People, Places and Things: Leveraging Insights from Distributed Cognition Theory to Enhance the User-Centered Design of Meteorological Information Systems

Abstract

At the same time as major constraints are being imposed on the Australian Bureau of Meteorology's (BoM) resources there are rising levels of end-user expectations about the availability, quality and delivery of weather services. These circumstances have led to an increasing workload on forecasters and recognition within the BoM of the need to re-design the information systems used to support the forecasting process. The forecast streamlining and enhancement project (FSEP) aims to guide the development, design and implementation of the next generation of these information systems. Significantly, the FSEP project has recognized that these information systems must aim to support not just the specialized skill sets of forecasters, but also the interactions between them in the forecasting process.

The need to thoroughly understand the weather forecasting process poses a major challenge for researchers due to the nature of the BoM's working environment: How can understanding of the information requirements of forecasters be acquired without interrupting the continuous work of forecasting? Compounding this research challenge is the fact that many of the most critical information requirements arise in the cognitive interactions between forecasters and because a 'key bottleneck' for weather products remains the situated, embodied and distributed nature of the interactions used to generate the forecast.

This paper explores the utility of distributed cognition (Dcog) theory as one approach to overcome these research challenges and generate insights for the design of the BoM's next generation of meteorological information systems. At the theoretical level, Dcog theory allows for the capture and validation of design insights through observing cognitive behavior viewed as a system of individuals interacting within their material environment. At the methodological level, the data collection techniques deployed allowed for the capture of the complex socio-technical nature of forecasters' information sharing without interrupting their work. This paper highlights the utility of Dcog theory in sensitizing designers to the cognitive implications of changes to information systems and/or work processes and highlights how the use of the Dcog can empower user centered design methodologies.

Keywords: distributed cognition, information systems research methods, user centered design methodologies

Introduction

The Australian Bureau of Meteorology (BoM) is a federal government funded national agency providing weather information in a range of formats to a wide range of clients. The BoM's activities take place 24 hours a day, 365 days a year with observational and forecast weather data collected and analyzed at regional offices based in the capital cities of each state and the Northern Territory.

In recent years, the BoM has faced increasing pressures due to the imposition of resource constraints concurrently with increasing customer demand for weather services. In response, the BoM has commenced the forecast streamlining and enhancement project (FSEP) in an effort to guide the development, design and implementation of the next generation of information systems for supporting meteorological staff in the forecast process. In implementing the FSEP project the BoM faced a number of challenges including how to acquire a detailed understanding of the weather forecasting process. Two aspects of this were: firstly, forecasters were frustrated by the support provided by the existing information systems, skeptical that FSEP would deliver better systems, and suspicious that the new FSEP paradigm might compromise their professionalism by automating aspects of the forecast process. Secondly, initial attempts to understand the forecast process have increased burdens on forecasters – the BoM has adopted a modified form of Extreme Programming (http://www.extremeprogramming.org/) as its software development methodology for FSEP. It enables incremental and iterative development, but relies heavily on end-user feedback, a process that has not been completely successful[1]. As a result, there was the need to generate a research approach that simultaneously retained the context of the forecasting activity, captured the processes and interactions involved but that did not add to the burden on forecasters[2] or take them away from their forecasting activities.

In this context, this paper explores the utility of distributed cognition (Dcog) theory as one approach to overcome these research challenges and generate insights for the design of the BoM's next generation of meteorological information systems. Dcog theory rejects the laboratory as the appropriate context for understanding and argues for studying cognition as it occurs in its natural setting (Hutchins, 1995a).

The key features of Dcog theory are that it uses a metaphor of cognition as computation and the unit of analysis distributes cognitive activity socially and technically across people, places and artifacts over time. Dcog views cognition as essentially cultural, and defines computation as the *propagation of representational states across representational media over time* (Hutchins, 1995a).

Data for this research was generated primarily through video observation, supplemented by ethnography drawn from the setting, including existing research from within the Bureau (Bally, 2003; Shepherd, 2002)[3] and secondary sources of information including

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[1] Gasson (2003) provides confirmation of similar problems faced by workers assisting software development done in an extreme programming environment.

[2] This paper uses the term "forecaster" to refer to meteorologically trained staff members who do the work of producing forecasts.

[3] These techniques minimised the need to disrupt forecasters by interviewing. The interview data from (Shepherd, 2002) was used as part of the process of grounding the analysis of the video observations.

the *Annual Report* (Bureau of Meteorology, 2002). A range of analytical techniques were applied to the data to uncover multiple perspectives and explanations on the variety of interactions that occurred in the forecasting process. This paper highlights the utility of Dcog theory in sensitizing designers to the cognitive implications of changes to information systems and/or work processes and highlights how the use of the Dcog can empower user centered design methodologies.

Contribution

This research aims to contribute design insights to enhance the user-centered focus of new meteorological information systems developed by the Australian Bureau of Meteorology (BoM) to support forecast work. To acquire these insights the research developed tools and techniques based on the principles of distributed cognition (Dcog) theory developed by Hutchins (1995a). This approach highlights that understanding users requirements for their information system involves recognizing that these requirements arise through the cognitive behavior of a system of individuals interacting with their material environment. Dcog opens the way to capture the complex socio-technical nature of forecasters' information sharing behaviors. Having captured this complexity the research explores how it might be translated into practical design insights and considers the theoretical implications of deploying Dcog to empower user-centered design. Significantly, the case study highlights how using the approach enabled the researchers to capture these design insights without needing to interrupt or burden the forecasters during their work at the BoM.

This paper makes three main contributions to IS research. First, it is a structured application of Dcog theory that develops a cognitive ethnography of a new research domain: meteorological forecasting. Second, it illustrates an adaptation of the theory by leveraging data from prior research activity in the domain and simultaneously minimizes burdening participants while strengthening the data analysis. Third, the paper demonstrates that although facility with Dcog is initially difficult to acquire, the approach has considerable merit in dealing with dynamic environments that include complex interactions between people, their workspace and the artifacts (technologies) they use.

It is anticipated that this paper will be of interest to IS academics and practitioners engaged in the task of understanding complex work environments and/or engaged in informing information systems design. More specifically, it will be of interest to researchers interested in capturing and validating the complex interactions and interrelationships between different aspects of a work environment, and in considering the consequences of changes in that environment (including work practices and technologies) across people, places and things.

Theoretical Background

Halverson (2002) lists activity theory, conversation analysis, coordination theory, distributed cognition theory, ethnomethodology, grounded theory, situated action and social/symbolic interactionism as some of the theoretical and methodological tools available to conduct research to generate insights to support the design of information systems. While other approaches including participatory design (Greenbaum, 1993) and user-centered design (Vredenburg, Isensee, & Righi, 2002) can be added, all approaches recognize the challenges involved in exploring human computer interactions (HCI). These challenges compound when the interactions extend beyond the individual to include groups.

In this context, Dcog theory has previously shown promise as a theoretical framework that can accommodate a research focus that addresses both computer-supported cooperative work (Rogers & Ellis, 1994), and the design of systems to support organizational memory (M.S. Ackerman & Halverson, 1998; M. S. Ackerman & Halverson, 2000). Dcog theory has also been proposed as a theoretical framework for HCI (Halverson, 1994; Hollan, Hutchins, & Kirsh, 2000)[4]. In essence, Dcog allows for the capture of design principles from observing cognitive behavior as a system of individuals interacting within their material environment, rather than by attempting to identify and formalize individual mental processes.

Dcog theory was first developed during the 1980s and presented in Hutchins' book, *Cognition in the Wild* (1995a). Dcog theory argues that human cognition can best be understood by considering it as a socio-cultural-technical phenomenon and that as such the meaningful components of cognitive activity cannot be limited to mental representations, but must include culture, social structures, people and tools. It rejects the approach of classical cognitive science which studies "the internal mental environment largely separated from the external world" (Hutchins, 1995a: 371). Dcog theory answers questions on how people acquire knowledge, and how the environment contributes to people's knowing something. Individual cognition is thus a part of a dynamic process and

[4] The link between Dcog and HCI has been examined in the resources model developed by (Wright, Fields, & Harrison, 2000), and in Walenstein's analytic *RODS* framework (2002). However, these extensions of Dcog (Perry, 1999; Walenstein, 2002; Wright et al., 2000) were not applied in the research reported in this paper.

situated in a socio-technical world. Supporters of Dcog theory also claim that its situation-specific unit of analysis provides flexibility and allows the construction of multiple representations of a functioning system (Halverson, 2002; Hutchins & Palen, 1998). Dcog research relies on ethnography to guide the collection and analysis of data (Hutchins & Klausen, 1996). In doing so, Dcog theory recognizes the importance of ethnography in systems design (Halverson, 2002; Rogers & Ellis, 1994) for revealing subtle features of collaborative activity (Halverson, 2002; Hutchins, 2003; Hutchins & Palen, 1998; Rogers & Ellis, 1994). By focusing on the information-processing element of activity (Perry, 1999; Rogers & Ellis, 1994) Dcog theory provides the analyst with tools to describe the details of a work environment in terms of processes and interactions at a level suitable for informing design (Halverson, 2002; Wales, O'Neill, & Mirmalek, 2002).

Dcog theory draws ideas, tools and techniques from a variety of sources of ethnographic theory and practice (Agar, 1986; D'Andrade, 1987, 1995; Geertz, 1988; Goodwin, 1994; Latour, 1986; Lave, 1988; Leigh Star, 1996, 1995). Ethnographic data collection methods include video observation, field notes, and interviews (Halverson, 1994, 2002; Holder, 1999; Hutchins, 1995a, 1995b; Hutchins & Klausen, 1996; Wales et al., 2002). However, support for Dcog theory is qualified by the difficulty of learning the approach and the time required for data analysis (Halverson, 2002; Rogers, 1997). The descriptive power also has to be balanced against the loss of rhetorical power because of the lack of named constructs (Halverson, 2002). Significantly, Dcog theory has recently been applied in the analysis of representational activity for understanding possibilities for using technologies to adapt a business to the on-line environment (Flor & Maglio, 2004) and considered in conjunction with a Human Centered Computing (HCC) design paradigm to develop a methodology for HCC systems for electronic medical records (Zhang, Patel, Johnson, & Smith, 2002). However, concerns remain over how these types of design insights are translated into the information systems built. As will be examined later in this paper, there is a concern that a fundamentally techno-centric orientation remains that fails to fully leverage Dcog to empower human centered design methodologies (Gasson, 2003).

Dcog Theory and Research at the Bureau of Meteorology (BoM)

In the dynamic context of the BoM forecasting process, Dcog theory appeared to offer an approach that could accommodate capturing the information interactions between forecasters, and deliberately not interrupting their work activity. Meteorological forecast work has several characteristics in common with other domains in which research successfully used Dcog theory, for example strong organizational processes, multiple workers working independently and together, and high use of information systems and other artifacts.

Before adapting Dcog theory for research at the BoM it was important to examine the considerable body of existing research conducted at the BoM into the forecast process. It informed this research of the current understanding of the forecast process and pointed to gaps in understanding that needed addressing.

A study identifying information flows had produced over four hundred diagrams of the weather forecast process (Bally, 2003). These diagrams were useful but failed to model the subjective and interactive elements of forecasting, including the tacit and implicit knowledge brought to bear in forecast decisions and the dynamic distribution of forecast decisions across people and artifacts. Of these diagrams, the informational perspective of the forecast process (represented in Figure 1) highlighted the existence of representations held internally in forecasters' memories or mental schemas. Therefore, staff members within the BoM's Forecast Streamlining and Enhancement Project (FSEP) recognized that for any meteorological information systems to be effective, the designers would need to have a better understanding of the processes by which those internal representations interact with the environment to produce forecast decisions.

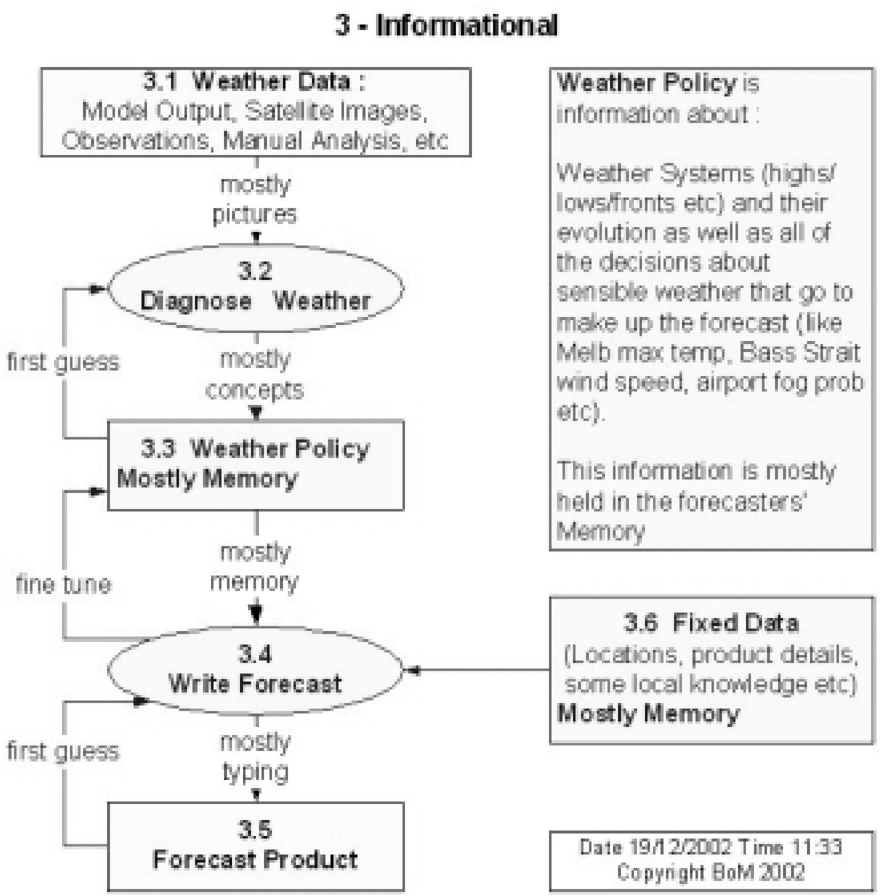

Figure 1: Forecast Informational Flows Analysis: Informational Perspective (Bally, 2003)

Parallel research into the forecasting process from a knowledge management perspective (Linger & Burstein, 2001; Shepherd, 2002; Stern, 2003) contributed to an understanding of the subjective aspects of the BoM forecast process. This additional research also revealed significant gaps in understanding the forecast process, including how forecasters collaborate to use the resources in their environment to access, transform and propagate the diverse representations of the weather situation in order to create a weather forecast product. To develop such understanding this present research adapted Dcog theory and conceptualized the forecasting process as a distributed cognitive activity in a dynamic socio-technical environment[5].

Methodology and Data Collection Techniques

The BoM fully supported this research and the organization appointed two staff members to support and liaise with the researchers: one from the Bureau of Meteorology Research Center (BMRC) and one from the Hobart Regional Forecast Office (RFC) where the research was conducted. Researchers attended the in-house FSEP conference and provided with copies of the forecast process diagrams developed by Bally at the BMRC. The FSEP conference provided the researchers with an overview of the resource problems facing the BoM in providing adequate information systems resources to their forecasters and considerable insights into the organizational, political and cultural issues entwined with the technical and human resource issues.

The research used ethnographic techniques to identify and analyze multiple interactions between forecasters, their information systems and other artifacts in the work environment, and how these interactions affected the forecast process.

The data collection was conducted in two phases: familiarization and video-analysis. In the familiarization phase extensive field notes were collected including detailed lists of

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[5] See (Gasson, 2004) for an illuminating presentation of a framework of analytical perspectives on socially situated cognition research in Information Systems, which includes Dcog as one theoretical lens.

artifacts in the work environment (and analysis of their cognitive consequences), records of informal conversations and diagrams of the forecast area layout. Sample charts and forecast products were also collected[6]. Based on this phase of the data collection, diagrams of the forecast area and interactions within it were developed, and screen shots of the applications used during the creation of a forecast were printed. Secondary sources including the BoM website (http://www.bom.gov.au/), the *Annual Report* (Bureau of Meteorology, 2002) and notes from the FSEP conference were also utilized. The familiarization phase enabled the generation of insight into the weather forecast process and its problems and guided more focused data generation and analysis. This phase also provided the researchers with knowledge of the terminology used by forecasters and their workflows. It informed the approach used for video observation and associated field note observations, and formed the foundation for the decision to video an entire forecast shift (approximately six hours) and to use that experience as a basis for choosing the primary constructs for analysis and the particular segment of the forecast for closer analysis. The familiarization phase also proved important in familiarizing the forecasters with the presence and the purpose of the researchers.

Before videoing the forecast, a structured field notes sheet (Figure 2) was developed to record actions by forecasters including time, comments on what was occurring, which software application was actively being utilized, other applications ready for use, and any

[6] To avoid interrupting the work of forecasters these charts and forecast products were often retrieved from the recycling bin at the end of the shift. The manner in which they were amended, scribbled on etc. provided evidence of the cognitive work occurring between forecasters.

other artifacts used. This allowed a more systematic and efficient notes recording, which meant the notes were very detailed and useful later in the analysis.

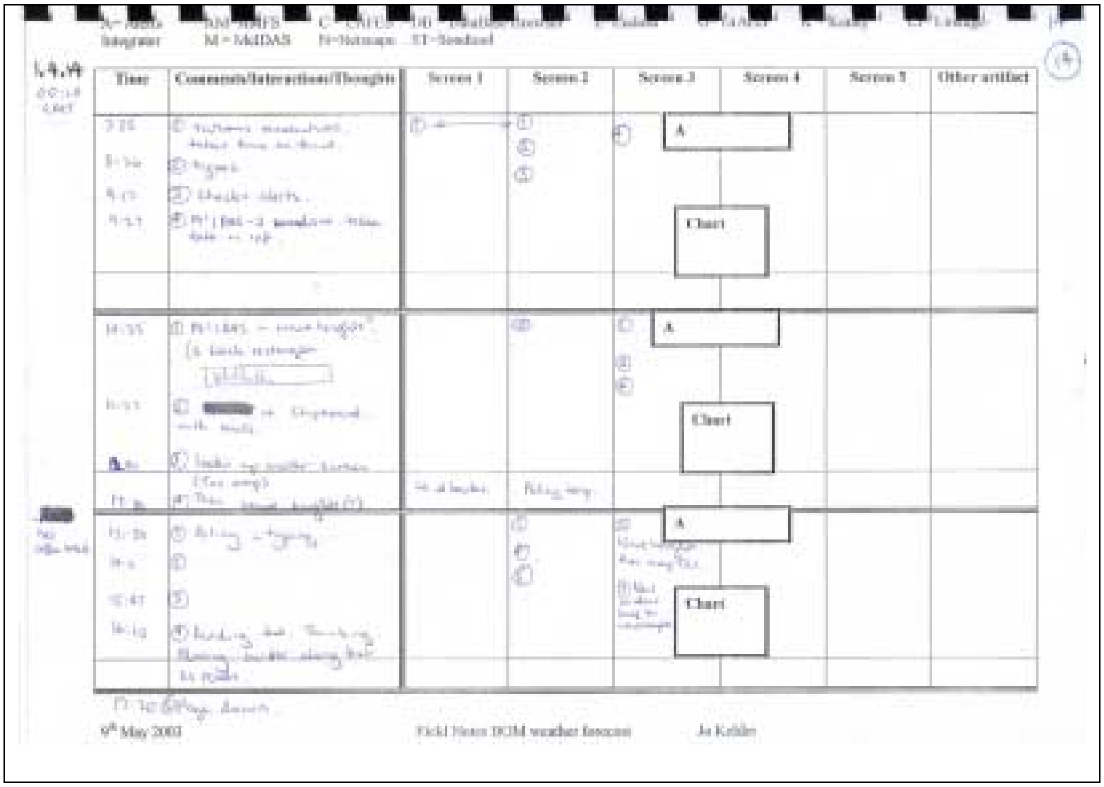

Figure 2: SampleVideo Notes Field Sheet, made anonymous

The second phase of the data collection involved videoing an entire forecast shift and supplementing that data with detailed notes of each new interaction between forecasters with each other or with the information systems and/or other artifacts in the work environment. Two weather forecast shifts were videoed and from these, one segment (the handover activity, 33 minutes duration) selected for detailed analysis (see Figure 3).

Figure 3: Handing over the forecast

The handover activity emerged as a critical part of the forecast shift structure. During handover, the outgoing senior forecaster must communicate and explain the forecast policy he has developed to the next senior forecaster and the technical officer (whose role is to answer telephone queries from the public). The handover is thus rich in interactions between individual actors and the artifacts they use. It involves a summary both of the previous shifts' forecast and of the forecast process and is the mandated occasion in the forecast shift where reasons for decisions are given. This process provided the researchers with access to data from which to elicit forecasters' mental models and schemas, and provided examples of socially distributed cognition that involved coordination with material resources in the environment such as charts and representations on computer screens. Table 1 summarizes the techniques and analytic focus for the two phases of the research[7].

Following (Hutchins & Klausen, 1996) the research analysis used multiple sources of data and presented and represented that data from different perspectives. The different data collection techniques allowed the researchers to vary the analytical focus and generate different data representations. These allowed the identification of interactions and processes that occurred during the forecast activity, cognitive properties of forecasting as a system, implicit schemas and cultural models used by forecasters to coordinate their actions. Integrating these results formed the basis for creating a detailed

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[7] Adapted from (Hutchins, 2001).

account of the handover process, and then generating twelve insights on the domain of the production of a weather forecast.

Table 1: Techniques and Tools for Data Collection and Analysis

	TECHNIQUES	ANALYTIC FOCUS	IDENTIFY	CONSTRUCTS
Familiarization	Field notes	Representational states and processes	Interactions	Artifacts
	List of Artifacts	Cognitive impact of artifacts in use	Cognitive consequences	
	Cognitive diary and task description	Cognitive texture of the forecaster's work	Knowledge types and computational tasks in use	
	Field notes, sample charts, sample weather products, photos	Social and material environment and evidence of cognitive activities.	Information use (how)	
Video Analysis	Videotape analysis • Transcript • Coding • Description • Insights	Social and material environment and evidence of cognitive activities. More systematic study of interaction of users with workplace technology and tools and with each other. Analyze behavior	Map behavior to theoretical concepts in the literature • Distributed cognition • Situated cognition • Inscriptions • Schemas and cultural models • Professional vision	Unit of analysis (socio-cultural-technical) Cognition as cultural process
	Email based questionnaire	Evidence for cultural models. Clarification, and explanation and insight into mental models	Cognitive properties. Cultural model/social structures	
	Shepherd (2002) transcripts	Evidence for cultural models	How information is used	

Analysis and Insights

Dcog theoretical principles guided and informed data collection and analysis, and the two were conducted iteratively. In particular, analysis of the familiarization-phase data collection informed data collection for the video analysis phase, and provided grounding for interpretation of the video transcript.

Initial analysis confirmed that weather forecasting is the result of a social process of constructing meaning about atmospheric phenomenon. A vast amount of data representing aspects of the inherently chaotic atmospheric conditions arrives in multiple forms and at different times. The forecasters' task is to interact with the data to produce a sensible prediction for the immediate and medium-term future. The primary challenge for forecasters is to manage the inherent unpredictability of not just the weather situation, but also of client responses to the forecasts they produce, and the variability of predictions given by various numerical data guidance models they use to support their conclusions.

From this initial analysis and drawing on Dcog theory, it was possible to identify three core constructs that highlighted aspects of the forecasting domain that required understanding for effective information systems design. These were: the socio-cultural-technical aspects unit of analysis; the use of artifacts to mediate cognition; the interpretation of cognition as a cultural phenomenon (See Table 1).

Using these three constructs, the second phase of analysis examined and analyzed the video data from four perspectives.

First Perspective

The first perspective focused on the setting of the research. It demonstrated the dialectical relationship between the setting and the forecast activity and the forecast area as situational territory (Suchman, 1996). The combination of constantly changing forecasters performing essentially the same, repeated cognitive task corresponds to Hutchins' (1995a) insight that there is a causal relationship between the real world situation and the inscriptions created by professionals. The production of a forecast depends on the willingness of individual forecasters to constrain their behavior to fit in with that of other forecasters, the constraints created by the nature of the technologies they use to represent different stages of the forecast, and the sequential constraints of the procedures they must follow. These constraints specify the social organization of the forecast process so that coordination is possible.

Second Perspective

The second perspective used coded transcripts of the videoed handover and investigated the inter-relationships between speech, gesture and movement in constructing meaningful communication between forecasters (Goodwin, 1994; Hutchins & Palen, 1998). A cognitive strategy of 'defensive pessimism' emerged as a deeply entrenched cultural phenomenon[8]. Conservative forecasts are a necessary strategy to prevent unnecessary loss of life or property that occurs if low probability severe weather events develop without forecast warnings sent out. Forecasters' communicative practices mirrored Lave's (1988) findings that there is a difference between everyday practice and what is considered *scientific* practice of knowledge. Forecasters surpassed solely rational scientific approaches to forecasting (with logical reasoning processes based on meteorological science) by incorporating pattern recognition, imagination and other non-

[8] The construct defensive pessimism has been contrasted with the concept of strategic optimism in the psychology arena. For further discussion see (Noram, 2001).

rational, non-computational strategies to judge expected weather outcomes. These strategies incorporated a highly subjective assessment of acceptable risk to clients if the forecast failed to predict a severe weather event. It was evident that a good forecast needed to take into account social, political and technical factors, and the inherently chaotic and unpredictable character of the weather.

Third Perspective

The third perspective focused on the evidence of forecasters' goals and expectations, the role of memory in forecasters' discussions and actor/artifact interactions in the work environment. It identified internal representations (schemas) for various aspects of the forecast process, enabling inter-subjective understanding so that forecasters could coordinate and discuss issues effectively. It also noted the use of artifacts to prompt memory, and artifacts that embodied some culturally developed understanding so that forecasters could make a perceptual judgment rather than perform a computation.

Fourth Perspective

The fourth perspective interpreted the observed behavior of forecasters, including all the elements in the setting (actors, artifacts and cultural factors). The handover was analyzed as a culturally constituted activity. This included social and organizational structures, the language, gestures and tools used for communication and tools constructed to aid memory and transform tasks. Some of these structures are internalized in the knowledge, skills and understanding of the forecasters (for example routines, remembered experience, scientific understanding of meteorology), while others are external (the Mean Sea Level pressure charts, printouts of forecasts based on a template and graphical and tabular presentations of the weather data).

These four different analyses of the data produced different varieties of information about the handover activity and formed the foundation for a theoretical account of the forecast process. Combining the three core concepts (cognition as cultural, socio-cultural-technical unit of analysis and artifacts mediating cognition), and the four analytical perspectives described above enabled a rich description of the weather forecasting in terms of the relationships between these different elements and the social processes these relationships enabled. This enabled generating twelve key insights relevant to achieving effective coordination of forecasters, existing information systems and other artifacts in the work environment. Table 2 is a summary of the twelve insights that emerged from the research. The next section explores how these rich design insights can be applied at a practical level for informing the design of new meteorological information systems.

Table 2: Twelve insights for meteorological information systems design

INSIGHT	DESCRIPTION
Forecasting is a distributed cognitive activity	Social, technical, cultural and organizational factors are critical for successful cognition and effect the quality of the forecast product. The culture of defensive pessimism that produces conservative forecasts is an integral part of forecasters' pride in their work and sense of responsibility to the public. Less conservative decisions will come from more reliable numerical weather prediction (NWP) guidance models and decision support. Shared context allows coordination and thus the creation, propagation and transformation of the weather forecast from shift to shift.
Forecasting is an embodied cognitive activity	The spatial layout and organization of artifacts, and the gestures used by forecasters as they speak coordinate to create multiple, interrelated representations of the current weather and relevant trends.
Forecasting is situated	Forecasting occurs in a shared workspace with local configurations that are constrained by stabilizing factors such as procedures and routines, technology available and the physical features of the workspace (Suchman, 1996). Individual forecasters share attitudes, values procedures and behaviors which allows the

INSIGHT	DESCRIPTION
	forecast process to proceed seamlessly as each worker temporarily occupies a position and reproduces the procedure. Individual differences are constrained by organizational culture and technology configurations, but each forecaster uploads, organizes and uses the data sources and software applications according to his/her preferences.
Forecasters are processors of symbolic structures	Forecasters' wisdom and judgment is central to the forecast process of selecting and processing weather information represented both internally and externally, and propagated via various media. Inter-forecaster discussion on the weather forecast consists largely of demonstrating the validity of reasoning behind a forecast judgment. Forecasters use scenario building and modus ponens reasoning to develop and defend their forecast judgments.
Forecasters are communicators	Forecasters work in a cultural web with social, political and organizational features. Communication language and content is adapted to the recipient (fellow staff or public client). Communication pathways are either direct (face-to-face or mediated via the phone, radio) or indirect (automatically generated weather forecasts delivered by fax or the Internet).
Artifacts are used as a communicative resource	Forecasters use artifacts as a resource to illustrate a point, or demonstrate the reasoning underlying a judgment. Forecasters use artifacts extensively in joint reasoning activities to anchor discussion to a particular instance and provide shared understanding of the context.
Artifacts are used as a memory aid	Artifacts can reduce the cognitive load on forecasters during communication or private cognition. They provide a sequential, temporal representation of weather features to represent a trend and support recovery of interrupted thought processes.
Artifact design has cognitive consequences	The forecast process involves assimilating a vast amount of data. Artifacts can transform a task from computational to perceptual, support reasoning processes and thus reduce the cognitive load on forecasters (Norman, 1993). Processed representations of data and artifacts that allow flexible data manipulation and display aid interpretation of data's significance. Information needs to be available at different levels of processing so that forecasters can choose the basis of their decisions (computational activity or perceptual judgment).

INSIGHT	DESCRIPTION
	Artifacts that enable shifting between seeing the representation and the thing that is represented (Hutchins & Palen, 1998) and embodied activity such as pointing allow more flexible interactions in discussion.
Information Access affects Communication	The layout of the forecast area and the physical size of artifacts that visually display weather representations affects inter-forecaster discussion and information sharing.
Information Redundancy affects communication	The proximity of forecasters to each other allows communication and overhearing of conversations. This provides a checking mechanism for interpretation of the weather and ad hoc sources of information.
Handover is a mediating structure	Handover is a culturally designed activity to coordinate people and artifacts to allow effective knowledge transfer from one forecast shift to the next. Handover is primarily a communicative activity and requires support in describing, showing and reasoning about the weather. Handover is supported by pre-computed solutions that require perceptual cognition (recognizing patterns from graphical representations) and information packaged for easy access and assimilation.
Procedures and routines are mediating structures	The procedures and routines constrain the forecasting activity, however interruptions are a given, and the routines need to allow for actor reconfiguration and task adaptation.

Translating Dcog Insights for application to Systems design

The practical applicability of Dcog to information systems design is not straightforward (Hollan et al., 2000; Rogers & Ellis, 1994). In the first instance, Dcog analysis provides indications of aspects of the cognitive environment such as particular work practices, information systems, and features of the workplace layout that hinder or facilitate the activity and these indications can be used as a foundation for more targeted, experimental research (Hollan et al., 2000). Developing a procedure for effectively translating these insights into functional specifications was initially outside the scope of the research. However, subsequent to the data collection and analysis, on-going interactions with the BoM revealed how insights generated by the research were used in design for the FSEP information systems and opened up a discussion on how this translation process could be formalized to empower user centered design methodologies.

From an IS design perspective, the need for further work in this area is evidenced not just by the history of IS design failures (where overly techno-centric design methodologies have often produced systems that do not meet organizations' and users' needs), but also by a recognition that even user centered design methodologies often end up falling into the same techno-centric design trap (Gasson, 2003). In this sense, techno-centrism can be viewed as a paradigm that focuses on the technological artifact and prioritizes it over system processes, information and goals. Decisions within the paradigm appear rational to the technology-oriented person (usually the systems developer) but marginalize consideration of other system elements. In this case, social aspects of work processes are ignored or simplified and technology elements made more complex. This process itself is also partly linked to business/career imperatives that encourage and/or reward designers for feature and functional complexity in technology design whether users require this complexity or not.

In response, user centered design methodologies have aimed to prevent systems design project failure by placing users at the center of the design process. A focus on the individual to ameliorate the tendency towards techno-centrism in design is achieved variously by introducing multi-disciplinary design teams. However, given that even in these multi-disciplinary teams there are individuals with a propensity to prioritize technology artifacts over information processes, it is perhaps not surprising that the result is that these user centered design methodologies end up focusing merely on usability issues rather than being truly human-centered (Gasson, 2003). In the case of the BoM this effect was evident in their use of the user-centered methodology Extreme Programming that has been criticized[9] because difficulties in communicating between systems developers and forecasters lead both groups to put their energies into addressing the easier problems of usability thereby failing to be truly user centered.

Gasson (2003) attributes the focus on usability at the expense of defining the organizational possibilities and constraints of a system, to the power of technologically oriented members of design teams subverting and over-ruling the social and work goals of users, and the fact that design problems are formulated as technology problems with a technological solution. Gasson's proposal for reorienting systems design towards the individuals using them does reduce the technological bias of systems design, but does not address or capture the dynamic, complex socio-cultural aspects of organizational work environments. Zhang et al. (2002) share Gasson's concerns and use Dcog in conjunction with Human Centered Computing (HCC) to address this aspect, however, it appears that by adopting a focus on hierarchies and technological solutions the ability to incorporate these work environment insights is severely constrained.

The research conducted at the BoM was a cognitive ethnography fitting into the framework of theory, cognitive ethnography and experiment suggested in Hollan, Hutchins and Kirsh (2000). It produced rich descriptive insights into the nature of the forecast work environment. Significantly, some of these insights were used by a BoM research staff members participating in the FSEP discussion to buttress arguments for particular functionality in the proposed new system (Bally, 2003) and in related systems

[9] Personal Communication. (anon., 2003).

including the Mandala knowledge management research project (Linger & Aarons, 2004, submitted).

This research also had a direct impact on the forecasters as evidenced by their reactions to a presentation of the research findings and acknowledgement that the Dcog perspective had produced a recognizable and insightful description of the way they went about their forecasting tasks and interacted with the work environment, technology and fellow forecasters[10].

This stated, it is evident that simply acquiring a richer understanding of how forecasters utilize their tools and environment in doing forecast work is not sufficient to have a sustained impact on the future design of meteorological information systems. Dcog produces insights into the dynamic and distributed nature of the cognitive work environment under observation. These insights provide a complex and rich picture that has implications for information systems design. However, this complexity and richness in turn generate two questions. *How do we translate these insights into functional specifications?* and, *can we avoid the techno-centric trap during the translation process?*

While aspects of both of these questions have been discussed above, it is clear that a number of additional issues require consideration to move towards an effective set of answers. Of course, for some uses of Dcog these questions may appear less important, for example, when Dcog is used as a tool to identify representational activity in order to identify technological implementations for a business (Flor & Maglio, 2004) the insights obtained are easily translated into computational technologies. The conceptualization of

[10] A concrete expression of this recognition was an offer to send the researcher interstate to communicate the results to “Head Office”.

the problem is technological, and the resolution consists of recommendations for a computational system. This may be sufficient in relatively simple work domains, such as a chain of hair salons (Flor & Maglio, 2004). However, for more complex and dynamic environments, such as weather forecasting or hospitals, focusing only on the representational transformations created in the course of work tasks is not sufficient[11]. In the context of the research presented in this paper, the BoM had already recognized that many of the aspects of forecast work were not amenable to formal representation including internal mental processes using judgment and wisdom, cultural and social understandings and expectations. Consequently, Dcog analysis was used not to simply trace the computational aspects of forecasting but rather to focus on the cultural aspects of the forecasting cognitive system. This analysis produced a rich and complex understanding of technological and non-technological aspects (the people and the place) of forecasting.

Dcog alerts the researcher to the fact that people use their environment to help them think. The environment contains people, the physical space, the cultural understandings and things (technologies to aid cognition), each of which reciprocally acts upon and are acted on by the other elements. This sensitizes the researcher to be aware of the ecology of the workspace and its wider environment and to seek to understand and faithfully describe it. This in turn helps to consider the consequences of changes in the environment

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[11] Flor and Maglio (2004) point out that the task domain and research interests of different Dcog analyses affects the final form of the model of a system's representational activity. Flor (Personal Communication, April 2004) has pointed out that "according to Hutchins there is no single distributed cognition method. DCog researchers can use any method that sheds light on cognition as a distributed phenomenon".

by illustrating the nature of the interrelatedness of the people, place and things connected to cognitive activities. In addition, Dcog provides a framework for considering possibilities of interrelationships between different aspects of the environment (people, physical space, things, work practices). This generates sensitivity to the conscious and sub-conscious uses actors make of their environment to fulfill their cognitive needs. In particular, changes to the physical/technical environment will have direct and second order effects on individual and group cognition. These effects may militate against goals and objectives of physical or technological changes by transforming the landscape into which a new system solution is placed. Critically, this is because people are adaptable and often use technologies in ways unintended by the original design. Often these unintended uses are of considerable value to users but are rarely captured as part of any new design process and are lost when a new solution is implemented

We have considered Gasson's (2003) dual-cycle model of Human-Centered Design which separates *system inquiry* from *system implementation*. The *system inquiry* half of the Gasson model is used to "open up" and to define organizational problems, and creates inter-subjectivity between the representative stakeholders that allows the *implementation* stage of the model (for technical or organizational change) to proceed according to well-established IS design methods. Gasson's methodology focuses on humans, and ameliorates the human centered bias towards technology rather than human-centered solutions. However, it relies upon the ability of representative stakeholders to articulate the complex (often tacit or implicit) socio-cultural aspects of their work environment, and the distributed nature of work processes and tasks. This suggests that there would be benefit in combining Dcog and user-centered (or human centered) design methodologies such as articulated in (Gasson, 2003) with the explicit aim of avoiding the technology trap and developing an approach that can capture the richness and complexity of social factors for IS design.

From a theoretical perspective, this combined approach suggests a reconceptualization of user centered design methodologies by re-positioning the place of the user. In essence, it is proposed that this combined approach simultaneously emphasizes the individual whilst acknowledging that significance of their cognitive interactions with people, places and things (technological and non-technological artifacts). This combined approach then orientates the *system inquiry* phase of user centered design methodologies to consider the people, place and things (PPT) elements. As a result, Dcog acts as a kind of prism to show that all three have potentiality for agency, and the scales of relative influence thereby assist the approach to avoid the techno-centric trap and remain truly user centered. Dcog does this by acknowledging the agency of technology to potentially bias systems design (Gasson, (2003), and by highlighting that individuals within the design team will have different perspectives that will influence the impact of this technology agency. This approach can then consider the impact of these interactions within and between the PPT elements and their design implications, thereby assisting in empowering the user centered design focus.

Conclusion

This paper has reported on research that has examined the utility of distributed cognition theory as an approach for analyzing the complex activity of weather forecasting amongst forecasters. The Dcog approach enabled the researchers to generate detailed insights with minimal disruption to the forecast process itself or the work of busy forecasters. This research has validated Dcog at both the theoretical and methodological levels as an approach suitable for sensitizing designers of the need to be aware of the cognitive implications of changes to information systems and/or work processes.

As an over-arching framework (Hollan et al., 2000), combined with user centered design methodologies, Dcog emerges as a useful approach to ensure a true user focus for design outputs. The previous section detailed some of the practical applications for IS design that emerged from the first attempt to use Dcog theory to investigate and understand the complexity of the weather forecasting domain. There is still however, a need for further research into the inter-relationships between the detailed insights generated and how these can best be translated into design principles to assist designers at a practical level with the development of new systems (Walenstein, 2002). On-going research by the authors of this paper is focusing explicitly on this problem in the broader context of the BoM's FSEP project.

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