Capturing User Experience: Using Distributed Cognition Theory to Inform the Sustainable Design of Meteorological Information Systems in Australia

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Abstract

The Australian Bureau of Meteorology (BoM), faced with the challenge of meeting rising end-user expectations and managing associated increases in the workload of its forecasters, has initiated the Forecast Streamlining and Enhancement Project (FSEP) to re-design its meteorological information systems (MetIS). The challenge for FSEP and for the research is to acquire the information requirements of forecasters without interrupting the continuous work of forecasting. This research challenge is compounded by 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 presents a case study exploring the utility of distributed cognition (DCog) theory as one approach to address these research challenges and to produce insights that capture forecasters' experiences as a context for the design of the BoM's next generation of MetIS. At the theoretical level, DCog theory allows for the capture and validation of design insights through observing cognitive behaviour as a system of individuals interacting within their natural 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 as a sustainable methodology for sensitising designers to an awareness of the cognitive implications of changes to information systems and/or work processes.

Keywords

Distributed Cognition, Computer-mediated communication, Information Systems research methods.

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 analysed at regional offices based in the capital city of each state. In recent years, at the same time as constraints have been imposed on the BoM's resources, there have been rising levels of end-user expectations about the availability, quality and delivery of 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[1] in the forecast process. From a technological perspective, the rapid development of meteorological data sources[2] and ever-increasing computational power has led to an almost exponential growth in the volume of 'weather' data to be assimilated and assessed. Indeed, the challenge for the BoM has moved quickly from one of acquiring access to sufficient information to dealing with the problem of information overload and the challenge of how best to present information in a manner that does not 'swamp the forecaster'.

One consequence of the speed with which powerful meteorological information systems have been deployed within the BoM has been the occurrence of a mismatch between these systems and the interactive manner in which forecasters work to produce a forecast. While these systems have very successfully taken over the

[1] The research focused on meteorologically trained staff engaged in the operational work of forecasting, and the paper generally refers to them as 'forecasters', and as 'actors' in the analysis section.

[2] The rise of global communications means that there are now vast amounts of data from weather observation stations, cooperative and volunteer observers, satellites, ships and aircraft being shared globally. Computers have become essential tools for both research and for large-scale numerical weather analysis and prediction.

numerical analysis component of forecasting, they have often made forecasters' work more complex, including the tasks of assessing and interactively communicating the relative value of various data types in different forms to support particular forecasting conclusions. The rigidity of output from these systems frequently hinders timeliness and reduces their responsiveness and utility in meeting forecasters' needs in the forecasting process. Two of the primary information systems resources provided by the BoM were variously criticised by forecasters as "flaky", "not visually user-friendly" and "clunky". As a result, many forecasters at the BoM have bypassed the ensemble of forecasting tools provided and supported by its Central Operations Services Branch (COSB) in favour of stand-alone software applications written by individual forecasters and shared via the intranet. One forecaster commented on the rationale for preferring to use a particular MetIS application, saying, "It's a Darwinian swamp: the survival of the fittest". This has created issues of quality control and verification.

In this context, a major challenge for research at the BoM in implementing the FSEP project was how to acquire a detailed understanding of the weather forecasting process[3]. This was particularly difficult as forecasting is a cognitive activity distributed across people and multiple artefacts (not just information systems). As a result, there was a 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 these forecasting activities.

This paper presents a case study exploring the utility of distributed cognition (DCog) theory as one approach to address these research challenges and to produce insights that capture forecasters' experiences as a context for the design of the BoM's next generation of meteorological information systems (MetIS). At the theoretical level, DCog theory allows for the capture and validation of design insights through observing cognitive behaviour viewed as a system of individuals interacting within their natural environment. 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). There are several key features of Dcog. It uses a metaphor of cognition as computation and the unit of analysis distributes cognitive activity socially and technically across people and artefacts over time. Another feature is that DCog views cognition as essentially cultural, and defines computation as the propagation of representational states across representational media over time (Hutchins, 1995a).

At the methodological level, the data collection techniques deployed in this research allowed for the capture of the complex socio-technical nature of forecasters' information sharing without interrupting their work. Data for the research were generated primarily through video observation, supplemented by ethnography drawn from the setting, including existing research from within the Bureau (Bally, 2003; Shepherd, 2002)[4] and secondary sources of information including the Annual Report (Bureau of Meteorology, 2002). A range of analytical techniques were applied to the data to uncover multiple perspectives and explanations of the variety of interactions that occurred in the forecasting process. This paper highlights the utility of DCog theory as a sustainable methodology for sensitising designers to an awareness of the cognitive implications of changes to information systems and/or work processes.

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-centred design (Vredenburg, Isensee, & Righi, 2002) can be added, all approaches recognise the challenges involved in exploring human computer interactions (HCI). These challenges are further compounded when the interactions extend beyond the individual to include groups.

In this context, distributed cognition 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 organisational memory (Ackerman & Halverson, 2000). DCog theory has

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[3] There were two aspects to this: firstly, forecasters were frustrated by the support provided by the existing information systems, sceptical 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 forecaster feedback.

[4] These techniques minimised the need to disrupt forecasters by interviewing. It is however, acknowledged that interview data from (Shepherd, 2002) was used as part of the process of grounding the analysis of the video observations.

also been proposed as a theoretical framework for HCI (Hollan, Hutchins, & Kirsh, 2000)[5]. In essence, DCog allows for the capture of design principles by observing cognitive behaviour as a system of individuals interacting within their material environment, rather than by attempting to identify and formalise 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 that studies "the internal mental environment largely separated from the external world" (Hutchins, 1995a: 371). In doing this DCog recognises the importance of ethnography in systems design (Halverson, 2002; Rogers & Ellis, 1994) for revealing subtle features of collaborative activity (Halverson, 2002; 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). 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). The approach 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 dynamical process and situated in a socio-technical world. DCog draws ideas, tools and techniques from a variety of sources of ethnographic theory and practice (Agar, 1986; D'Andrade, 1995; Goodwin, 1994; Latour, 1986; Lave, 1988). Ethnographic data collection methods include video observation, field notes, and interviews (Halverson, 2002; Holder, 1999; Hutchins, 1995a, 1995b; Hutchins & Klausen, 1996). However, support for DCog theory is qualified by the difficulty of learning the approach and the time required for data analysis (Halverson, 2002). The descriptive power also has to be balanced against the loss of rhetorical power because of the lack of named constructs (Halverson, 2002).

DCOG AND RESEARCH AT THE BOM

In exploring the BoM's forecasting process DCog theory appeared to offer an approach that could accommodate capturing the information interactions between forecasters while deliberately not interrupting their work activity. Prior to adapting DCog to conduct research at the BoM it was important to examine existing research conducted at the BoM into the forecast process. Firstly, a study identifying information flows had been produced with over four hundred diagrams of the weather forecast process (Bally, 2003)[6]. 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.

Consequently, it was recognised that to be effective any information systems design would need to have a better understanding of the processes by which those internal representations interact with the environment to produce forecast decisions. Additional research into the forecasting process from a knowledge management perspective (Linger & Burstein, 2001; Shepherd, 2002) contributed to understanding the subjective aspects of the forecast process at the BoM. However, this research also revealed that significant knowledge gaps remained. These included understanding how forecasters collaborate to use the resources in their environment to access, transform and propagate the diversity of representations of the weather situation, in order to arrive at the endpoint of a weather forecast product. To enhance this understanding, this present research adapted DCog theory and conceptualised the forecasting process as a distributed cognitive activity in a dynamic socio-cultural-technical environment. The next section explores the methodology and data collection methods used in developing this approach.

[5] 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.

[6] 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 where the forecast decisions are distributed across people and artefacts.

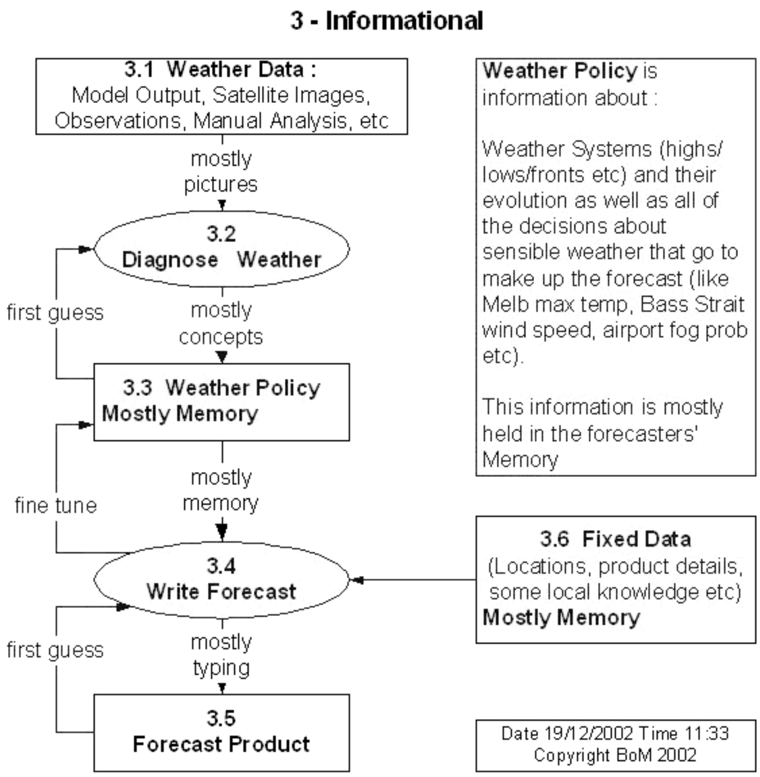

Figure 1: Forecast Informational Flows Analysis: Informational Perspective (Bally, 2003)

METHODOLOGY

Data Collection

The BoM appointed two staff members to support and liaise with the researchers: one from the Bureau of Meteorology Research Centre (BMRC) and one from the Hobart Regional Forecast Office (RFC) where the research was conducted. Researchers attended the in-house FSEP conference and were provided with copies of the forecast process diagrams developed by 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 organisational, political and cultural issues entwined with the technical and human resource issues.

In conducting this research ethnographic techniques were used to identify and analyse the interactions between forecasters, their information systems and other artefacts in the work environment, and how these interactions impacted on the forecast process. The data collection was conducted in two phases: familiarisation and video-observation.

In the familiarisation phase extensive field notes were collected including detailed lists of artefacts 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[7]. Diagrams of the forecast area and interactions within it were created and printed screen shots of the applications used during the creation of a forecast. 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 utilised. This phase enabled the generation of insight into the weather forecast process and its problems to guide more focused data generation and analysis[8]. This analysis formed the foundation for decisions on the video-observation phase. It was decided to video an entire forecast shift (approximately six hours) and use that experience as a basis for choosing the primary constructs for analysis and the particular segment of the forecast for closer analysis.

[7] 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.

[8] This phase also provided the researchers with knowledge of the terminology used by forecasters and workflows that enhanced the approach used for video observation and associated field note observations.

The video-observation phase of the data collection involved videoing the 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 artefacts in the work environment. Before videoing the forecast, a structured field notes sheet was developed to record actions by forecasters including time, comments on what was occurring, which software application was actively being utilised, other applications ready for use, and any other artefacts used. This allowed a more systematic and efficient notes recording, which meant the notes were very detailed and useful later in the analysis.

Analysis Overview

Two weather forecast shifts were videoed and within these, one handover segment (33 minutes duration) was selected for detailed analysis. The handover activity emerged as a critical part of the forecast shift structure. It is the occasion for the outgoing senior forecaster to 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 artefacts they use. It involves a summary both of the previous shift forecast and of the forecast process. It is also 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.

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. Guided by DCog constructs, the results were integrated to create a detailed account of the handover process, and to generate twelve insights into the production of a weather forecast. These are listed in Table 2, at the end of the next section.

A WALKTHROUGH THE DATA ANALYSIS

Familiarisation Phase

The DCog literature provides a suite of constructs that have successfully been applied in computer-supported collaborative work. These constructs promote detailed analytical and observational note taking and are used as heuristic tools to guide initial data collection and prevent the privileging of actors over artefacts. The interpretive focus of three particular DCog constructs was chosen after detailed consideration of secondary sources of data (extensive field notes, existing interview transcripts, FSEP conference notes, the Bureau's Annual Report).

The Bureau's Forecast Streamlining and Enhancement Project (FSEP) had identified a critical gap in knowledge about the forecast process: the subjective, tacit elements of forecasters wisdom, judgment, experience and communication. Similarly, familiarisation with the forecast setting confirmed the initial field notes that forecasters used artefacts in multiple ways (most of which were unintended by their designers) and that articulating those uses was an important component of understanding the forecast process.

This led to a decision to deploy constructs that drew attention to the cultural rather than computational aspects of forecasting and the selection and deployment of three key DCog constructs: forecasting as cultural, artefacts and the socio-cultural-technical unit of analysis. Each interpretive decision was grounded in the sum of ethnography available to the researchers thereby ensuring validity and exposing 'surprises or the unexpected' that could then be further investigated and analysed.

Video-observation Phase

Drawing on the principles of DCog theory, the next stage of analysis examined and analysed the video data from four perspectives. The video transcript samples in this section of the paper are examples from the video-observation transcript relating to the insights developed, with an indication of the context. The video data was transcribed using the Jefferson transcription system[9] as provided on Transana, a software application (http://www.transana.org/) that supports multi-modal transcription and analysis of video data.

The first analytic perspective focused on the setting of the research. Two features of the forecast process, exemplified in the video data of the handover activity were immediately obvious to the researchers: the prevalence

[9] Symbols used: *((comments not part of the transcription))*; <speech slower than normal pace>; ↑ = upward inflexion; >speech more rapid than normal pace<; word emphasized; word cut off-; [marks point of overlapping speech or sound such as phone ringing while actor speaking].

of interruptions and the frequency of actor relocation between artefacts (see Transcript 1). In the thirty-three minutes of the handover between shifts, the out-going senior forecaster had to answer seven phone calls and make a radio broadcast. All three actors in the handover (two forecasters and one technical officer) constantly moved via wheeled chairs, and this relocation is reproduced at an individual level by each forecaster during a shift as they move to a new screen or chart or to another forecaster for discussion. These observations contributed to Insights 5, 7 and 12, listed in Table 2.

CONTEXT	VIDEO TRANSCRIPT
Senior forecaster (L) speaking during handover	OK *((all move on chairs toward the weather chart desk))* So if you look at some diagnostics now for er today, well let's first have a look at a few of the charts ((L picks up charts on a clipboard)) let's go back a bit *((walks over and puts a collection of 2-3 clipboards over near screen one and comes back to weather chart desk))*
Senior forecaster running out of time and offloading a phone call to the aviation forecaster (D).	Phone: brr brr L: And er those differences start to get more prominent er >over time< L: Um *((starting to move backwards in chair towards phone, looking at watch and around to see if anyone else can take the call, just about to pick it up when))* Yeah. Can you get that one↑ please D? Thanks. *((moves back to weather chart desk and B and M))* L: OK,

Transcript 1: Forecaster interruptions and relocation

Analysis of the forecast setting as situational territory (Suchman, 1996) also led to Insight 3, as a dialectical relationship between the setting and the forecast activity was evident. The combination of constantly changing forecasters performing essentially the same, repeated cognitive task (in this case handing over a shift) 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 behaviour 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 organisation of the forecast process so that coordination is possible.

The second analytic 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). The embodied nature of forecasting (Insight 2) was displayed frequently. Information Redundancy (Insight 10) was evident in the occasional participation of (D) to supply additional information (see Transcript 2).

CONTEXT	VIDEO TRANSCRIPT
Senior forecaster (L) discussing the weather with oncoming forecaster, using MSL pressure chart	L: …and the gradients haven't been very tight aligned *((traces with hand over chart to indicate location))* and ah a high ah in our area and over the last um few days↑ this has just moved very slowly *((gesture over chart to indicate speed))* I mean in >pretty rapid< progression …
Aviation forecaster (D- not participating in handover) supplies a lost chart without comment	L: I printed myself out a spare copy↑ Phone: [brr brr L: and it went away↑] *((goes to answer the phone, looking about as goes, meanwhile D puts the clipboard with the forecast on the weather chart desk))*

Transcript 2: Forecasters using gesture and information redundancy

The third perspective of video data analysis focused on the evidence of forecasters' goals and expectations, the role of memory in forecasters' discussions and actor/artefact interactions in the work environment. It identified evidence of internal representations (schemas) for various aspects of the forecast process that enable inter-subjective understanding so that forecasters could coordinate and discuss issues effectively. For example, the order of discussion of the weather replicated the structure and process of forecasting represented in the Informational perspective of the forecast process developed by Bally (2003) (see Figure 1), and actors receiving the handover often anticipated the end of a discussion segment by the outgoing senior forecaster by starting to move their chairs over to the next artefact anchoring the discussion before he did. The existence of mental representations was also evident in the use of professional language to discuss the weather and the use of representations of the weather to demonstrate the issues under discussion (see Table 1).

LANGUAGE	EXAMPLES
Technical	upper ridge, zonal flows, involuted, gradients, high, low, change lines, 06Z, deceleration, covergence, slope, cape, 'a trace', trough, jet
Jargon and Shorthand	'two-fifty' (numbers without units, guess from context), GDats, McIDAS, EC, GASP, UK, US , Maatsuyk-, Maccas, NCEP, Mesolaps, LAPS, 'the models'
Geographical Locations	Flinders Island, Lower Rocky Point, Maatsuyker Island, Macquarie Island
Descriptive of the weather	Snakes, sandwiched, tailing off, dropping back, 'impale itself on New Zealand', nudge, swing, 'a drawn out affair'
Confidence Level	Wary, suspicious, not too trusting, have to wonder, question, significance, degree, 'possible that', 'to be on the safe side'
Weather Dimensions	Rates of movement (deceleration), depth, height, substance, travel, evolve
Numerical Weather Prediction Models	Differ, be at odds, fall apart, agree, say (something), model the weather
Forecasters Relation to the Weather	'we've got', 'we've had', 'have a look at', 'we/you see', 'you/you'll notice'
Forecaster Reasoning about the Weather	"If this [model] is right then we'll have …. But if this [model] is right … it might be more …", "I think"

Table 1: Forecaster Professional Language

This analytic perspective also highlighted the culture of defensive pessimism in which forecasters' reasoning is embedded, in particular in the practice of *modus ponens* reasoning (creating scenarios based on "if … then" arguments) which enriched the understanding of Insight 4. The analysis also noted the use of artefacts to prompt memory, and artefacts that embodied some culturally developed understanding (such as the Mean Sea Level Pressure chart or the CAFeS application which provides a graphical user interface) so that forecasters could make a perceptual judgment rather than perform a computation. Artefacts were constantly used as the focus of any comments (see Transcript 3). This evidence led to Insights 1-3, 5-8 and 11-12 (see Table 2).

CONTEXT	VIDEO TRANSCRIPT
Senior forecaster (L) using an artefact in conjunction with speech	So what we might just do is er just track that over the next couple of days over here *((L moves on his chair over to screen 1: CAFeS application; others shift too))* So you can see that …

Transcript 3: Forecasters using artefacts to communicate

The fourth perspective interpreted the observed behaviour of forecasters, including all the elements in the setting (actors, artefacts and cultural factors). The handover was analysed as a culturally constituted activity. The social and organisational structures, the language, gestures and tools used for communication and the tools constructed to aid memory and transform tasks were identified. Some of these structures are internalised 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, graphical and tabular presentations of the weather data).

Integration and Drawing Conclusions

The video-observation phase of the analysis produced understanding of the relationships between actions in the research setting, and the underlying cultural models driving and coordinating those actions. The results of each perspective were then mapped to Dcog theory, in particular the conceptualisation of cognition as a cultural phenomenon and "the propagation of representational state across representational media" (Hutchins & Klausen, 1996: 19). This map was integrated into a theoretical account of handover (as far as it generalised to represent the weather forecast process), and then used to generate twelve insights (listed in Table 2 and discussed in the next section) into the domain of weather forecasting.

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 artefacts, 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)
Artefacts are used as a communicative resource	Forecasters use artefacts as a resource to illustrate a point, or demonstrate the reasoning underlying a judgment. Forecasters use artefacts extensively in joint reasoning activities to anchor discussion to a particular instance and provide shared understanding of the context.
Artefacts are used as a memory aid	Artefacts 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.
Artefact design has cognitive consequences	Processed representations of data and artefacts 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 artefacts 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 artefacts 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.

Table 2: Twelve Insights for Meteorological IS Design

DISCUSSION AND CONCLUSION

The process of data analysis described above led to twelve key insights being generated that are relevant to the effective coordination of forecasters, existing information systems and other artefacts in the work environment. These insights into interactions in the forecast work environment displayed a high level of inter-relatedness. More importantly, by providing insight into these interactions it becomes possible to consider ways of re-designing the forecasting process by making changes to the system including to the structure and role of the information systems and/or other artefacts. By understanding the role these artefacts have in the communicative and cognitive activities of forecasters it is becomes possible to examine ways of re-designing the process.

Analysis of the video transcription, grounded in other ethnography, confirms 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. Through an initial analysis and drawing on DCog theory it was possible to identify three core constructs that highlighted aspects of the forecasting domain: the socio-cultural-technical unit of analysis; the use of artefacts to mediate cognition; the interpretation of cognition as a cultural phenomenon.

This research has revealed that forecasters use their information systems and other artefacts as communicative resources to identify particular weather features, as an anchor for their discussions and to demonstrate judgment in generating shared agreement on a weather forecast. These artefacts are also used as a memory aid, reducing the cognitive load on any individual by enabling them to perceive rather than remember the content of what was discussed (Norman, 1993). In particular, artefacts 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 by providing a basis for shared (inter-subjective) understanding. Artefacts can also transform a task of assimilating a vast amount of data from a computational one, to one of perceptual judgment.

This research has also confirmed the cultural nature of weather forecasting such that social, technical, cultural and organisational factors are critical for successful cognition and affect the quality of the forecast product. Individual forecasters share attitudes, values procedures and behaviours that allow the forecast process to proceed seamlessly as each worker temporarily occupies a position and reproduces the procedure. Forecasting occurs in a shared workspace with local configurations that are constrained by stabilising factors such as procedures and routines, technology available and the physical features of the workspace (Suchman, 1996).

Forecasters clearly use shared cultural models (schemas) to coordinate their forecasting activities. These schemas form a web of expectations including how to deliver a handover, how the weather situation should be assessed and communicated and how different artefacts can be deployed in this process. There are also accepted norms for dealing with interruptions and looming deadlines and recovering interrupted thought processes. The existence of a culture of defensive pessimism emerged from analysis of the reasoning processes and communicative practices adopted by forecasters. 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.

The role of trust, experience and subjective judgment in the forecasting process contrasted with a priori expectations of a purely rational scientific approach to forecasting. Wisdom and judgement are 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 judgement.

The research presented in this paper has revealed that the procedures and routines embedded in the organisational structure of the forecast process have been culturally constituted over time and internalised in forecasters' long-term memory so that each step in the handover and wider forecast process is normally taken without external structures to remind them. It has also demonstrated a significant cultural aspect in artefact design and use. Weather charts in particular rely on inscriptions that have been developed over many centuries. These include the large, paper Mean Sea Level pressure (MSL) charts, and digital charts such as the numerical data models used to guide the forecast. The forecast process uses many artefacts such as the MSL chart that have partial solutions to frequently encountered problems embedded in their structure.

By deploying a socio-cultural-technical unit of analysis that included all elements in the setting without privileging actors over artefacts, it was possible to illuminate the nature of forecasting as a cognitive activity. First, forecasting is distributed both socially and technically. It involves inter-forecaster discussion and communication, and interactions with multiple artefacts used for representing the forecast steps, including artefacts incorporating partial and pre-computed solutions. Second, forecasting is embodied. Gesture is an important part of communication in the forecast setting, and forecasters' movement between artefacts via wheeled chairs was a property of the system that had an impact on the flow of the handover activity. Third, forecasting is situated. That is, it occurs in a context of social, cultural and organisational factors that impact on the forecast product.

This paper has presented a case study that has examined the utility of distributed cognition (DCog) theory as one approach to analysing the complex activity of weather forecasting amongst forecasters and to produce insights that capture forecasters' experiences as a context for the design of the BoM's next generation of meteorological information systems. The DCog approach enabled detailed insights to be generated with minimal disruption to the forecast process itself or the work of busy forecasters. This paper highlights the utility of DCog theory as a sustainable methodology for sensitising designers to an awareness of the complex cognitive interactions that must be supported and enhanced by new MetIS, and the cognitive implications of changes to information systems and/or work processes. As an over-arching framework DCog emerges as useful for HCI research and design (Hollan et al., 2000; Wright et al., 2000). There is however, still a need for further research into the inter-relationships between the detailed insights generated and how they can best be translated into higher level design principles to assist designers at a practical level with the development of new systems (Walenstein, 2002).

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