. We illustrate initial ideas and themes by investigating different knowledge exchange scenarios during breakdowns in two different case study organisations. The research question that we focus on is: *How does IT support the exchange of knowledge between individuals in breakdown situations?* This paper is organised as follows: we briefly introduce the theory of DC as a basis for knowledge exchange and the relevance of breakdowns for this study. We then introduce the two case study organisations and explain major themes and ways in which individuals draw on IT in their knowledge exchange practices. We conclude with a discussion and outline avenues for further research.

DISTRIBUTED COGNITION, KNOWLEDGE EXCHANGE AND BREAKDOWNS

The theory of DC seeks to explain the interactions among people and technologies (Hollan et al., 2000; Hutchins, 1995 & 1995a; Kirsch & Maglio, 1994; Lakomski, 1999 & 2003; Lave and Wenger, 1991; Suchman, 1987). The principal claim of DCT is that cognitive activities are best understood as interactions between agents and physical systems and with other people. In DCT, cognition differs from earlier theories of the human mind, which are rooted in philosophy and used Artificial Intelligence (AI) to model the human brain and cognition (Dreyfus and Dreyfus, 1988; Newell and Simon, 1972, 1976). AI implies a view of how humans learn and embodies the symbol manipulation and neural network approaches. Over years, human cognition was beginning to be explored beyond the individual human skull by considering it as distributed between other knowers and their material contexts (Lakomski, 1999). This interrelationship between cognition and culture, referred to as 'situated action', challenged the traditional symbol manipulation approach in the sense that it takes the role of the environment, context, social and cultural settings and situations in which users find themselves into account when studying human knowledge. It doesn't focus solely on the internal processing structures of the human brain (Norman, 1993), but views the human mind as an extension of the internal self into the environment. Lave and Wenger (1991) describe this blending of the inner with the outer as 'knowledge or cognition in everyday practice' and confirms the view of knowledge being distributed over mind, body, activity and culturally organised settings.

The extension of human cognition into the environment brings artefacts as knowledge embedded objects into focus: humans have a close interaction with artefacts in the environment. They interact with these and use whatever knowledge and tools available are on hand to resolve problems or act on unforeseen circumstances. In this interaction of a person or system with its environment, 'planning' plays an important role as well as the different representational states material sources are in at different points in time (Suchman, 1987; Rogers, Y, 1993). Clarke (1998) explains how individuals rely on the setting up and manipulation of their physical environment to simplify their cognitive skills. In these circumstances, the human brain performs some operations while other operations are delegated to the manipulation of external media (from the environment). The environment then becomes a scaffold for human thinking and problem solving.

One of the most prominent rival theories to DC is Activity theory (AT) (Engeström, 1999; Nardi, 1996 & Kuuti, 1996). DCT and AT are closely related: they both emphasize 'cognition' and both derive from other theories by incorporating the cultural and social aspects of cognition. However, there are a few intrinsic differences. In AT, the individual is the centre of everything while DCT focuses on the whole socio-technical system that includes both people and artefacts (Halverson, 2002). AT also appears to be a more complex theory in terms of all the conceptual constructs and their relationships (Engeström, 1999). DCT on the other hand have less conceptual constructs and its conceptual model appears to be more simplistic than that of AT. Also, the theoretical constructs of AT are well named or labelled, whereas this is not the case for DCT (Hutchins, 1995b) – it does not explicitly name nor represent its constructs in a way that gives the same rhetorical naming power as is the case for AT. Finally, the notion of 'process' forms an integral part of AT while it is incorporated in the process of analysis for DCT and hence would seem not that obvious to the unexperienced (Halverston, 2002).

DC theory is based on three kinds of distribution of cognitive processes (Hollan et al, 2000); the first is: cognitive processes or knowledge may be distributed across members of a social group which when interpreted, implies that people need to connect or link to other people in their environment to exchange knowledge. The second kind of distribution is that cognitive processes may involve coordination between internal and external or material and environmental structures, which when interpreted implies a link or connection between people and environmental artefacts or vice-versa. The third kind of distribution of cognitive processes is that DCT claims that processes

may be distributed over time in such a way that the results, outcomes or products of early events can transform the nature of later ones (Hollan et al., 2000). These three conceptual themes form the basis of the DCT.

Knowledge exchange or 'sharing' forms the basic underlying collaborative mechanism in a DC system. Knowledge and the sharing of it are closely related. Knowledge exchange is a process that involves a sequence of events, activities and actions that all evolve over time. It also assumes a source and destination in the form of individuals or groups with the roles of offering and acquiring or bringing and getting (Hendriks, 2004). Explicit knowledge is shared between people in the form of reusing or exchanging stored artefacts, while the sharing of tacit knowledge always creates something new (Snowden, 1999). Knowledge exchange becomes vital when things go wrong in everyday situations i.e. when breakdowns occur – human actors then need to succumb to the artefacts and other people in their immediate environments to extract knowledge. Vera and Simon (1993) describe breakdowns as occasions when "... *the properties of an artefact suddenly become apparent because of a problem either with the artefact itself or with the knowledge of the user*". The strength of the DCT is particularly evident during breakdowns as humans have a natural, basic cognitive ability or capacity to solve breakdowns adaptively. Through the interaction with artefacts and people, knowledge exchange processes are set in operation in order to make new plans, devise workarounds, or compile impromptu solutions. Since DC is a more biologically realistic account of human cognition and learning that considers the socio-technical system of both individuals and environmental artefacts equally important, it's therefore a more useful theory to explore breakdown situations as it takes all these elements into account.

The role of ICT (Information and Communication Technologies) in Knowledge work is widely acknowledged in the form of tools such as intranets, e-mail, groupware and data warehousing to support the capture, storage and sharing of knowledge (Newell et al., 2002). These approaches focus on the storage and exchange of explicit knowledge while IT support for tacit knowledge exchange is still under-explored. It is during breakdowns that invaluable explicit and tacit knowledge is exchanged using both people and artefacts. The notion of breakdown and the role of IT correspond to Heidegger's terms of 'ready-at-hand' and 'present-at-hand' (Winograd and Flores, 1986; Dahlbom and Matthiason, 1993). It is only when breakdowns occur that artefacts come to the forefront of activities (i.e. artefacts become present-at-hand, and the user notices it). In the normal (routine) situation the tool is 'ready-at-hand' as an unobtrusive extension in knowledge work and 'is invisible' from the worker's viewpoint.

The theory of DCT has not yet been employed in the KM arena and we attempt to approach the creation and exchange of Knowledge in breakdown situations through this lens. We contend that it may shed new light on ways in which IT can support the exchange and creation of new knowledge and that it may also provide further insights into ways in which IT can be designed and employed to support knowledge exchange in situations where breakdowns occur.

RESEARCH APPROACH

DCT research methodologies are not bound to one single data collection or analysis technique, but instead combine a number of specific research techniques. Some of these techniques have been applied, developed and refined in other disciplines and include interviews, observations, surveys, video and audio recordings (Hollan et al, 2000; Rogers, 1992; Winsor, 2001; Silverman, 1998). An important part of this type of analysis method is to represent the raw data collected at different levels of detail and abstraction. This should also represent changes in the representational state of the cognitive system. The preliminary study of this ongoing research started off with an in-depth literature study followed by the collection of data in the form of interviews from different case study organisations. The reason for conducting initial interviews was to gather information about the different work practices of individuals in an attempt to get a deeper understanding of how individuals perceive breakdowns and how they handle them. These confirmed the notion of a DC system, and provided valuable insight into ways in which individuals claim they do their everyday work, what their work practices are and what different artefacts and tools they use. Being a preliminary investigation, initial findings are shared in the descriptions that follow.

Two case study organisations are involved and the focus is on individuals that operate in a variety of team set-ups. Teams are variable in size, members are often part of more than one team at the same time, and in some cases team members rotate within and across teams with respect to their roles and responsibilities. Some teams are dispersed between branch offices for some projects. We briefly describe the different types of organisational settings for the two case study organisations, Organisation A and Organisation B.

Organisation A is an administrative department within a large educational organisation. Its team members are responsible for a variety of administrative services to students and academics in the organisation. The focus is on knowledge intensive service oriented tasks such as student advice, queries, counselling and guidance in undergraduate and postgraduate subject/course selection, help desk and other support services to students, academics and other administrative colleagues. Team member interaction involves not only interaction within designated teams, but also interaction with other teams in the same department, or with other departments in the

same organisation. The service-oriented nature of the work requires the day-to-day solving of situation specific problems within short periods of time. Breakdowns occur as a result of rotating team members, insufficient experience of team members at times requiring immediate action, or uniqueness of situations where prior experience is neither immediately apparent nor available.

Organisation B customizes and develops Web-based Geographical solutions to customers in Australia. The organisation has branch offices both nationally (Adelaide, Brisbane and Melbourne) and internationally (Asia and America). Teams comprise members that are, depending on the projects' size and intensity, all co-located or often dispersed between offices (e.g. Adelaide, Brisbane and Melbourne). The work is knowledge intensive in nature and the organisation's major focus is on the re-use of existing artefacts, while also minimising risks associated with the software engineering life-cycle. Due to the intricate set-up of teams and nature of the work, breakdowns occur as a result of technical integration of heterogeneous work products and problems associated with the management of teams.

Handling breakdowns or workarounds for breakdowns: In both organisations it has been observed that individuals handle breakdowns by revisiting their familiar or well known 'information chains'. These chains comprise a combination of people or experts forming part of their social networks plus a collection of artefacts either created by themselves or others. Both elements have been built up through years of work practices and experiences. These information chains often have links to other experts and their artefacts. So the process of solving breakdowns starts with the individual's immediate environment (or the 'centre') and then gradually moves outwards (to the 'periphery') to incorporate more experts or artefacts from a larger environment to come up with solutions. E.g. when a breakdown is encountered in Organisation B, the individual would start asking questions to fellow team members, managers or known experts from their social networks, or post queries to known, familiar Email or FAQ lists. When no solutions are found, more answers are sought by extending the environment to include more experts and artefacts from other teams or environments nationally. Individuals seek solutions by moving slowly up the information chain as a result of directives such as "try this... or ask that person... or have a look at this ..." and so forth. When no answers are found nationally, this process is repeated internationally. At some point in time solutions are found through a process of coordinating an individual's internal cognition with people and resources distributed in the environment. This results in the creation of new knowledge through the process or learning and taking of action. Solutions are then internalised or reified as solutions that are applied or used in the 'centre'. This is consistent with the theory of work practices unique to Communities of Practice (Wenger, 1998). We now illustrate the application of DCT in the above breakdown situations. The resolution of breakdowns in both cases is not immediately apparent and hence workers draw on the knowledge of co-workers, use of IT and other artefacts to find effective workarounds.

Data collection: 11 open-ended, semi-structured interviews were conducted over a period of 6 months in both organisations to gain insights into ways in which individuals work, exchange knowledge and handle breakdowns. Apart from the interviews, informal discussions were held on how IT tools are used, in particular how individuals draw on IT in workaround practices to solve breakdowns. Limited observations were done merely to get an idea of the IT tools, platforms and artefacts that are used. This did not include detailed observations of work practices and workarounds during these events. Initial data collected, were analysed to identify specific themes derived from DCT (Miles and Huberman, 1984).

The knowledge exchange practices of individuals according to DCT conceptual themes are as follows (for each discussion point the role of IT is also included):

- (1) Individuals claim that the knowledge they need to solve breakdowns are not all located in the mind of an individual but are distributed across members of a social groups:

Organisation A: "... I do not have all the knowledge in my head although I am tempted to say I have... I rely on others in my team, others in the department, also other people from other departments, even faculty... I deal with others; it could be people like 'X' or 'Y'. If he is not available I can ask other staff in the office who've been in that role before and know some of the answers"

Organisation B: "... we have a pool of technical staff ... I don't know everything for an example the person that flew down to come and see me and explain what he has done - he had done things before, he has examples and documents... here everyday is a new challenge, my own experience is not adequate for these situations"

Individuals prefer to reach other people using the telephone or face-to-face conversations or meetings. However, once they know each other, or cannot get hold of people using these mechanisms, they would always rely on and use Email. Email therefore takes on a major role in linking of people to exchange knowledge and share artefacts. Individuals perceive Email as central to the network-building work practices for people both co-located and geographically spread out in other parts of the institution, nationally or internationally. The Internet and organisational intranets are also often used to find the right contact person or expert about a specific topic. Discussion and Email lists are useful to log problems and find answers to questions that are not evident immediately. These tools and artefacts become pointers to knowledgeable individuals or experts in specific topics

or areas. Hence, IT supports the process of building an individual's social network and interaction with others within the same or other teams/departments, offices nationally and internationally.

Organisation A: *".. I use the website to find people or web pages to get the right person ... if they want more detailed information that I cannot answer I pass them on to 'X'.. There are a variety of people and links to take me to the right person.. "*

Organisation B: *"... there are various Email lists in the company (nationally and internationally)... I just put in a query in a list to all offices around the world....if I need something I usually have to know someone to find it for me in another office (nationally)... if you have a good relationship with someone at another office they find it (artefact) for you... if I post a query (to an Email list) I always get a solution or pointers to right directions"*

(2) Cognitive processes involve coordination between the internal and external or material and environmental structures and is often embodied in artefacts created by others

Organisation A: *" .. I have access to the work of others ... the entire handbook is on the Web,.. I can find the right person by looking at the subject pages ... I can find the right person using the handbook for the whole institution, ... I have access to her Email and can look at how she answered queries about [topic] or I can work out what she did for other events ... there is a lot of computer based information out there you know, but I can also look at procedures that are in binders ... "*

Organisation B: *"... my project manager knows what can be re-used ... we have a meeting, communicate to peers, they say they know how to do this or that.... you just get it off the central server... we try never to reinvent the wheel but my reusing what there is...Email records absolutely everything...it's not too hard to delve into all documents associated with a specific project..."*

IT is indispensable in cognitive processes that require coordination between internal and external or material and environmental structures. Individuals can't actually do their work well without the tools and artefacts 'out there' in the environment – they use it as a basis for subsequent knowledge exchange and it often serves as their extended memory that they can revisit. They tend to use a collage of tools and artefacts, in particular IT tools that support each individual's way of working in the best way:

Organisation A: *"... I use a Mac platform, my notebook and my PC, .. if I am doing website work I prefer the Mac as it tends to be an easier interface,... if I am doing Email I use this one for Outlook ... I access a lot of policies and procedures.. we have multi user access to the one database and that's critical, its central to administration ... with Email there's a lot of information and resources that I would not have access to otherwise .. you have information that can be supplied to students and without technology I would be nuts.. I don't know everything".*

Organisation B: *"..if I don't know I just hit Google, the technical information on the web is very good...we try to re-use as much as we have done before... you cannot carry all the source code generally [in your head]...if I have no clue I just hit Email, someone would answer around the world".*

(3) Finally DCT claims that the distribution of cognitive processes may be such that over time, results of products of earlier events can transform the nature of later events –

Organisation A: *"... there's lots of info out there that I can refer to from the past years, or about what happens with this or that – I can refer to that – so I use some of these as a kind of timeline to remind me to do things... I can look up and see what happened or was done before ... and I don't have to rely on the staff so much remembering what happened in the past. That's why we document things and record stuff so we can use it as a reference for the next...".* Also the mere existence of artefacts that have been useful in the past help in individuals to re-use and/or change the work of others *".. I look at what happened in the past ... its helpful for me in that I don't need to start from scratch and then ask staff what happened last year. It saves some time because we already have it and it's a good starting point for me to use that and then I can decide of if the procedures should change for next year and then going by my experience, I can restructure that for the future".*

Organisation B: *"...stuff done 10 years ago, you find it all on CD filed under Pete's desk...history is important such as what issues there were, what actions have been taken... its important for other companies and clients to know what we are doing, keeping them in the loop and also for accountability".*

The record keeping capability provided by IT appears to be essential in breakdowns. Often recording of lines of thinking in the form of comments when making critical decisions, serve as a basis for constructing a view or history of events to support subsequent action. Also the 'history' helps new lines of thinking and grants new insights in unusual situations and subsequently often results in the creation of new knowledge.

Organisation A: *"... there is always [a] record you can go back to ... documenting things helps for the future, at least somebody else will know why I did it, ... it's all about pushing the boundaries.. we can just take the old stuff, so it's current....we can know why things have been done and who did what..."*

Organisation B: *"...I look at things produced (standard artefacts), what has been done, it helps my thinking, ...it helps for accountability.. I can track what you said I should do and this is what I did..."you can see what*

happened and some comments associated with it can be quite good - it helps to relate myself a bit better to the work..”

Analysis: Recurring themes

Table 1 lists the different kinds of conceptual themes on which the DCT is based. The initial data analysis confirms the distributed nature of cognitive processes and the notion that human workers ‘don’t know everything’ but that they rely on other workers and existing IT systems, tools and artefacts to exchange knowledge. A deeper analysis of the interview data identifies different ways in which the distributive cognitive processes are actually realised (column 2) and column 3 describes ways in which IT is harnessed in these cognitive processes. Environmental artefacts and the social networks that people construct over time are core elements in the strategies and plans people devise to solve breakdowns – hence the people-to-people link, and people-to-artefact link becomes more prominent and moves to the centre of problem solving strategies and workarounds. DCT explains how human cognition works: knowledge is not centrally located in the head of one individual but distributed as knowledge resources ‘out there’ in an individual’s ‘known’ environment and with these individuals almost always reconstructs new solutions (based on previous situations and similar problems) during breakdowns. This is based on social networking built over time and interacting with the various resources from the environment. Some interviewees were newcomers to the organisation or recent additions to work groups and they have over a short period of time managed to build their own social networks they draw and rely on. Without these and existing IT tools and artefacts of their own and others, they would not be able to cope or take immediate actions and hence exchange and create new knowledge. This implies also a learning process in which the cognition of individuals expands and they then gradually become experts based on knowledge exchange and acts of doing.

DCT highlights the importance of environmental resources and social networks in knowledge exchange scenarios as interviewees claim they would not be able to perform as expected without IT tools and artefacts. Somehow, the right actions are taken and best decisions and plans are made during workarounds using whatever and whomever they can from their environments. Artefacts take on a central role in cognitive processes during breakdowns: they evolve over time, but are also re-used across individuals in an attempt to come up with solutions in an attempt not to reinvent the wheel or re-developing new artefacts.

Type of distributed cognitive processes or Conceptual themes of DCT	Elements and practices in support of distributive of cognitive processes	IT support for Distributed Cognition processes
Distribution of Knowledge across members of a social group	<ul style="list-style-type: none"> -Each individual builds his/her own social network over time -Social networks are built by ‘who-knows-who’, ‘who-knows-what’ and ‘who-did-what’ principle -Members of social networks span organisational boundaries 	<ul style="list-style-type: none"> -The Internet and Intranet help to find/link the right people -Email is useful to contact/link to people and establish/building social networks -Email is often the preferred medium to get in touch with others locally/globally or inside/outside the organisation
Cognitive processes Involve coordination between internal and external or material and environmental structures	<ul style="list-style-type: none"> -Individually created artefacts take on a central role in knowledge exchange scenarios -Artefacts evolve over time and are reused -Collages of tools are used -Even Email as a ‘lean-medium’ has become central to knowledge exchange 	<ul style="list-style-type: none"> -Access to artefacts happens as follows: via servers, access to other individual’s Email accounts, Web interfaces, or personal Emails requests to get distributed artefacts from other servers. -Open access to central databases or other artefacts are essential -Collages of tools are used ie: the Internet, Intranets, different types of databases, server documents and templates (artefacts), heterogeneous workstations and platforms. Well-known and functional tools are preferred for knowledge work. -There is a continual switching between heterogeneous tools and artefacts to link context, events and people Archived Emails services or other archives can be accessed. Email supports multiple points of contact, enhances communication for co- and dispersed location. Revisiting Emails, archives and/or artefacts reveal lines of individuals’ thinking, reasoning and decisions taken.
Results of products from earlier events can transform the nature of later events	<ul style="list-style-type: none"> -Formerly created artefacts can be used/modified/reused towards facilitating and supporting decision-making and making of plans for new situations -Without being aware, cognition is constructed ‘on-the-spot’ to solve situational problems 	<ul style="list-style-type: none"> -Open server directories enable the searching of ‘historical’ artefacts or documents created by others -Prior experiences and decisions can be recorded and /or documented or logged -Queries and keyword searches can locate appropriate tools and artefacts that share a context (this includes both structured and unstructured data files)

Table 1: Conceptual themes of DCT and IT support for DC processes

They are central to some work practices while on the border for others and are overall supportive objects in knowledge exchange processes. Another interesting aspect is that individuals draw on a collage of IT tools in their solution to problems – they rely and (re)use tools and artefacts that they have experience with and know would work in breakdowns.

FINDINGS

The initial data analysis reveals that the notion of a DC system is apparent in ways in which individuals interact, devise plans and strategies to solve breakdowns and produce workarounds. Based on the required conceptual themes of DCT we have identified three types of knowledge exchanges required to support this theory. The first two - the people-to-people link and people-to-artefact link -both allow individuals to harness the distribution of cognitive processes. It was also found that a third type of link, namely the artefact-to-artefact link is required to support and complement the former two links in order to promote knowledge exchange. Representational media and products are in different states at certain points in time in a cognitive system, which makes this link and essential element to reconstruct or build up a history of events. This history is particularly important when plans are made for workarounds. Based on these links, a number of mismatches with respect to knowledge exchange and IT support for DC have been identified and are summarised in Table 2. This table lists the mismatches for knowledge exchange based on conceptual themes consistent from DCT namely the people-to-people link, the people-to-artefact link and finally the artefact-to-artefact link. It is clear that there are many findings from this study, many of which have been identified by other studies. Hence we have chosen to discuss only the important novel aspects revealed due to the DCT lens applied to this investigation. (These elements are marked with an * in table 2.)

The people-to-people link is essential in the exchange of knowledge. As indicated in table 2, one of the major findings in terms of IT mismatches, is that IT such as organisational websites and Intranets fail to link the right people/experts to exchange knowledge. Also, it is often quite difficult to locate experts with particular skills due to inconsistent web interfaces, not making this information publicly available or in the event of this information publicly made available, it not being maintained regularly. Hence, person-skills directories should form an integral part of IS design or work environments while interfaces to these directories should enable quick and easy access to the right person. The people-to-artefact link is just as important as the people-to-people link for knowledge exchange – present-at-hand artefacts come into focus as crucial elements in problem solving. This link also helps in identifying a number of IT mismatches to support knowledge exchange for DC during breakdowns. One of the most prevalent is the inability of an individual to locate and find useful contextual artefacts. Also, individuals are not aware of artefacts created by others they can use or reuse or which may be valuable for knowledge exchange in breakdowns. Consider in particular how useful notes or remarks of previous critical decisions may be in situations that require workarounds (that are similar to previous situations). This ‘non-awareness’ of important artefacts created by others; often result in the development or creation of duplicate work. Another problem is that various team members do not contribute equally towards the context, history and decision rationale of artefacts (Joshi, 1991). This highlights the importance of trust and the value of free contributions by individuals to promote knowledge exchange.

The third type of link namely the artefact-to-artefact link identifies mismatches due to the absence of cross-links between artefacts based on a shared context, duplication of artefacts and problems associated with free-text searching. Query-based searching is often difficult, may be time consuming and requires experienced people to define search criteria while Intranet search tools are often inadequate in yielding useful results.

Type of Knowledge Exchange required for DCT conceptual themes	IT/DCT conceptual theme mismatch
The People-to-people link	<ul style="list-style-type: none"> -Internal or external websites to find an expert or skilled person in a specific area fails as person-skills directories do not exist or are not properly maintained * -Internal or external websites are poorly designed to link people-to-people: often ‘going external’ can be more helpful in finding the right person internally * -People’s job descriptions on websites are incomplete or do not reveal real skills or expertise * -Web interfaces of different departments in the same institution are inconsistent, which results in lengthy and frustrating searches * -There are not standard way of presenting people information in one organisation* -Synchronous linking of people required in critical decision-making or during breakdowns cannot happen due to people not being physically traceable using IT

Table 2: DCT: IT mismatches for DCT knowledge exchange during breakdowns

Type of Knowledge Exchange required for DCT conceptual themes	IT/DCT conceptual theme mismatch
The People-to-artefact link	<ul style="list-style-type: none"> -Difficult to locate and search for artefacts associated with a specific context or created by specific people* -Difficult to know who has been involved in creation, use, design or tools and artefacts* -Constant navigation between heterogeneous artefacts and tools creates frustration -Non-standard naming conventions -Knowing a specific person is often the only way of getting access or being pointed to a specific artefact* -Poor organisational standards and policies with respect to organising and storing artefacts make it hard to for people to locate specific artefacts* -Imbalance between people-artefact contributions in terms of context, history and comments on critical decisions* -Unawareness of useful/important artefacts about a specific context* -The turnaround for queries on Email or discussion lists may be too long -Discussion lists based on specific content should be more specialised, they often cover -People do not all open up their work to allow others to access it* -Not all artefacts are available in one central location for others to access*.
The Artefact-to-artefact link	<ul style="list-style-type: none"> -Artefacts/tools are not linked based on a specific context and content* -Artefacts are not categorised according to a context -No standard way of organising or storing artefacts -Free text searching of and between artefacts not always successful* -Increased duplication or artefacts

Table 2: DCT: IT mismatches for DCT knowledge exchange during breakdowns (cont)

CONCLUSION

We applied DCT as a basis for knowledge exchange in organisational settings. This theory provides a useful lens for this investigation as it identifies new insights into ways in which IT can be harnessed to exchange knowledge during breakdowns. It identifies a number of mismatches in IT to support knowledge exchange for DC. These findings may have useful implications for rethinking the architecture, structure and design of IT environments, tools, systems and artefacts to support knowledge exchange in breakdowns. It suggests that from an organisational viewpoint IT should be harnessed to link the right people within teams and across teams (both within and outside organisational departments and boundaries). It also suggests that standards and policies may need to be in place to organise the way in which individuals and teams use/apply IT to create, use and organise artefacts for knowledge exchange. Even though artefacts can be reused, the rate at which collections of unstructured data grow can often not be managed in organisations resulting in cognitive overload of workers. Mechanisms to inform individuals of useful or usable content may save the duplication of work or reinvention of the wheel. Findings of this ongoing research emphasize the growing importance of IT and artefacts in the exchange and creation of new knowledge. It also suggests that current environments embedded with IT systems, tools and artefacts do not consider DCT to foster knowledge exchange in breakdowns. We further contend that IT environments can be enriched to address these problems in order to foster the externalisation and creation of new tacit knowledge.

Future research will proceed with more in-depth data collection in the form of on site observations, field notes and video clips and follow-up interviews to confirm individuals actually use IT to exchange knowledge during breakdowns. The various representational states of material and environmental artefacts will also be investigated. We intend to complement initial findings and explain how individuals make plans and find strategies to develop workarounds for breakdowns and how IT can support this. We will focus on IT mechanisms and ways in which IT can be harnessed to foster knowledge exchange for breakdowns in the areas required to link people-to-people, people-to-artefacts and artefacts-to-artefacts. We presume that ICT environments can be enriched as follows: incorporating people/job/skills directories in the design of tools and/or artefacts, enforcement of standards and policies and developing of conventions to store, locate, (re)use artefacts, incorporating and acknowledging information needs of individuals and teams based on work practices and using these to link people to usable and useful artefacts, incorporating reminder systems to notify individuals of artefact changes and applicability or importance based on usage patterns, and finally developing incentives to share and contribute to the central pool of IT resources in order to build trust for knowledge exchange. We envisage that this will foster knowledge networks and provide solutions on IT tool and artefact (re)design to support critical knowledge exchange in breakdowns.

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