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PEOPLE, PLACES AND THINGS: LEVERAGING INSIGHTS FROM DISTRIBUTED COGNITION THEORY TO ENHANCE THE USER-CENTERED DESIGN OF METEOROLOGICAL INFORMATION SYSTEMS

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ABSTRACT

There are many challenges in developing information systems to support information intensive collaborative work such as weather forecasting. The Australian Bureau of Meteorology has instituted the forecast streamlining and enhancement project (FSEP) for its next generation of meteorological information systems (MetIS) and significantly, has recognized the critical importance of grounding new MetIS in a thorough understanding of the weather forecasting process. This poses a major challenge for researchers due to the forecasters' very busy 24/7 deadline-driven working environment and from the fact that critical information requirements arise from the situated, embodied and distributed nature of cognitive interactions between forecasters.

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 Bureau's next generation of MetIS. 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 captures the complex socio-technical nature of forecasters' information sharing without interrupting their work. This paper highlights the

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utility of Dcog theory in sensitizing designers to the cognitive implications of changes to information systems and/or work processes and how the use of Dcog can empower user centered design methodologies.

INTRODUCTION

The Australian Bureau of Meteorology is a federal government funded national agency providing weather information in a range of formats to a wide range of clients. The Bureau'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 Bureau has faced increasing pressures due to the imposition of resource constraints concurrently with increasing customer demand for weather services. In response, the Bureau 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 (forecasters) in the forecast process. In implementing the FSEP project the Bureau 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 Bureau has adopted a modified form of extreme

CONTRIBUTION

This paper presents a cognitive ethnography of weather forecast work using meteorological information systems. It is an example of the kind of IS design insights that can be generated using tools and techniques based on the principles of distributed cognition (Dcog) theory developed by Hutchins (1995a). Significantly, the ethnography highlights how using Dcog theory enabled us to capture these design insights without needing to interrupt or burden the forecasters during their work.

A list of insights does not translate easily to functional design specifications. In this paper, we explore a role for Dcog theory and the insights it generates and consider the theoretical implications of deploying Dcog to empower user-centered design.

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 minimizing the burden on 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 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 from a human centered perspective.

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. This has not been completely successful, and exhibited similar problems outlined by Gasson (2003).

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 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 Bureau'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 our 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). The interview data from (Shepherd, 2002) minimized the need to disrupt forecasters and was used as part of the process of grounding the analysis of the video observation. Secondary sources of information included the *Annual Report* (Bureau of Meteorology, 2002) and other Bureau documents.

We applied a range of analytical techniques 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 Dcog can empower user centered design methodologies.

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 (Ackerman & Halverson, 1998, 2000). Dcog theory has also been proposed as a theoretical framework for HCI (Halverson, 1994; Hollan, Hutchins, & Kirsh, 2000). 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). Extensions of Dcog (Perry, 1999; Walenstein, 2002; Wright, Fields, & Harrison, 2000) were not applied to our research, but are examples of how Dcog can be used as a framework that leads to practical design decisions and reification of good design moves (Walenstein, 2002).

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 knowing something. Individual cognition is thus a part of a dynamic process and 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). 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 (D'Andrade, 1995; Goodwin, 1994; Latour, 1986; Lave, 1988). Ethnographic data collection methods include video observation, field notes, and interviews (Halverson, 1994, 2002; Holder, 1999; Hutchins, 1995a, 1995b; Hutchins & Klausen, 1996; Wales, O'Neill, & Mirmalek, 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

In the dynamic context of the Bureau 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, including 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 Bureau, it was important to examine the considerable body of existing research conducted at the Bureau into the forecast process to establish the current understanding of the forecast process and expose 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

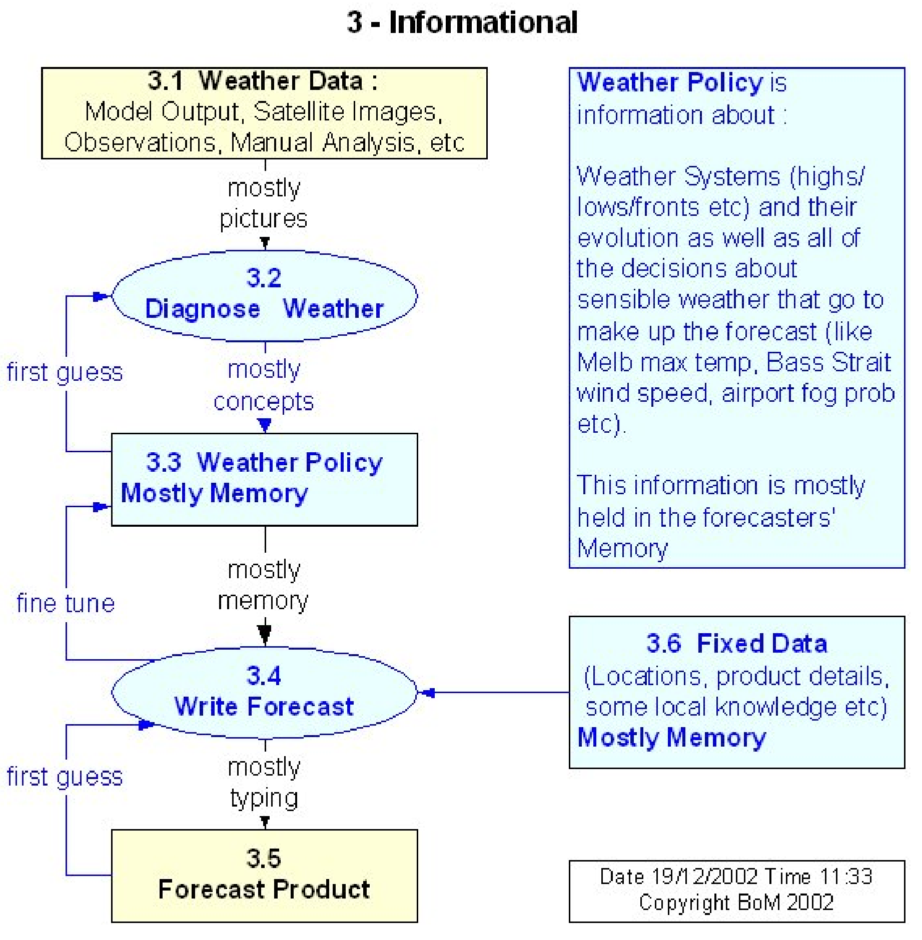

Figure 1. Forecast Informational Flows Analysis: Informational Perspective (Bally, 2003)

forecast decisions across people and artifacts. Of these diagrams, the informational perspective of the forecast process (Figure 1) highlighted the existence of representations held internally in forecasters' memories or mental schemas. Therefore, staff members within the Bureau's Forecast Streamlining and Enhancement Project (FSEP) recognized that for any MetIS 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.

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 Bureau 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 we adapted Dcog theory and conceptualized the forecasting process as a distributed cognitive activity in a dynamic socio-technical environment (Gasson, 2004).

Methodology: Data Collection and Analysis

The Bureau fully supported our research and the organization appointed two staff members to support and liaise with us: one from the Bureau of Meteorology Research

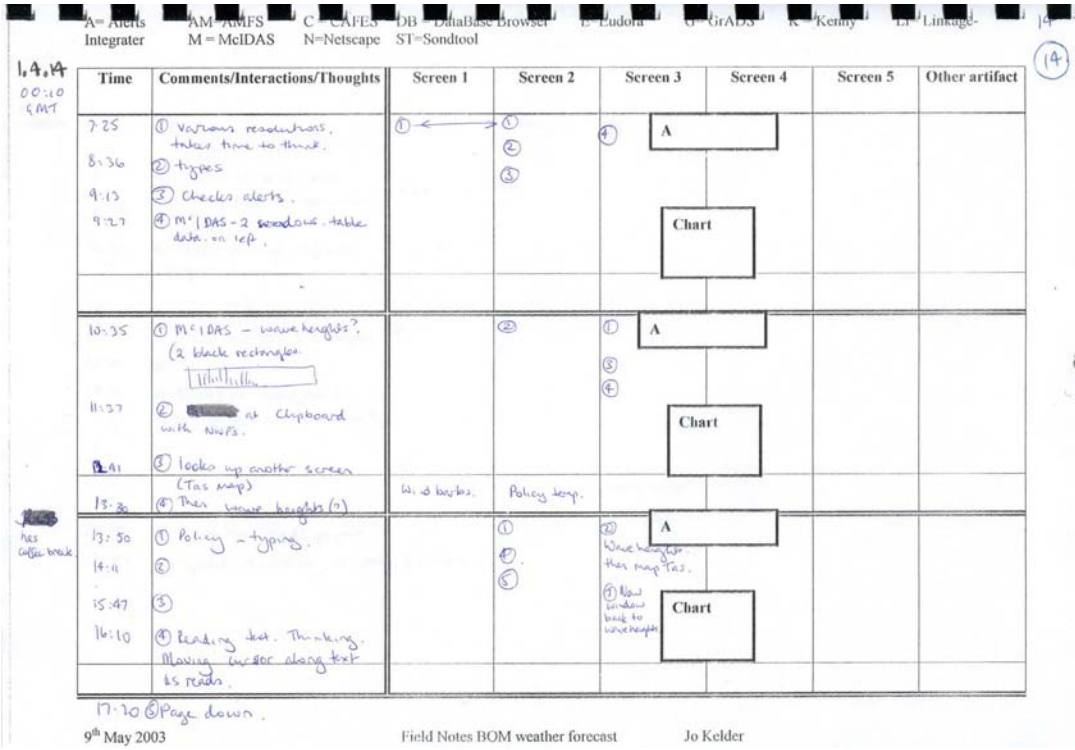

Figure 2. SampleVideo Notes Field Sheet, made anonymous

Center (BMRC) and one from the Hobart Regional Forecast Office (RFC) where we conducted our research. We attended the in-house FSEP conference and were given copies of the forecast process diagrams developed by the BMRC (Bally, 2003). The FSEP conference provided us with an overview of the resource problems facing the Bureau 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.

We 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 and analysis occurred in two broad phases: general familiarization and video-observation. However, the two phases had some temporal overlap, and the analysis used some data, including supplementary data and secondary data, in both phases.

Thus, 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 other artifacts used. This provided a systematic and efficient recording tool, which meant the notes were very detailed and useful both for the final stage of the familiarization phase and later in the video observation analysis.

We used these field notes together with supplementary field data in the familiarization phase to create a *technology inventory* for the setting in conjunction with a *cognitive diary and task description* (see Table 1). We also used the field notes from the video observation phase to identify the *handover* between forecast shifts, as the key activity for analysis for our research. Table 1, adapted from (Hutchins, 2001) summarizes the techniques and analytic focus for the two phases of our research, and the constructs which emerged from the familiarization phase and fed into the video observation phase.

Table 1. Techniques and Tools for Data Collection and Analysis, adapted from (Hutchins, 2001)

	TECHNIQUES	ANALYTIC FOCUS	IDENTIFY	CONSTRUCTS
Familiarization	Field notes	Representational states and processes	Interactions	
	Technology inventory	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	Artifacts
	Field notes, sample charts, sample weather products, photos, organization documentation	Social and material environment and evidence of cognitive activities.	Information use (how)	
Video Observation	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	

Supplementary data included field notes of informal conversations, screen shots of the applications used during the creation of a forecast, collections of sample weather charts and forecast products. These charts and forecast products were often retrieved from the recycling bin at the end of the shift to avoid interrupting the work of forecasters. The penciled notes, scribbles and diagrams provided evidence of the kind of cognitive work done by forecasters. We also used secondary data sources including interview transcripts from Shepherd (2002), the Bureau website (http://www.bom.gov.au/), the *Annual Report* (Bureau of Meteorology, 2002) and notes from the FSEP conference to support and ground the analysis.

We used the *cognitive diary and task description* and *technology inventory* to identify artifacts with clear cognitive consequences when used. Each artifact was then analyzed to determine the goals served by using the artifact, the knowledge required to make use of it and how its use changed the way a user remembered, decided, computed, figured, reasoned, saw, knew or understood something. We also considered how use of an artifact was embedded in the larger socio-cultural system of the activity, evidence that elements of the technology maintained consistency with prior conventions and whether the user interface of the technology included representations that made the task easy or difficult. This analysis process exposed the cognitive consequences of various artifacts for the forecast activity and highlighted the important role of artifacts in the socially distributed activity of *handover* between forecast shifts.

The familiarization phase generated insight into the weather forecast process and its problems, which then guided how we approached the video observation and associated field note observations. In particular, this phase prompted the decision to video an entire forecast shift (approximately six hours) on two separate occasions, and to use that experience as a basis for choosing the primary constructs for analysis as well as the *handover* activity (33 minutes duration) for closer analysis. This phase of our research also proved important in familiarizing the forecasters with our presence and the purpose of our research, and familiarizing us with the terminology used by forecasters and their work routines.

During handover (see Figure 3), the outgoing senior forecaster must communicate and explain the current forecast policy to the next senior forecaster and the technical officer (whose role is to answer telephone queries from the public). The activity includes a summary both of the previous shift's forecast policy and of the cognitive processes that led to that policy. It is the mandated occasion in a forecast shift where forecasters give verbal reasons for decisions and judgments. The handover is thus rich in interactions between individual actors and the artifacts they use. It also provided us 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.

Following (Hutchins & Klausen, 1996) our research analysis used multiple sources of data and presented and represented that data from different perspectives. The different data collection techniques allowed us 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 account of the handover activity, and then generating twelve insights on the domain of the production of a weather forecast. The characteristics of handover (summary of forecast shift activity with justification for decisions made) gave us confidence to generalize these insights to the complete forecast process.

Figure 3. Handing over the forecast

ANALYSIS AND INSIGHTS

Dcog theoretical principles guided and informed data collection and analysis, and we conducted the two iteratively. Our initial analysis provided evidence for a Dcog expectation that weather forecasting is the result of a socio-technical and cultural process of constructing meaning about atmospheric phenomena.

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. They achieve this by collaboratively interacting with the data, using social and cultural practices and shared understandings established over decades of evolving professional forecast practice.

From our initial analysis, particularly the results of the *cognitive diary and task description*, 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 and the interpretation of cognition as a cultural phenomenon (See Table 1).

Using these three constructs, the second phase of analysis examined and analyzed four generations of video and other data from different perspectives, adopting the analysis strategy developed by Hutchins & Klausen (1996) which explicitly establishes connections between data and the theory used to interpret it.

First Perspective- from raw video and supplementary data

The first perspective focused on the setting of our 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. Forecasters' inscriptions include the many practices used to transform weather events into visual and graphical displays and the professional vocabulary used to discuss particular weather features (Goodwin, 1994).

Thus, 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. Examples of these constraints include: all forecasters produce forecast products in line with the forecast policy set by the senior forecaster; the functionality (or not) of meteorological information systems provided by the Bureau and compliance with strict deadlines for issuing a forecast product. These constraints specify the social organization of the forecast process so that coordination is possible. This was most evident during the video observation when there occurred a breakdown in organization due to staff illness. The forecasters on the shift reorganized their work and reallocated certain tasks in order to meet deadlines for forecast products and delivering radio broadcasts. The *ad hoc* coordination flowed from shared understanding of the tasks, weather representations and other inscriptions embedded in the forecast work practices.

Second Perspective- from video transcripts coded for verbal and other behavior

The second perspective 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. The defensive pessimism (Noram, 2001), is a cognitive strategy for dealing with risk situations. Forecasters have the task of converting probabilistic judgments about the weather into deterministic text forecasts. Conservative forecasts (biased towards accepting the worst case scenario) are a strategy to prevent unnecessary loss of life or property that occurs if low probability severe weather events develop without forecast warnings being issued.

Related to this, 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-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- action descriptions

The third perspective created descriptions of forecasters' actions, related to the evidence of forecasters' goals and expectations, the role of memory in forecasters' discussions and actor/artifact interactions in the work environment. Our analysis identified internal representations (schemas) for various aspects of the forecast process that created inter-subjective understanding so that forecasters could coordinate and discuss issues effectively. It also noted the use of artifacts to prompt memory. During the handover, for example, the participating forecasters moved (on wheeled chairs) to the artifact that would represent the next stage of the discussion. The Mean Sea Level (MSL) pressure charts, satellite picture or graphical representation of precipitation functioned to remind the outgoing forecaster of the information to impart. This movement from artifact to artifact is such a feature of forecast work that the carpet frequently needs replacing along that strip of floor. Our analysis also noted artifacts that embodied some culturally developed understanding so that forecasters could make a perceptual judgment rather than perform a computation, for example, a drawing of closely aligned isobars on an MSL pressure chart instead of a table of numbers representing the MSL pressure for different locations.

Fourth Perspective- interpreting action descriptions using Dcog theory

The fourth perspective interpreted the observed behavior of forecasters, including all the elements in the setting (actors, artifacts and cultural factors). We analyzed the handover 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 MSL pressure charts, printouts of forecasts based on a template and graphical and tabular presentations of the weather data).

Theoretical Account and Insights

These four different analyses of the data produced varieties of information about the handover activity and formed the foundation for a theoretical account of the forecast process. Combining the three core constructs (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. We then used this account to generate twelve key insights relevant to achieving effective coordination of forecasters, existing information systems and other artifacts in the work environment (see Table 2).

The next section explores using Dcog theory to reconceptualize user-centered design methodologies and reduce their inherent techno-centric bias, by bringing to the foreground the interrelatedness of the people, place and things connected to cognitive activities.

TRANSLATING DCOG INSIGHTS FOR APPLICATION TO SYSTEMS DESIGN

The practical applicability of Dcog to information systems design is not straightforward (Hollan, Hutchins, & Kirsh, 2000; Rogers & Ellis, 1994). There have been several attempts to extend Dcog to provide practical design support (Hollan, Hutchins, & Kirsh, 2000; Perry, 1999; Walenstein, 2002; Wright, Fields, & Harrison, 2000). For example, Dcog analysis is used to provide 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, Hutchins, & Kirsh, 2000).

Our research at the Bureau 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 that were valuable to the organization.

Some of these insights were used by Bureau staff members participating in the FSEP discussion to buttress arguments for particular functionality in a proposed new system (Bally, 2003) and applied in related systems research including the Mandala

Table 2. Twelve insights for meteorological information systems design

INSIGHT	DESCRIPTION
Forecasting is a distributed cognitive activity	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 organisation 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	Individual differences are constrained by organisational culture and technology configurations, but each forecaster uploads, organises and uses the data sources and software applications according to his preferences.
Forecasters are processors of symbolic structures	Forecasters' wisdom and judgment is central. Forecasters use scenario building and modus ponens reasoning to develop and defend their forecast judgments.
Forecasters are communicators	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	Processed representations of data and artifacts that allow flexible data manipulation and display aid interpretation of its 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).
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.
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.

knowledge management research project (Linger & Aarons, 2004, submitted). In addition, forecasters at the Hobart RFC reacted to a presentation (Kelder, 2003) of our findings with surprise that our research had produced a recognizable and insightful account of the way they worked. They commented that this was an account they had not ever considered or articulated for themselves, but thought was important to communicate to the systems developers working on the FSEP.

However, 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 the Bureau's MetIS. Developing a procedure for effectively translating these insights into functional specifications was outside the scope of our research and this paper is a (largely) theoretical attempt to consider a more extended role for Dcog theory in applications design for systems such as MetIS.

Dcog produces insights into the complex, dynamic and distributed nature of the cognitive work environment that has implications for information systems design. However, this complexity in turn generates two questions: *How do we translate these insights into functional specifications?* and, *Can we avoid the techno-centric design trap identified by Gasson (2003) during the translation process?*

For some uses of Dcog these questions may appear less important. 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". For example, when Dcog was used as a tool to identify representational activity in order to identify technological implementations for a business (Flor & Maglio, 2004) the insights obtained were easily translated into computational technologies. The conceptualization of the problem was technological, and the resolution consisted 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, focusing only on the representational transformations created in the course of work tasks is not sufficient.

In the context of our research, the Bureau 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, we used Dcog analysis not to simply trace the computational aspects of forecasting but rather to focus on the cultural aspects of the forecasting cognitive system, and on understanding both the technological and non-technological (the people and the place) aspects of forecasting.

Dcog alerts the researcher to the fact that people use their environment to help them think. Any environment contains people, the physical space, the cultural understandings and technologies (things) to aid cognition, each of which reciprocally acts upon and is acted on by the other elements. Dcog 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. Illustrating the nature of the interrelatedness of the people, place and things connected to cognitive activities helps to consider the *consequences* of changes in the environment.

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 mitigate the influence of goals and objectives of physical or technological changes by transforming the landscape into which a new system solution is placed. This happens because people are adaptable and often use technologies in ways unintended by the original design (Halverson, 1994). Design processes for new systems rarely capture these unintended uses, which can be of considerable value to users but lost when a new solution is implemented.

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. It is also evident 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). This effect is evident in the Bureau's use of the user-centered methodology Extreme Programming. This approach has been criticized (anon., 2003) over difficulties in communicating between systems developers and forecasters which lead both groups to put their energies into addressing the easier problems of usability instead of grappling with the harder issue of the dynamic, social, cultural and technical complexity of forecast work and how support it.

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.

Gasson's (2003) dual-cycle model of Human-Centered Design 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 she articulates (Gasson,

2003) to avoid the trap of thinking of workers as merely technology users.

From a theoretical perspective, a combined approach suggests a reconceptualization of user centered design methodologies by re-positioning the place of the user. In essence, we propose 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 all three elements: people, place and things. 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 user-centered systems development approaches to avoid the techno-centric trap and remain truly user centered. Dcog does this by highlighting the agency of technology to potentially bias systems design and by acknowledging that individuals within a design team will have different perspectives that will influence the impact of this technology agency. This approach can then encourage all team members to engage in critical self-reflection consider the impact of the interactions within and between the three elements and whether their own translation for systems design falls into the technology trap. This should assist 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 us to generate detailed insights with minimal disruption to the forecast process itself or to the work of busy forecasters. Our 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.

Dcog combined with user centered design methodologies emerges as a useful approach to ensure a true user focus for design outputs. The previous section detailed some of the practical applications for MetIS 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. On-going research by the authors of this paper is focusing explicitly on this problem in the broader context of the Bureau's FSEP project.

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