Framing Movements for Gesture Interface Design

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Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

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Statement of Contributions to Jointly Authored Works Contained in the Thesis

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- Brereton, Bidwell, Donovan & Campbell were responsible for data analysis and writing of the paper. Buur was responsible for running video collection and collaborative analysis activities and for feedback on the paper draft.

- Partially incorporated as paragraphs in chapter 4.

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Donovan, J. et al., 2003. Exploratypes: expressing and provoking actions. In *3rd Danish HCI Research Symposium*. Roskilde University

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Abstract

Gesture interfaces are an attractive avenue for human-computer interaction, given the range of expression that people are able to engage when gesturing. Consequently, there is a long running stream of research into gesture as a means of interaction in the field of human-computer interaction. However, most of this research has focussed on the technical challenges of detecting and responding to people's movements, or on exploring the interaction possibilities opened up by technical developments. There has been relatively little research on how to actually design gesture interfaces, or on the kinds of understandings of gesture that might be most useful to gesture interface designers.

Running parallel to research in gesture interfaces, there is a body of research into human gesture, which would seem a useful source to draw knowledge that could inform gesture interface design. However, there is a gap between the ways that 'gesture' is conceived of in gesture interface research compared to gesture research. In this dissertation, I explore this gap and reflect on the appropriateness of existing research into human gesturing for the needs of gesture interface design. Through a participatory design process, I designed, prototyped and evaluated a gesture interface for the work of the dental examination. Against this grounding experience, I undertook an analysis of the work of the dental examination with particular focus on the roles that gestures play in the work to compare and discuss existing gesture research.

I take the work of the gesture researcher McNeill as a point of focus, because he is widely cited within gesture interface research literature. I show that although McNeill's research into human gesture can be applied to some important aspects of the gestures of dentistry, there remain range of gestures that McNeill's work does not deal with directly, yet which play an important role in the work and could usefully be responded to with gesture interface technologies. I discuss some other strands of gesture research, which are less widely cited within gesture interface research, but offer a broader conception of gesture that would be useful for gesture interface design. Ultimately, I argue that the gap in conceptions of gesture between gesture interface research and gesture research is an outcome of the different interests that each community brings to bear on the research. What gesture interface research requires is attention to the problems of designing gesture interfaces for authentic context of use and assessment of existing theory in light of this.

Keywords

Gesture, participatory design, dentistry, gesture theory, gesture interface.

Australian and New Zealand Standard Research Classifications (ANZSRC)

120304 Digital and Interaction Design 50%, 209999 Language, Communication and Culture not elsewhere classified 30%, 110599 Dentistry not elsewhere classified 20%.

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Chapter 1: Introduction

When people talk to one another, they perceive and respond to a myriad of subtle shifts in the tone of voice, stance, and gaze. Their hands arc out before the body in unscripted, but coordinated and coherent dances of meaning. In the work of a person skilled in their trade, we often see how they respond with their movements in a fluid and open way to a complex and changing environment. And when people work cooperatively, as they often do, one appreciates these aspects of movement as intricately entwined. Gestures serve to convey meaning, achieve skilled work, and coordinate the actions of multiple participants. Given the beauty and expressiveness of our bodies as they engage in the world in these ways, it is striking that when we use computers, we are forced into rigid postures where we stare at a screen while tapping at keys and occasionally shuffling a mouse from side to side. In the face of the computer, the lively dance of the body is stifled and stilted.

How can we improve this? Is there a way to draw on our rich abilities to know and inhabit our worlds through our bodies in the design of computer interfaces?

Within Human-Computer Interaction (HCI), one long-standing idea for how to address these questions is to allow the use of *gestures* as a way of interacting with computers. Interest in so-called gesture interfaces dates back to the beginnings of the field of HCI and has over that time encompassed many different interaction paradigms. For much of its history, gesture interface research has been concerned with the technical challenges of detecting and responding to gestures or with exploring the new interaction possibilities afforded by technical advances. The related questions of how to design gesture interfaces so they fit with authentic settings of use and what kinds of theoretical understandings might be appropriate for gesture interface design have received less attention.

In terms of theory, recent years have seen somewhat of a shift. Though the technical agenda in gesture interface research is still predominant, there is an increasing interest in and awareness of gesture research. Gesture research includes researchers from a wide variety of disciplines, including linguistics, conversation analysis, psychology, semiotics, and anthropology. As yet though, only a few key gesture researchers, all with a focus on gestures and *communication*, have gained much recognition in the field of gesture interface research.

A notable example in this respect is the cognitive linguist, David McNeill. He is perhaps the most widely cited gesture researcher within gesture interface research. He has served on the panel of gesture interface conferences and has also co-published with gesture interface researchers (Cassel & McNeill, 1999; Quek et al., 2002). His research is concerned with *gesticulation* (spontaneous idiosyncratic communicative movements accompanying speech) and with demonstrating a cognitive coupling between speech and gesture production (McNeill, 1992, 2005). Though McNeill's work has become widely cited within gesture interface research, there are many areas of gesture interface research for which theories such as his are difficult to apply. The reason for this is that the 'gestures' employed in many gesture interfaces often have little resemblance to human-to-human conversational gestures such as gesticulation.

This thesis is built on the argument that gesture interface research would benefit from looking further into gesture research than it currently does. There are a number of strands of gesture research that take a much broader view of gestures than as purely communicative movements, but these are little known within gesture interface research. It seems plausible that these broader approaches to gesture research may prove useful theoretical additions to gesture interface research. This provides the motivation for the research question that this dissertation seeks to address, which is:

What is the appropriateness of existing research into human gesture for the design of a gesture interface within an authentic context of use?

The aim of this thesis is to start a discussion about theoretical views of gesture for gesture interface design. In order to ground the discussion, I take the view that it is important that the research be carried out in relation to an actual design project for an authentic context of use. The intention of grounding the discussion in this way is that the thesis can also constitute a case study for practical gesture interface design methods and processes.

1.1 Relations between theory, design and technology

The research question addressed in this dissertation touches on three interrelated and overlapping areas of research, which are the fields of theory, design, and technology (Figure 1). As a basic sketch, in the context of this research question we can describe these fields in the following ways; theory involves research that seeks to develop basic understandings of human gestural activity, technology involves developing systems that can detect and respond to gestures, and design involves seeking to understand and improve the processes and practices by which technical systems are created.

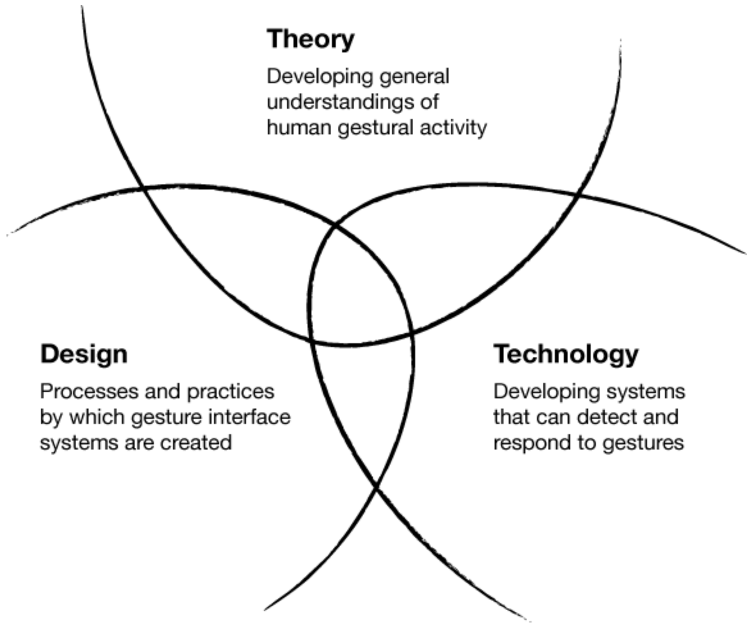


Figure 1: My research crosses between three fields.

The research question of this dissertation contains an assumption that theoretical frameworks *can* be useful for design. This, in turn, raises two further questions that should be addressed before proceeding, which are:

- What are the (appropriate) contributions that theory can make to design?
- How can this appropriateness be assessed?

One position is that theoretical frameworks provide *generally applicable knowledge* for design about the phenomenon around which their designs are based. In this respect, we might judge the appropriateness of a theoretical framework by the sufficiency and design-relevance of the account it is able to provide for design. From this perspective, a sensible way to assess the appropriateness of theory would be to *start from theory* and then try to apply the information from the theory into a design process. One might then carry out an evaluation of the resulting design and trace the success (or otherwise) of the design back to the resources provided by the theory.

A second position is that theoretical frameworks are useful because they provide *contingent resources* for engaging with a phenomenon of interest that sensitise designers to some of the variety and complexity they are likely to encounter. The primary concern of the designer should be to understand the details of the design context and draw on theory in so far as it helps them in this. This suggests that one might *start from design*, with an awareness of theory and use the experiences gained from this to ground a reflective discussion back to the appropriateness of theory.

This dissertation takes the second of these positions as a starting point for the research. One reason for this is that I am not assessing the appropriateness of a single theoretical framework, but attempting to open up for a consideration of a wider range of theoretical views and research on human gesture. The work of McNeill is a starting point and a focus, but I'm as much concerned with highlighting other strands of gesture research that are less well-known in gesture interface design. It is not the aim (nor is it envisaged) to definitively say that a particular theory is more or less appropriate for gesture interface design. Rather it is hoped that the borders of applicability of different theoretical approaches can begin to be probed and prodded, so gesture interface designers can start to think about the kinds of understandings of gesture that will be useful to the particulars of their design context.

In this dissertation, design provides a way of moving between the particulars of an authentic context of use, the technical means by which gesture interfaces are created, and the theoretical frames which can be brought to bear. The design approach taken (participatory design) provides a means to engage people who are expert in the domain of the design context and build an understanding in the terms of that context. It also allows one to work with the technical means of an interface as a design material, rather than allowing the process to be driven by a technical agenda. The design activities are not an end point in the thesis. Rather, they serve as a set of framing activities against which a subsequent detailed analysis and discussion of existing theory is grounded.

1.2 A working definition of gesture

There is a gap between the conceptions of gesture represented in gesture interface research in comparison to many researchers into human gesture. There are also strands of gesture research that have a much broader conception of gesture that would be worth considering for gesture interface design. A foundational question for the research is therefore to be explicit about what *my* definition of gesture is. This is no easy task, as evidenced by the many different definitions that researchers have used. As Corradini and Cohen wryly observe, 'everyone claims to know what a gesture is, but nobody can tell you precisely' (Corradini & Cohen, 2002). My aim in this dissertation is to bring a number of different strands of gesture research into a discussion of the appropriateness of existing gesture research for gesture interface design. Therefore, I need a working definition of gesture that is broad enough to accommodate the ways that gesture is conceived of across these different strands of gesture research and to include the kinds of movements that are practically detectable by gesture interface technologies. As it turns out, this is very broad indeed.

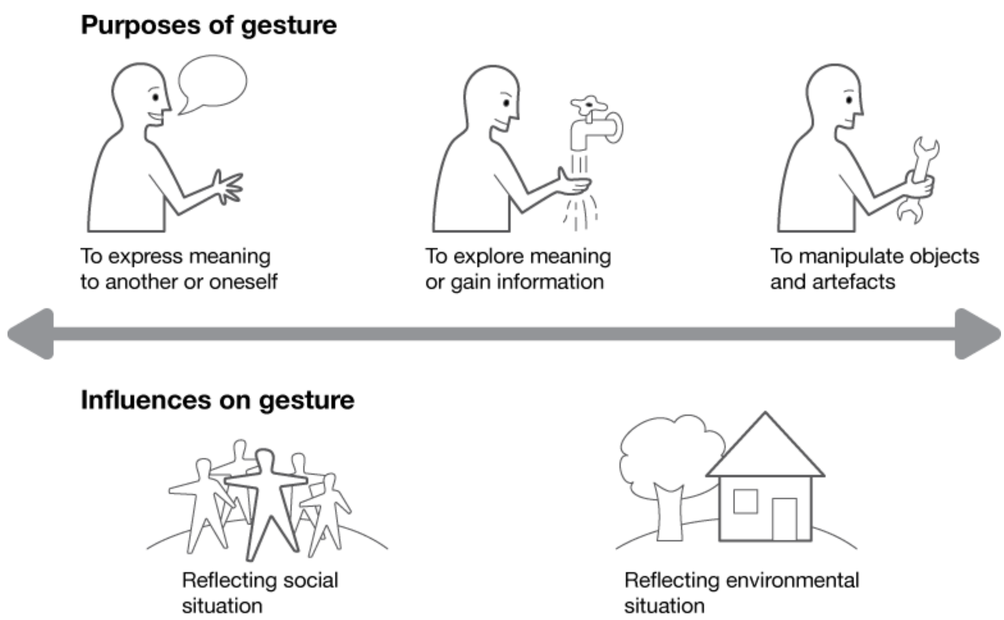


Figure 2: Gestures as embodied movements.

As a working definition, I take gestures to mean embodied movements (Figure 2). Any movement of the body can be considered a gesture. Gestures can be produced for a variety of purposes, including for the purpose of expressing meaning to another or oneself, to explore meaning or gain information from the world, and to manipulate objects and effect material changes in the world. Gestures should be seen as situated in a social and environmental context, which influences and shapes their production and makes them intelligible as such.

In everyday usage and in much gesture research, typically only *communicative* movements are regarded as gesture (the person on the left in Figure 2), whereas *manipulative* and *exploratory* movements are not. Considering the title of this dissertation (Framing Movements for Gesture Interface Design) in the light of the above definition, it is clear that I have set the frame very wide for the research. It must be acknowledged that in taking such a broad view, there is a danger that 'gesture' becomes indistinguishable from mere movement. Alternatively, it may be that there is no such thing as 'mere movement', but that all embodied movement involves gestural qualities of judgement and care (Ingold, 1999, 2001). This is an important point, which I will return to again in later chapters.

1.3 Structure of the dissertation

The structure of this dissertation follows a conventional format in terms of the progression of the chapters, but it takes a novel methodological approach, which bears foreshadowing.

In the next chapter (Literature Survey p. 11), I present a survey of literature relevant to the thesis drawn from two broad areas. I first present an overview of the variety of gesture interface research that has been undertaken and show that the technical feasibility of gesture interfaces has been demonstrated for a wide range of applications and map out some of the variety of gestural movements that have been employed in these interfaces. I then take up an existing critique, originally made by Cassell of the ways that 'gesture' has been conceived in gesture interface research compared to research into human gesture (Cassell, 1998). In the time since Cassell first made this critique, there has been an increase in awareness within gesture interface research toward gesture research. Prominent gesture researchers such as McNeill are now regularly cited within the gesture interface literature. However, the disparity Cassell identified between the conception of gestures in gesture interface research and that of gesture researchers in large part still remains. Through an examination of the broad area of gesture research that McNeill contributes to, I propose that one reason for this is the *communication* focus of much of this research. I go on to identify other traditions of gesture research, which have a broader conception of 'gesture'.

These other traditions of gesture research are much less frequently cited in gesture interface research, but may prove useful in informing the design of gesture interface systems, so are deserving of more attention.

In order to assess the appropriateness of these different strands of gesture research for gesture interface design, it is important to engage in the design of a gesture interface for an authentic context of use. Adopting this approach has a profound effect on the organisation of the research and requires careful consideration of the methodological consequences. I present the reasoning I worked through for organising the research methods in chapter three (Design-Engaged Research, p. 49). I draw literature from within the field of HCI and the broader area of Design Research to articulate my approach with respect to two key issues that design researchers face. These are: how design artefacts can contribute to research, and how design practice can be integrated into a process of research. An important methodological contribution of the dissertation is the approach I took of engaging in a detailed analysis of the work of existing dentistry practice *following* and *grounded by* my design process as a way of articulating some aspects in which gestures play an important role in the work of dentistry. This approach suggests the potential for a widening of the possible relations between design research and other more analytically focused research approaches.

I devote the whole of chapter four to describing in detail the design project that I engaged in for the research (Designing for the Dental Surgery, p. 77). The design project was carried out in the context of the dental surgery and ended up concentrating on the problem of how to design a gesture interface to support dentists in accessing and updating an electronic patient record during a routine examination. This is a long chapter, because it deals with the whole design process, from initial contextual enquiries in the design context, through the framing of the design problem, development of a design concept, and the final collaborative design evaluation of a working prototype. The chapter deals with the specifics of one design project, so it would perhaps be a mistake to draw out too general lessons for the process of gesture interface design. Nevertheless, several novel design methods were developed which seemed useful in the process and may be of value to other gesture interface designers. The main contribution of the design project, in terms of this thesis is in the knowledge that was built about the work of dentistry, the role that gestures play within this, and what possibilities there might be for gesture interfaces to support this work.

Engaging in this process of design gave me a good understanding of the work of dentistry and the role that gestures play in it. However, there were aspects of the roles that gestures play in the work of dentistry, which were pertinent to my research question but difficult to demonstrate in the dissertation based on the design project alone. I therefore undertook a subsequent analysis of one episode of interaction from a dental exam that had been video-recorded during the design project. The results of this analysis are presented in chapter five (The Gestures of Dentistry, p. 159). The chapter first describes the analytic approach taken and gives an overview of the setting within which the data was gathered. The next two parts of the chapter then present several vignettes showing instances of gesturing within the examination. The first of these parts includes instances of gesturing related to explanations given by the dentist to the patient about the shape and structure of the teeth and jaw, which I label 'tooth gesturing'. The second part, examines the relation between gestures and the coordination of the work of the examination. I label the gestures involved in this aspect of the work 'coordinating gestures'.

I turn back to a discussion of existing gesture research for gesture interface design in chapter six (Discussion, p. 207). The discussion begins with and mainly concentrates on the work of McNeill, because of his prominence within gesture interface research. It is shown that McNeill's definition and taxonomy of gesture is a good fit for sequences of 'tooth gesturing' identified in chapter five. Additionally, through a commentary on a design concept developed early in the design project, it is shown how his theory can give relevant insights for design. In the later part of the discussion, I consider the examples of 'coordinating gestures' and show how these are less amenable to definition and description within McNeill's framework. I argue that this is because of the focus of this kind of gesture research on purely *communicative* movements. Drawing on the areas of gesture research with a broader conception of gestures identified in the literature survey, as well as discussions from within HCI on the notion of context, I discuss how these broader conceptions can be useful to gesture interface researchers in the ways that they frame movements as gestures for design. This discussion is also situated in relation to the experiences and results of the design project. I argue that it is important that gesture interface designers maintain a commitment to *design* for particular contexts rather than hoping that pre-existing theoretical frameworks will allow us to create better or more natural gesture interfaces.

The final chapter of the dissertation presents conclusions, implications, and suggestions for further research (Conclusions and Implications, p. 257). This chapter is in large part a reflection on the relationship between theory and design, which is a theme that runs throughout the thesis. I argue that the usefulness of theory for design will always be contingent upon the particulars of the design context. Therefore, the development of theory for gesture interface design is likely to require a continuing programme of research in which gesture theory, design practice, and technical means are brought together in the design of gesture interfaces for authentic contexts of use.

This kind of integrative research is difficult and risky to carry out, but vitally important for the development of the field. Given the potential scope of such an undertaking, it is important to be circumspect about what can be achieved. This thesis will not go as far technically as a solely technical thesis, as far theoretically as purely theoretical thesis, or as far in design terms as a solely design focussed thesis. However, by moving between these areas, it is hoped to contribute a first small step to a more integrated approach to gesture interface research.

Chapter 2: Literature Survey

In the field of Human-computer interaction, gesture interfaces have been a subject of interest for almost as long as the field itself. If we reflect on the way we use gestures in our everyday lives, it is easy to understand researchers' motivation for trying to make computers responsive to gestures. In our everyday world, gestures form an important part of how we interact with one another. We use gestures to help us make ourselves understood and other peoples' gestures help us understand them. However, does the work that has been done within gesture interface research line up with what we know about human gesture? Are there further areas of human gesture research that could be drawn on to enrich gesture interface design?

This chapter begins with a survey of representative examples of gesture interface research to give a sense of the breadth of research that has been undertaken. This field of research has been concerned predominantly with the technical challenges of detecting and recognizing movements as gestural interactions, or with exploring what interaction possibilities are opened up by technical advances. No single type of movement is consistently identified and employed as a 'gesture' within this research, either explicitly or implicitly through the kinds of movements that are employed as gesture interactions. What gets framed as a 'gesture' in gesture interface research is largely determined by technical feasibility and consequently encompasses a wide range of different kinds of movements.

Following from this last point, in the middle part of the chapter I take up an existing critique of the kinds of movements that are employed in gesture interfaces compared to the kinds of movements that many researchers into human gesture take as their focus. Gesture research is a growing area that attracts researchers from a range of different disciplines and viewpoints, so it is not really possible to point to a single unified view or theory of gesture. Nevertheless, much gesture research focuses on the communicative function of gestures, especially gestures accompanying spoken discourse. Certainly, within gesture interface research it is a prominent few of these *communication-focussed* gesture researchers that are most widely cited. This is somewhat puzzling, given that these researchers all *define* gestures in terms of their communicative functions, which cuts out many of the movements that might be employed as gestural interactions in gesture interface research. I focus in particular on the work of the cognitive linguist, David McNeill, who is one of the most widely cited gesture researchers within gesture interface research. If we are to draw on elements of McNeill's research for gesture interface research, we must first appreciate the purposes behind his research. McNeill's aim in researching gesture is to explain the underlying cognitive processes of spoken and gestural discourse.

In the final part of the chapter, I present some broader views of gesture than the communication-focussed gesture research exemplified by McNeill. The authors within this section are not widely cited within gesture interface research. Yet, their work opens up for a wider conception of gesture, which is deserving of consideration from gesture interface research.

2.1 Development of Gesture Interface Research

The banner 'gesture interface' has a long lineage within the field of Human-Computer Interaction and encompasses many different approaches to interaction. The common ground across gesture interface research is a desire to improve computer interfaces by allowing people to employ gestures as an input modality. As we shall see, precisely what is meant by 'gesture' here is difficult to pin down. This is due both to the breadth and long history of gesture interface research and to the fact that the predominant concerns of gesture interface research have been with the technical challenges of detecting and recognizing gestures or with exploring the interaction possibilities afforded by technical advances, rather than the nature of gesture itself. The wide range of different kinds of movements covered by the term 'gesture' in this field ranges from two dimensional pen movements, to pre-defined hand-postures, to gestures with input devices, to attempting to respond to spontaneously occurring conversational gestures.

From the earliest years of human-computer interaction as a field, researchers have researched and written about the possibility of employing gestures as a mode of input. In 1963, the pioneering SketchPad system used light-pen gestures from a RAND tablet in a drawing application (I. E. Sutherland, 1963). Several other interfaces employing two-dimensional 'pen gestures' were based on the RAND tablet, notably a text-editing application where people could use proof-reader's symbols to edit the text (Coleman, 1969) and the related GRAIL (Graphical Input Language) project, in which a system was built that let people construct flowcharts using only light-pen interactions (Ellis, Heafner, & Sibley, 1969). The GRAIL system could recognise quite a large set of gestures, including upper-case English letters, numerals, six shapes for flowcharts, an erase gesture, and seventeen 'special symbols'. Since this time, so-called Pen User interfaces have become widely used in mobile computing and more recently in tablet computers. Though it might seem strange to consider the movement of a stylus on a flat surface as a gesture, researchers have found that pen-based computing does retain some of the temporal relationships with speech as those between natural gesture and speech production (Quek et al., 2002). Within the literature on pen-gestures, the key characteristic that seems to define these interfaces as 'gestural' is not the form of the input device itself, but that the continuous line of input from the pen is interpreted into discrete symbols (e.g. the proof-reader symbols of the GRAIL system). Accordingly, other kinds of two-dimensional input devices (e.g. the mouse) can be used in a gestural fashion (Moyle & Cockburn, 2003) and two-dimensional gestural interactions can be combined with other interaction styles such as direct manipulation and menu-selections (Kurtenbach & Buxton, 1991).

The capability for three-dimensional position tracking was also developed early in the history of HCI, during the 1960's. The Lincoln Wand was a hand-held device that used ultrasonic signals to track the position of the wand in space (Buxton et al., 2005). At around the same time, an early virtual reality environment was developed that used a mechanical linkage to track the position and orientation of a users' head within an area of several meters (I. E. Sutherland, 1998). The user wore a head-mounted display showing a virtual scene. Position information derived from the mechanical linkage was used to update the picture to give the impression of looking around and moving in a three-dimensional space. Virtual reality applications have continued to be a significant portion of gesture interface research and saw renewed interest in the 80's with increases in computing power and the availability of improved input devices such as the DataGlove (Sturman & Zeltzer, 1994).

Position tracking continued to improve during the 60s and 70s and by the end of the 70s the 'Polhemus' position tracking system was introduced. This system used magnetic fields to determine the position. The user would wear a small box that could detect its position and orientation in a three-dimensional magnetic field. These position sensors were used in the widely referenced gesture interface described in the paper titled, 'Put that there' (Bolt, 1980). Using this system, people could point to a location on a projected video image and create or modify shapes by issuing an accompanying speech command. This interface is the seminal example of what has become known as a multimodal interface. Gestures have continued to be an important part of multi-modal interface research (Billinghurst, 1998).

Computer Supported Cooperative Work (CSCW), with its focus on how people carry out work as a collective undertaking highlighted the importance of factors such as tacit knowledge and the physical arrangements of artefacts and space as well as gestures for the accomplishment of work (Tang, 1991; Heath & Luff, 1992). The focus of CSCW on supporting collaborative work naturally called for the development of interfaces that could accommodate the interactions of multiple users. A common approach has been to provide large shared displays that users can interact with using gestures. One interesting example introduced the notion of collaborative gestures, that is, gestures that interpret the coordinated gesturing of more than one person as a single command (Morris, A. Huang, Paepcke, & Winograd, 2006). The system provided a drawing program where up to four users could collaborate on the creation of a picture. It was implemented on a DiamondTouch display (Dietz & Leigh, 2001), which is a large format display capable of detecting multiple touch inputs. Collaborative gestures used by the system were used to control functions of the software such as modifying properties of the drawing of another user, passing an on-screen image to another user, clearing the screen, combining photos and so on. The kind of gestures included pointing and dragging movements with the finger and a small number of hand-postures. Another system, called 'ClearBoard', was designed for enabling collaborative drawing by remote users (Ishii & Kobayashi, 1992). This consisted of two networked whiteboards where video from each was transmitted and projected onto the whiteboard of the other to create the illusion that both sides were drawing on the same surface, but from different sides. An interesting aspect of the system is that it did not use gestures as a direct input modality, but the goal of supporting gestural interactions between users was an important consideration for the researchers. This was achieved by displaying the video of users in such a way as to allow their partner to maintain a shared spatial orientation and awareness of posture, gaze and gesture.

Coming to prominence at the start of the 90's, ubiquitous computing (Weiser, 1991) was the recognition (or vision) of a change in the nature of interactive devices away from single user general-purpose desktop computers to multiple smaller dedicated computing appliances and 'smart' environments. The advantage being that people could draw on their experiences interacting with the world to assist them in their interactions with computational technology and technology could become invisible and our interactions with it more natural. Gestures are a plausible input modality for this kind of interface, especially gestures that allow users to interact unencumbered. A typical example was a 'smart room' instrumented with video cameras, which allowed users to interact with computational elements by gesturing to the camera (Pentland, 2000b). This work relied on technological development of machine vision techniques that made it possible to detect people in video frames and respond to their movements in real time. Since this time, camera-based gesture detection has become one of the most common technologies underlying gesture interfaces, especially in ubiquitous computing systems.

Another significant strand of gesture interface research has been in the area of embodied conversational agents (Cassell, 1998). These are systems where on-screen characters are animated to make gestures along with their speech. A common aim of such systems is to make systems more engaging to users, for example in a museum guide context (Corradini et al., 2004). Application has also been made of these techniques in sign-language synthesis for teaching purposes (Yeates, Holden, & Owens, 2003). Embodied conversational agents are notable in comparison to other kinds of gesture interface systems in that they often focus on the synthesis of gestures in addition to the detection of gestures.

More recently, gesture interface ideas have been applied to mobile computing applications. In many cases, this work is a continuation of two-dimensional pen user interface gesture interface research (Pirhonen, Brewster, & Holguin, 2002), but examples of three-dimensional gestures are also possible. For example, one system used a small infrared sensitive camera embedded in a pendant, which users could make movements in front of and have these movements recognised as gestures (Gandy, Starner, Auxier, & Ashbrook, 2000). Researchers have also demonstrated the feasibility of using camera-enabled mobile phones as a form of gesture input device. One method is to face the camera away from the user and use variations in the stream of pictures from the camera to deduce movement, thus allowing a user to draw two-dimensional gestures by moving the camera (Wang, Zhai, & Canny, 2006).

2.2 A taxonomy of gesture interface interactions

By way of introduction in this short history, we have seen some of the strands in gesture interface research. In pen-based user interfaces gestures are made with a stylus on some kind of tablet input device. In virtual reality interfaces gestures are used as a means of interaction in a virtual world, often using gloves as input devices. In ubiquitous computing interfaces gestures are used to interact with a computationally augmented environment often detected by cameras. In CSCW there has been recognition of the importance of gesture for coordinating work and attempts to utilise gestures as a means of interaction between multiple users, often around large shared display devices. In embodied conversational agent interfaces, gestures are used as a way of animating computer-generated characters and for interpreting the gestures of the user. These developments have been made possible by developments in technology, as well as being spurred by the wider trends of human-computer interaction.

Surveying the technologies and paradigms of gesture interface research is useful for giving an overview of the historical development of this stream of research, but it doesn't help much for putting together a view of the range of different movements that have been employed as gestural interactions within gesture interfaces. In this section, I use an existing taxonomy for gesture input, which relates user actions on one dimension and the relations of these to system actions on the other (Sturman & Zeltzer, 1993).

Alternative classifications of the kinds of gestures employed in gesture interfaces have also been proposed. Kurtenbach and Hulteen presented an organization of the uses of gesture in computer interfaces based on the degree of multi-modality in the interaction (Kurtenbach & Hulteen, 1990). At one extreme of the continuum, gestures are accompanied by other modes of input and the gestures function as arguments or modifiers for the interaction. At the other extreme, gestures are the primary channel of interaction. Wexelblat identified two broad categories of approaches to open-handed gesture recognition systems. The first category contains systems in which the hands are used as a sort of 3D mouse for direct manipulation. The second category contains systems where the hands are used to create a command language for command-based inputs (Wexelblat, 1995). Quek et al. identify two types of gestures around which the research so far has been focussed. They call these, manipulative and semaphoric gestures (Quek et al., 2002). They define manipulative gestures as those that tightly couple the actual movements of the gesturing hand or arm to the entity being manipulated. Semaphoric gestures, are defined to be any gesturing system that uses a predefined dictionary of static or dynamic hand or arm gestures. Other authors have provided reviews of gesture interaction based on particular technologies (eg. vision (Pavlovic, Sharma, & T. S. Huang, 1997), (Wu & T. S. Huang, 1999) and glove-based (Sturman & Zeltzer, 1994)).

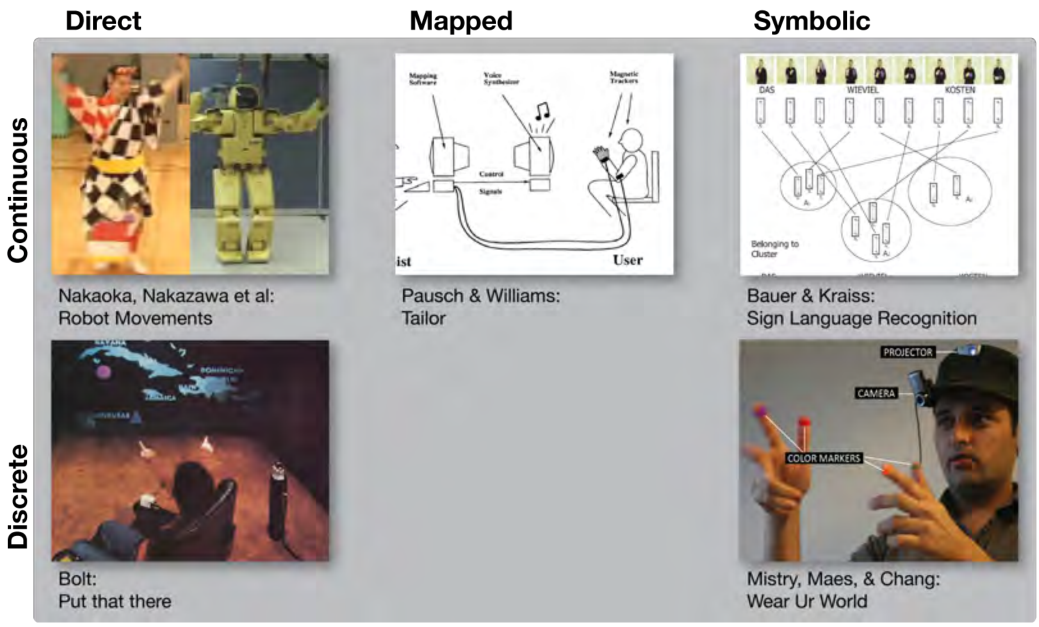


Figure 3: A taxonomy of gesture interfaces.

Though the taxonomy I use here was originally developed for glove-based input devices it can also be applied to other types of gesture input technology and accommodates the categorisations of other researchers (Wexelblat, 1995; Quek et al., 2002). On one dimension, the taxonomy distinguishes between discrete and continuous control and on the other between direct, mapped, and symbolic relations between gesture and computer actions. The taxonomy is presented in Figure 3 along with pictures of five representative gesture interfaces, which I discuss in detail in the following sections.

2.2.1 Continuous, direct gesture interactions

Nakaoka, et al. describe a system whereby the movements of a robot could be generated from human dance gestures (Nakaoka, Nakazawa, Yokoi, Hirukawa, & Ikeuchi, 2003). First, human dance motions were recorded using motion capture and were then used to generate a symbolic representation consisting of primitive motions consisting of essential postures in arm motions, and step primitives in leg motions (Figure 4).

Figure 4: Creating robot motions from human dance (Nakaoka et al., 2003).

In terms of the taxonomy in Figure 3, this system consists of continuous input from the person dancing with a direct relationship between the movements of the dancer and the robot. Such interactions are rather rare in gesture interfaces. Usually the gesture interface does not respond with such a *direct* mapping of continuous human gesture, but for the task of programming robot movement, it is a plausible approach.

The authors state that although there are general abstract models for describing human behaviour, they felt it was necessary for their application to have a model specific to dance. Their model has a two-level structure. On one level are *motion primitives,* which describe the high-level structure of the dance, like a musical score. On the other level are *styles,* which express skill or characteristics of motion details. Interestingly, the authors mention that the motion primitives 'represent the intentions of the dancer in some sense', so this model for imitating human behaviour also in a sense a model of human movements and their relationship to intentions.

2.2.2 Continuous, mapped gesture interactions

Tailor (Figure 5) was a system for generating speech synthesis using gesture input to allow people with disabilities such as cerebral palsy to produce speech (Pausch & Williams, 1990). The program used an articulator driven speech synthesis technique to produce synthesised speech from a computer model of the parts of the mouth and vocal tract that shape speech sounds (the articulators). Analogue gesture input into the program provided parameters to alter the shape of the articulators in the computer model and thereby the resulting sound. The key features of the system were that it could be customised to users with different movement abilities and that it could compensate for user fatigue by adjusting the mapping from inputs to program parameters.

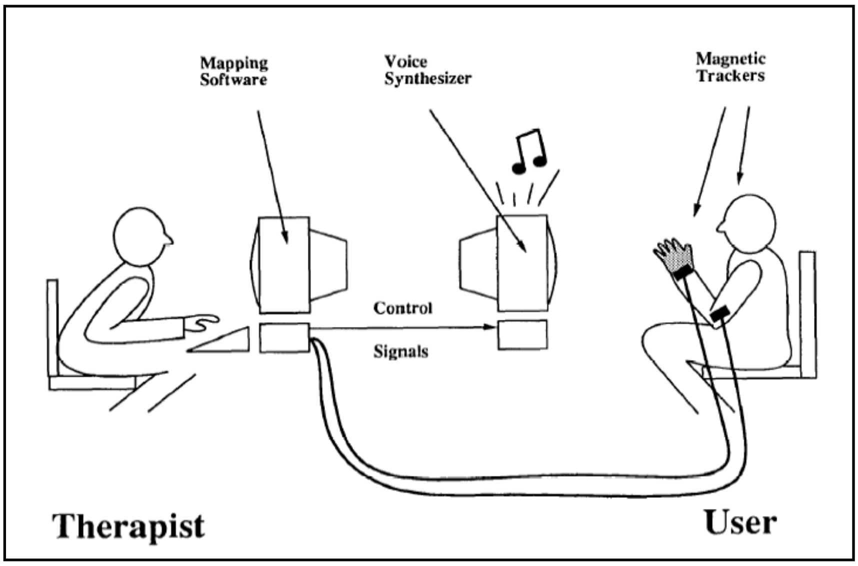


Figure 5: Mapping movement to speech synthesis (Pausch & Williams, 1990).

In the terms of the taxonomy shown in Figure 3, this system combines continuous input with a mapped relationship between the movement and the system actions. This means that the input can be extensively customised for different users with different movement ranges and levels of control. This work is unusual in that the authors go on to describe the process a therapist would follow with individual users to design a mapping from their best range of physical motion to the inputs of the program. In this process, the input device is first used to record the user's movements to determine what arcs and extents of movement are comfortable for the user. From this, an ideal curve is generated and mapped onto the inputs of the program. The process of generating this mapping requires the input of therapist and user, as well as computational assistance.

2.2.3 Continuous, symbolic gesture interactions

A common application of gesture recognition has been the task of recognising sign languages. Bauer and Kraiss present a video-based system for recognising continuous input of German Sign Language (Bauer & Kraiss, 2002). Recognition of continuous data is a more difficult problem than recognition of discrete input data. A particular problem for this type of recognition is how to segment a stream of continuous input data into appropriate frames for a recognition system.

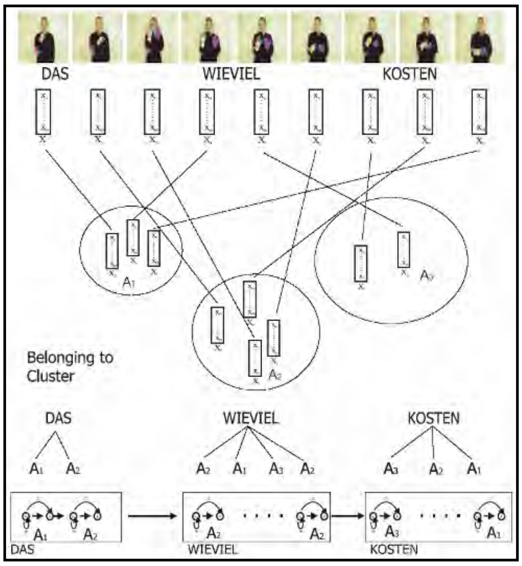


Figure 6: Continuous recognition of Sign Language (Bauer & Kraiss, 2002).

In this system, the problem of segmentation was addressed by using a Hidden Markov Model method for gesture recognition. A Hidden Markov Model is a statistically derived, probabilistic state transition model, which is trained to match an input pattern. A gesture recognition system that uses Hidden Markov Models would typically have one model for each different gesture to be recognised. When an unknown gesture is made, the system compares it to the models and can tell which model it fits to best (Rabiner, 1989). In the system developed by Bauer and Kraiss, Hidden Markov Models were developed that matched sub-units of sign language gestures. Given a continuous stream of input data, the system was able to build a tree of probable sub-units, which could then be formed back into complete signs (Figure 6).

The use of sub-units is an interesting aspect of the work and deserves further explanation. The concept of sub-units is more familiar in speech, where we have the notion of phonemes to represent the sound-components of words. Phonemes have proven useful in speech recognition, because rather than training a separate Hidden-Markov Model for each word, it is possible to train fewer, more generalised models at the level of phonemes. This has a number of benefits, it makes the problem of recognition less computationally expensive, it makes recognition systems more extensible, and it makes the system more speaker-independent.

A difficulty in applying the idea of sub-units to gesture recognition is that although there are some phonetic models of sign languages, they depend on simultaneous production of subunits (Armstrong, Wilcox, & Stokoe, 1995, p. 69), or where sequential schemes are used, "…no unified lexicon of transcription based on this approach exists for sign language" (Bauer & Kraiss, 2002, p. 70). Given these problems, Bauer and Kraiss adopted a different approach, in which sub-units were automatically derived from training data using a k-means clustering algorithm. Sub-units derived in this way were called fenones.

2.2.4 Discrete, direct gesture interactions

A notable early gesture interface was 'Put that there' (Bolt, 1980). Using this interface, a person could point to a position on a screen and issue an accompanying speech command to create, move or alter a shape (Figure 7). This is the archetypal example of a system that combined (deictic) gestures and speech in a so-called multi-modal interface. The system consisted of a large back-projection screen displaying a map and a number of shapes. The users arm position was tracked using a magnetic position sensor, and their speech was detected with a head-mounted microphone.

Figure 7: 'Put that there' combined deictic gestures and speech input (Bolt, 1980).

In terms of the taxonomy shown in Figure 3, this system combines discrete input with a direct relationship between the input and the action. Although the user's pointing gestures are continuously interpreted by the system, the actual input is restricted to a discrete coordinate based on the accompanying speech input. The speech and gesture played complementary roles in the interface. A typical command might consist of a spoken component, 'put the blue circle there', with an accompanying gesture specifying the location referred to by the pronoun 'there'. However, an interesting aspect of the interface is that the speech and gesture did not need to be combined in fixed ways. A user could specify a command using speech only, (eg. 'Put the blue circle to the left of the yellow square') or with gesture playing a much more prominent role, (eg. 'Put that there', with gestures specifying the positions referred to by 'that' and 'there').

Since the development of the Put That There system, many other researchers have explored the possibilities of multi-modal interfaces that combine speech and gesture. Eighteen years later in a review of this literature, Billinghurst observed that, despite a body of research showing the potential benefits of combining speech and gesture as an input method and a well developed technical capacity for performing speech and gesture recognition, such interfaces had not been widely adopted (Billinghurst, 1998). Following from this review, the author identified several recommendations for the design of these types of interfaces noting that 'the most important recommendation is to carefully consider the appropriateness of multi-modal input for the particular application and to evaluate the user interface at every step of the design process' (Billinghurst, 1998, p. 62).

2.2.5 Discrete, symbolic gesture interactions

An example of a gesture interface that employs discrete, symbolic gesture interactions is the 'Wear Ur World' (also known as 'SixthSense') system. This is a wearable computing platform with a novel gesture interface (Mistry, Maes, & Chang, 2009). The interface is notable because it combines elements of augmented reality, wearable computing, tangible computing and gesture interactions. A user wears a hat-mounted projector and camera attached to a mobile computer. The projector is used to display digital information on surfaces and objects in the physical world. The user can interact with this information with hand gestures, which are detected by the camera (Figure 8).

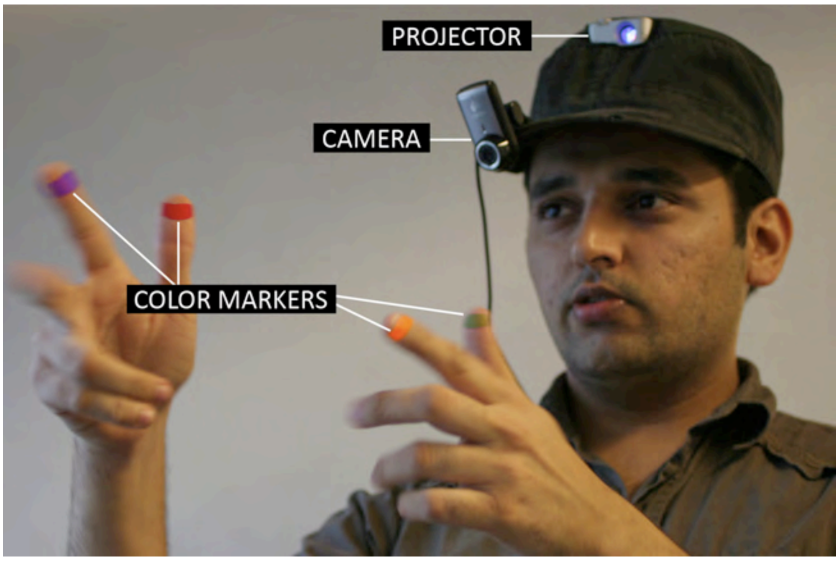


Figure 8: Wear Ur World: Discrete symbolic gestures (Mistry et al., 2009).

The system was prototyped with several simple interactive programs in order to demonstrate the feasibility and usefulness of the approach. These included a map application, a drawing application, a photo-capture application, and a weather application. In terms of the taxonomy in Figure 3, these programs actually respond to a number of different kinds of control movements, including continuous direct interactions in the drawing program to move a paint brush and continuous mapped interactions in the map program for functions such as pan and zoom.

What I want to draw attention to here are the discrete, symbolic gesture interactions that were used as commands in the system. These are either in the form of discrete hand-postures, such as a two-handed 'framing' gesture made around a scene that the user would like to take a picture of in the photo-capture application, or line symbols traced out in the air with the index finger, such as a 'star' symbol, which launches the weather application.

2.3 What does 'gesture' mean in gesture interface research?

There is a strong technical focus in gesture interface research. Researchers in this area have demonstrated the technical feasibility of gesture as a means of input across a wide variety of settings and explored interaction possibilities of new technologies as they have become available.

The related question of what are the theoretical understandings of gesture that might be appropriate for informing gesture interface design has received much less attention. It should be clear from the preceding sections that 'gesture' in gesture interface research glosses a range of different kinds of gesture interactions. As I have shown, gestures can be taken as continuous or discrete inputs by gesture interfaces, and the relation between gestures and system actions can be either a direct, mapped, or symbolic. Gestures can consist of two-dimensional movements of a pen, mouse or finger. They can be static hand-postures, or short pre-defined movements. They can involve pointing gestures and can rely on a speech modality for additional input. They can be recognised from continuous sign-language production. They can co-exist with other interaction approaches such as direct manipulation. They can even be drawn from continuous movements of the body and used to control movements of robots or speech synthesis programs.

The argument given for employing gestures as an input modality in gesture interface research, is often to do with their *naturalness*. To take just one example from the preceding discussion, the 'Wear Ur World' system projects digital information onto the physical world and 'proposes natural hand gestures as the mechanism to interact with that information' (Mistry et al., 2009, p. 4112). This claim of naturalness, which is often made for gesture interactions, is worth questioning. We need not accept a-priori that there is an advantage of pre-defined gestures over simply having a short-cut keyboard combination (Wexelblat, 1997). One plausible area to look to, for an understanding of what 'natural' gesture might be is the body of research into human gesturing. I survey some work from this area in the next section. I will be particularly interested in the following question: *are the 'gestures' of gesture interfaces the same as the 'gestures' of human gesture research?*

2.4 Gesture Research

Just as there are many different approaches to the idea of gesture interfaces, so are there many approaches to the study of gestures themselves. Gestures have been a phenomenon of interest for many different fields and this has resulted in a wide variety of theoretical perspectives on the subject. In this section, I survey some of the different theoretical approaches to gesture research into human gesturing. The purpose is to look at how different researchers have viewed gesture and to provide a background from which to consider how appropriate to the needs of gesture interface design these different strands of research are.

When approaching this research on gestures, we first need to establish how gestures are defined by researchers, because this determines what kinds of movements get considered as gestures and can help us understand the purposes of the research. As we shall see, there is quite some diversity in how gestures are defined by different gesture researchers, with some drawing a much tighter frame around what movements they consider as gesture, and others including a much broader range of movements. One aspect of gestures that all definitions do agree on is that they consist of movements of the body. Beyond this, most definitions choose one or more further characteristics to distinguish gestures from other types of human movement. Four basic dichotomies that appear to have been useful for researchers when attempting to define gestures are listed below in Table 1 (Nespoulous & Lecours, 1986).

Table 1: Four dichotomies in definitions of gestures.

Act Movements that are used to effect a material action in the world.	**Symbol** Movements that are made for a communicative purpose.
Autonomous Movements that exist independently of other modes of communication.	**Partial** Movements that rely for some part of their meaning on another communication modality.
Centripetal Movements made for the benefit of the person gesturing (gesturing to yourself).	**Centrifugal** Movements intentionally directed toward another person.
Transparent Movements with a self-evident meaning.	**Opaque** Movements with an unclear meaning.

The most important of these dichotomies for gesture research is the act – symbol dichotomy. This sets up a distinction between movements that are used to effect a material action in the world (act) and movements that are employed for a communicative purpose (symbol). By this distinction, what we might in everyday language describe as gestural marks of a painter would not be described as gestures, but the gestures of art-gallery patrons as they discuss her painting would be.

The autonomous – partial dichotomy distinguishes between gestures that are produced independent of other communication modalities on the one hand (autonomous) and those that rely for their meaning on a co-occurring communication modality (partial). This would distinguish between for example, the semaphore-like gestures of a traffic police officer and the pointing gestures that might accompany a verbal explanation of which route to follow on a map.

The centripetal – centrifugal dichotomy distinguishes between movements that are made for the benefit of the person gesturing (centripetal) and those that are intentionally directed toward another person (centrifugal). This would distinguish between a gesture we might make for our own benefit such as counting off on the fingers as we think through a list of items and a gesture where we communicate a particular number to another person by holding up a corresponding number of fingers.

The transparent – opaque dichotomy distinguishes between gestures where the meaning of a gesture is self-evident from the form of the gesture (transparent) or less so (opaque). The idea that gestures might provide the basis for a universal language of human communication was of great interest to gesture researchers historically (Kendon, 2004, pp. 38-40). Of course, we now understand that all gestures depend on a shared cultural understanding for the interpretation of their meaning, so it is not really possible to speak of any gesture as being truly 'transparent'. Nevertheless, one may distinguish between gestures with a more conventionalized and abstract relation to their meaning and those that are more iconic and imagistic. In this way, some gesture researchers would distinguish a conventionalised 'ring' gesture made by forming a circle between the thumb and index finger and extending the remaining fingers, from a gesture where someone mimes the action of running. Whereas the former relies strongly for a shared cultural knowledge of its conventional form and meaning, the latter has a more iconic and referential relation to a common physical action.

If we examine any of these dichotomies in detail, we are likely to be able to find examples of gestures that blur the boundaries between one or other of the distinctions. For example, can a counting-off gesture that is made in the presence of another person really be said to be either purely for the benefit of the person making it or for purely for the benefit of their partner? The truth is, there really are not clear boundaries between gestures and other kinds of movements. As the prominent gesture researcher, Adam Kendon states, 'it is not possible to specify where to draw the line between what is gesture and what is not' (Kendon, 1997, p. 109).

2.4.1 A continuum of kinds of communicative gestures

Despite the difficulty of drawing firm boundaries around precisely which movements are gestures or not, most gesture researchers take *communicative* movements as their main point of focus (the act – symbol dichotomy above). Kendon, for example, defines gesture as movement where 'an individual engages in movement whose communicative intent is paramount, manifest, and openly acknowledged' (Kendon, 1986, p. 31).

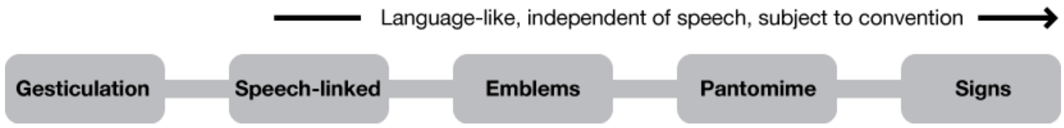


Figure 9: Kendon's continuum of communicative gestures.

Different types of communicative gestures can be ordered on a continuum based on their relationship to speech as shown in Figure 9. This arrangement is known as 'Kendon's continuum', however it was arranged into the continuum shown here by McNeill (McNeill, 1992, p. 37). I use the terminology of McNeill's later formulation, which differs slightly from how he originally presented it (McNeill, 2005, p. 5). As we move from left to right along this line, gestures become more language-like, more subject to cultural conventions and less dependent on speech.

At the right-most end of the continuum is the category of *signs*, which are the gestures employed in fully formed gestural language systems, such as those of the deaf. The gestures employed in sign languages perform the same role that speech does in spoken languages and sign languages assume the same structural properties characteristic of spoken languages (Goldin-Meadow, 2005, chap. 13). Sign languages are not derived from spoken languages, but instead have their own distinct structures. Nevertheless, sign languages share many characteristics with spoken language. They have lexical store of signs, with standards of form. There are also grammatical and morphological patterns for combining signs into meaningful sentences (McNeill, 2005, p. 5). Sign languages also share with spoken languages the characteristic that a community of practitioners exists who understand, use and maintain the language. Indeed, the structure of American Sign Language is different from the structure of British Sign Language (Goldin-Meadow, 2005, p. 195).

Second from the right end, *Emblems* are culturally conventional gestures such as a 'thumbs-up' gesture. Emblems are usually produced independently of speech. Unlike the signs of sign languages, emblems do not form part of a linguistic structure, but they do adhere to standards of form. This means that there is a correct way to perform an emblematic gesture. For example, if a person were to extend their thumb and *open* their hand rather than holding it in a fist, they would no longer be performing a 'thumbs up' gesture (Goldin-Meadow, 2005, p. 5). Though they do not comprise part of a structured linguistic system, emblems do share some characteristics with the signs of sign languages, as follows: they typically consist of a relatively limited set of hand shapes, movement patterns and locations of performance; they are usually performed one-handed, but when they do involve two hands, there is often a high degree of asymmetry between the hands; and a high proportion consist of some articulation to a part of the head or face (Kendon, 1995a, p. 52).

Frequency, form, and meaning of emblem gestures are variable between cultures. Kendon, for instance, has carried out studies of gestures within a Southern Italian context where there exists fairly large vocabulary of emblems, which are employed extensively in communication (Kendon, 1995b). He has found that such gestures are frequently employed in parallel verbal expressions, which can have equivalent or contrasting meanings (Kendon, 2004, p. 177). This highlights that though emblems are often defined as being produced independently of speech, such details may be derive from particular cultural practices rather than universal features. According to Kendon, the most salient characteristic of these gestures (and the term he uses for them) is that they are 'quotable', meaning that people can recall them if asked and can produce a gloss for them (Kendon, 1995a, p. 50).

Pantomimes are gestures made to depict objects or characters or to act out actions. Like emblems, pantomimes are usually produced independently of speech, though they may be accompanied by onomatopoeic vocalisations (McNeill, 1992, p. 37). An example would be acting out the action of a story without words. Studies of deaf children raised by hearing parents, have found that such children often develop their own systems of gestural communication, which share some characteristics with fully developed sign languages (Goldin-Meadow, 1995). These studies hint at a possible role for pantomimes in the development of the gestures of sign languages. In one case, a boy told a story involving a motorcycle (Scroggs, 1981, as reported in Kendon 1995). At the first mention of the motorcycle in the story, the boy acted out mounting the motorcycle, starting it up and revving the motor, all through an elaborate pantomime. On subsequent mentions of the motorcycle, only the gesture of the hand revving the motor was retained. Thus, it seems that pantomimes provide the starting point from which more symbolic and simplified sign gestures can be derived (Kendon, 1995a).

Compared to signs, emblems, and pantomimes, *speech-linked* gestures are more dependent on speech, being integrated into the grammatical structure of the speech. Gesticulation (which I discuss below) is also integrated with speech, but a key difference is that speech-linked gestures are integrated with speech sequentially by substituting a gesture for a spoken verb, rather than concurrently as an imagistic complement to verbal utterances (McNeill, 2005, p. 5). For example, someone might say 'you should ______ that out' with a throwing gesture substituting for the missing verb.

On the left-most end of the continuum, *gesticulation* refers to gestures that are performed along with speech during normal conversation. In comparison to gestures to the right end of the continuum, people are less conscious of their gesticulations. However, according to McNeill, gesticulations are the most frequent kind of gestures (by which he means communicative gestures) in daily use (McNeill, 2005). Gesticulation is intricately linked to speech production, and tends to rely on contrasting modes for conveying meaning. McNeill describes the manner of expression of gesticulation as 'global synthetic' (McNeill, 2005, p. 10). By this he means that the meaning of a gesture's 'parts' depends on the meaning of its 'whole' (meaning is global) and that a single gesticulation can combine several distinct meanings, which are spread throughout the accompanying verbal utterance (gesticular expression is synthetic).

2.4.2 A taxonomy of gesticulative gestures

Of the different kinds of communicative gestures comprising Kendon's continuum, above, gesticulation has been a particular focus of research, particularly McNeill, and Goldin-Meadow, who focus on this kind of gestures exclusively. In fact, in both cases they use the word 'gesture' to refer to 'gesticulation' exclusively. McNeill's definition for gesture (gesticulation in the terms of Kendon's continuum) is *spontaneous idiosyncratic communicative movements accompanying speech*.

Within this category, several different kinds of gestures have been identified as playing a role. Although, as Goldin-Meadow notes, 'there are almost as many schemes for classifying the gestures that accompany speech as there are gesture researchers', the differences are mainly in the size and number of divisions (Goldin-Meadow, 2005, p. 7). There is, in fact broad agreement across the taxonomies of several gesture researchers (Kendon, 2004, chap. 6). Table 2 below compares four well-established taxonomies of gesture. The gestures in each row are broadly equivalent. Where no corresponding category exists, I have left the cell blank. I will describe each of these types of gesture using the terms of McNeill, which are listed in the first column (McNeill, 1992).

Table 2: Comparison of gesture taxonomies (adapted from Wexelblat, 1997, p. 4).

McNeill	**Kendon**	**Rimé & Schiaratura**	**Efron**	**Identifying Characteristics**
Iconic	Physiographic	Physiographic	Kinetographic	Picture the content of speech
Metaphoric	Ideographic	Iconic	Ideographic	Portray the speaker's ideas, but not directly the speech content
Deictic		Deictic		Pointing at thing/area; space around body used
Beats	Gesticulation	Speech-marking	Baton	Marking the rhythm of speech
(Emblems – doesn't regard as gestures as such).	Autonomous gestures	Symbolic	Symbolic/ emblematic	Standardized gestures, complete within themselves, without speech

Iconic gestures are gestures where the movements of the body directly mimic the content of the speech. For example, when a person recounting a story in which a character bent back a tree makes a hand motion that mimics the act of bending the tree, that person is making an iconic gesture.

Metaphoric gestures are similar to Iconic gestures in that they also picture the content of the speech, however metaphoric gestures do not represent a physical action or object, but an abstract idea. An example of a metaphoric gesture is a person making a gesture that presents an abstract idea such as the genre of a story as a space bounded by two hands (a conduit metaphor, in McNeill's terms (McNeill, 1992)).

Deictic gestures are pointing gestures. They may or may not point to something that is physically present. The thing pointed at can be a physical object, a place or an abstract idea. In conversation and narratives, most deictic gestures are abstract in nature. In this way, abstract ideas obtain a physical location in an unfolding conversation or narrative.

Beat gestures are rhythmic movements of the arms and hands that correspond to the rhythm of speech. Beats differ from Iconic and Metaphoric gestures in that the form of the gesture does not vary depending on the content of the speech. Beats tend to be quick movements of the hands up and down, side to side or in and out. Although beats can appear insignificant compared to other gestures, according to McNeill, they reveal a lot about the thought processes of the person making them because they tend to coincide with and give emphasis to important words in the speech (McNeill, 1992). This importance is not so much tied to the meaning of the words, as it is linked to the structural role that they play in the conversation (for example, introducing new characters, themes or summing up).

2.5 Drawing on gesture research for gesture interface design

The preceding two sections have given a very brief introduction to some of the ways that gesture researchers have defined and categorised movements as gesture. We have seen that gestures are commonly distinguished from other kinds of movements by focussing on the communicative purpose that they play. We have seen that several different kinds of communicative gestures can be identified and arranged on a continuum depending on their relationship to spoken language from the signs of sign languages through to the spontaneous gesticulations that accompany normal speech. Within the category of gesticulation itself, we have seen that several different types of gestures have been identified (beats, iconics, metaphorics, diectics), which tend to serve different functions in relation to the expression of meaning.

Though the introduction has been brief, we have enough of a picture to be able to compare back to the kinds of gestures that have been included in gesture interface research, and discuss whether 'gesture' really means the same thing across these fields. The short answer is that the gestures taken as a focus for gesture interface research and those taken as a focus for gesture researchers described above are quite different. I am not the first to make this observation; notably, Cassell has pointed out that gesture interfaces have largely ignored *gesticulations,* the spontaneous, idiosyncratic, communicative gestures accompanying speech that McNeill takes as his focus (Cassell, 1998).

Instead, she argues that the majority of gestures employed in gesture interfaces tend toward *emblems* for instance systems that use pre-defined gesture command sets. An example of this from the literature reviewed in the first part of this chapter would be the gesture commands used in the Wear Ur World system, such as where the user traces out the shape of a star with their index finger (Mistry et al., 2009). There are many examples of gestural commands like this in the gesture interface literature. Cassell suggests that their prevalence is due to the fact that they are consciously produced and therefore easier to remember (Cassell, 1998). However, it also seems likely that another factor for their prevalence is to do with technical feasibility; it must surely be more feasible to detect a gesture that adheres to pre-defined standards of form than one that does not.

Another form of gestures that gesture interfaces have employed is what Cassell calls *propositional gestures*, which are gestures that carry semantic content along with accompanying verbal utterances (Hinrichs & Polanyi, 1986). The precise distinction between propositional gestures and gesticulations is not entirely clear from Cassell's presentation, since in the examples she gives, gestures are accompanied by speech and include what might otherwise be identified as *deictic* and *iconic* gestures. Indeed other authors include iconic, metaphoric, and deictic gestures under the grouping of propositional gestures (McClave, 1998). The main distinction Cassell makes is that these are instances of gesturing in which the speaker is consciously conveying some information through the gesture and is therefore conscious of the gesture and the gesture is not spontaneous. One example of gesture interface research that Cassell discusses is the 'Put That There' system (also described in the first part of this chapter). In this system, a user could point to a shape on a projected map and say 'move that, there', with deictic gestures specifying the object to move and the destination (Bolt, 1980). Cassell argues that the interaction between these gestures and speech is more like the interaction of grammatical constituents than of complementary communication channels (Cassell, 1998). This would bring these gestures closer to the category of *speech-linked* gestures from Kendon's continuum.

Though not mentioned by Cassell, there has also been a lot of interest in gesture interface research in the area of sign language recognition. The gestures that these systems deal with are *signs* in the terms of Kendon's continuum, which as we have seen are also quite distinct from gesticulation gestures. The system from Bauer and Krais for continuous sign language recognition, which was presented in the first part of the chapter, is an example of this kind of research (Bauer & Kraiss, 2002). One motivation commonly given for pursuing this research is to develop assistive technologies for deaf people, such as automatic sign language translation systems. In most research on sign language recognition, this is the only motivation given, but Bauer and Kraiss are unusual in acknowledging a second motivation, which is, '…that sign language recognition serves as a good basis for the development of gesture human-machine interfaces' (Bauer & Kraiss, 2002, pp. 64-5). What seems attractive about sign-language recognition is that it requires recognition of a continuous stream of gestural activity (which is a worthwhile technical challenge) but also provides a vocabulary of meanings against which the accuracy of recognition results can be assessed. Nevertheless, as we have seen from Kendon's continuum, *signs* are quite unlike other kinds of communicative gestures (especially gesticulation), so it is far from clear how sign interactions would serve as a basis for gestural interactions involving other forms of communicative gestures. Moreover, as Braffort notes, given the overwhelmingly technical focus of this research, it may not even be appropriate to use the terms 'sign language recognition':

> Unfortunately, the real aim of the studies is often to validate a given technique, which is supposed to be able to give a better recognition rate, a better precision in image processing, etc. It appears inappropriate to use the terms 'Sign Language recognition' in this context (Braffort, 2002, p. 6).

Cassell's purpose in pointing out the disparity between the kinds of gestures that had been employed in gesture interface research and the kinds of gestures that had been the focus for gesture research was to highlight that *gesticulation* had been largely ignored. Cassell speculates that the root cause of this omission might be that we are often not conscious of the gestures we make when speaking, whereas other kinds of gestures, such as emblems, 'propositional gestures', and signs are more available for conscious reflection (Cassell, 1998). As I have pointed out above, it also seems likely that technical considerations have also played a role, consciously produced gestures with standards of form are more feasible to detect and respond to than spontaneous, unconscious gesticulations with no set standards of form.

According to Cassell, for gesture interface research to ignore gesticulation is a serious omission, because gesticulations make up the vast majority of our everyday communicative gestural activity (Cassell, 1998). In fact, according to McNeill, 90% of communicative gestures co-occur and are co-expressive with speech (McNeill, 1992, p. 23). As already mentioned, the notion of naturalness of interaction has been consistently invoked as a motivation for gesture interface research. Cassell states her argument for focussing on gesticulations in these terms too, stating:

> Thus if our goal is to get away from learned, pre-defined interaction techniques and create *natural* interfaces for normal human users, we should concentrate on the type of gestures that come naturally to normal humans (Cassell, 1998, p. 192).

The kind of gesture interface that Cassell went on to create from this work is known as Embodied Conversational Agents (as described in the first part of the chapter). Cassell's critique of the omission of gesticulations from gesture interface research is particularly important, because she had both studied as a graduate student within McNeill's research group and was very familiar with theories of gesture research, and was also a computer scientist and was able to apply insights from gesture research to the field of gesture interface research for the development of Embodied Conversational Agents. Her work clearly shows that there is value in crossing between theoretical understandings of human gesture and gesture interface research and her argument has been important within gesture interface research for raising awareness of research into human gesturing and a critical awareness of what it is we talk about when we say 'gesture'.

Since the time that Cassell put forward her argument, gesture interface research has become more aware of gesture research and researchers such as McNeill, Kendon and Goldin-Meadow are regularly cited within the field. We should not assume from this, however, that the relation between gesture interface research and gesture research is settled. Cassell showed how gesture theory could be used to inform the design of one particular kind of gesture interface, but there remain many other kinds of gesture interfaces for which the relation to theory is less than clear. I seek to address this in the remainder of this chapter.

2.5.1 Getting beyond naturalness as an objective for gesture interfaces

A difficulty for gesture interface research in HCI that is not often acknowledged is that understandings of 'natural' human gesture activity cannot be applied in a straightforward way to human-computer interaction. In fact, there is *no* comprehensive classification of natural gestures that would give us a complete understanding of gestures in HCI (Corradini & Cohen, 2002). This follows from Suchman's observations of the fundamentally limited capacity of computers to participate in situated human interaction (Suchman, 1987). Gestural interaction with a computer is fundamentally different to gestural interaction with another person in conversation, because computers cannot participate in gestural interaction in the same (situated) way that people can. I may very well gesture angrily *to* my computer if it makes an error as I would to an inconsiderate driver, but this is not gestural *interaction* (the computer will not console me in return). Even if the *form* of gestures taken as input to a gesture interface is identical those made to another person in conversation, the *meaning* cannot be the same, because in human conversation one is dealing with an interaction partner with whom one shares (hopefully) an inter-subjective understanding of the interaction. A rare acknowledgement of this problem from a gesture interface researcher and the implications it has for informing gesture interface design from gesture theory came from Wexelblat who wrote of his experiences of applying gesture classification systems to the task of transcribing human gesture as follows:

> …to write down classifications of the gestures required using knowledge about the scene being described and about subjects' intentions. This information would

> not be known by a computer system attempting to understand the same gesture (Wexelblat, 1995, p. 186).

Yet much of the work in gesture interface design drawing on research into human gesture assumes that transparency of interaction with computers approaching that of inter-human discourse is possible. From such a perspective, it is a logical step to look for guidance on how to shape the interactions of gesture interfaces to what is known about inter-human conversational interaction and 'the kinds of extractable features that can aid in its comprehension' (Quek et al., 2002, p. 172). Consider Cassell's vision for Embodied Conversational Agents:

> We imagine computers that communicate like we do, producing and understanding gesture, speech, intonation and facial expression, thereby taking seriously the currently popular metaphor of the computer as conversational partner (Cassell, 1998, p. 192).

Figure 10: Embodied Conversational Agents (Cassell, 1998).

As I have pointed out above and as is reflected in this quote, there is a strong assumption running through gesture interface research that employing gesture as an interaction modality for computer interfaces can help make computers more 'natural' to interact with. However, if we take the examples of gesture interfaces presented in the first part of this chapter, it really is difficult to sustain any claim of naturalness for gesture interaction. Consider the Wear Ur World system in which a user walks around with a computer and camera attached to their body, is able to project data out onto the surfaces of the environment, and interact with this information through holding their hands in a limited set of pre-defined postures. Or take Cassell's own work, in which three dimensional computer generated characters have their gestures animated to match their accompanying speech (Figure 10). Neither of these examples are natural and nor are the other gesture interface systems that I have presented. Of course this does not mean that these systems are not useful for particular tasks, or don't present interesting new possibilities to interaction. Indeed, their value may lie in the fact that they allow us to do things that are not 'naturally' possible.

Accepting Suchman's argument that the kinds of interactions we can have with computers are fundamentally different to those we can have with other people implies that we should reappraise the ideal of *naturalism* in gesture interface research. A plausible alternative goal for gesture interface research would be to seek to create systems that are a *good fit for particular contexts* of use.

On the one hand, this would serve as a constructive complement to the technical focus that persists within the field and on the other it would suggest a more critical relation to existing gesture theory. This is not to say that understandings of human gesturing would not be useful for the design of gesture interfaces, but it calls for:

- The need to understand the purposes of gesture research, not just to look at definitions and taxonomies
- The need to consider broader conceptions of gesture than purely communicative movements accompanying speech

2.5.2 Understanding the purposes of gesture research

Coming to the area of gesture research as an outsider, the concepts, categories, taxonomies and definitions of gestures that I presented earlier in this chapter provide a comfortingly clear and stable framework, which would seem to be useful for understanding the range and detail of human gestural behavior. Clear taxonomies, definitions and categories have a strong pull for HCI research, because they promise to provide a structure for organizing the world in ways that are more amenable to computational representation.

However, there is a danger in this if we accept the frames of gesture research without also understanding their purposes for adopting these frames. This is because the purpose of the research plays a big role in how researchers frame aspects of the world as either relevant to their research or not. As Nespoulous, Perron et al. observe:

> "…methods of investigation are bound to vary according to the stated objectives and to the nature of gestural behaviour studied. For instance, the analysis of a corpus of American Sign Language…obviously does not present the same problems as those raised when observing the earliest gestural behaviour of neonates…or again, when studying mimogestuality accompanying discourse" (Nespoulous, Perron, & Lecours, 1986, p. 13).

In this section, and in the later discussion chapter, I take the work of McNeill as a focus and summarize what the underlying motivations for his work are. I take McNeill, because he is probably the most widely cited gesture researcher within gesture interface research, because he has published with gesture interface researchers, and because he provides a particularly clear definition, and distinction between different types of gestures (all of which have been presented above).

McNeill is a cognitive linguist and therefore, his research endeavour draws from, builds upon, and responds to a *linguistic* research tradition (McNeill, 2005, chap. 3). He seeks to produce a general account of the relation between gesture and speech, in particular to explicate the relationship between gesture and speech in support of a hypothesis about the nature of the processes underlying their production. He seeks to demonstrate that speech and gesture are produced as a unified dynamic dialectic process of growth and differentiation between imagistic and language components of thought.

The central theoretical concept in this respect is the 'growth point'. The growth point is McNeill's term for the idea that all utterances begin as a point of meaning (or the intention to express some meaning), which grows through a cognitive process of differentiation and specialization into speech and gesture components. Speech, he argues becomes the carrier of analytic, synthetic aspects of the meaning and gesticulation becomes the carrier of global synthetic aspects of the meaning.

From this perspective, the classifications of gestures presented earlier in this chapter are not a primary concern for McNeill. This is significant, given that (as noted above) for researchers coming from traditions of computer science and engineering, the clear classification of gestures into different kinds that McNeill provides is likely to be an attractive and defining part of his work. Yet for McNeill, it is rather more a preliminary part. As he writes:

> "Gesture classification plays little role in the dialectic analysis to follow; gesture content regardless of type, is far more significant" (McNeill, 2005, p. 38).

The purpose of identifying different kinds of gestures in relation to spoken and gestured meaning is really for the purpose of identifying (and providing evidence for) how the different parts of the meaning of a growth point are distributed across the two modalities.

This is also the reason for McNeill's narrow focus on *gesticulation*, because he is interested in the integrated between gesture and speech, and gesticulation is by definition gesture that is integrated into speech. In fact, McNeill uses 'gesture' to refer to 'gesticulation' throughout his work. This is potentially confusing for those unfamiliar with his focus on gesticulation because they may assume that he is discussing a wider range of kinds of gesture than is actually the case.

The focus on gesticulation also has an important impact on the kinds of empirical material that McNeill has drawn on for his studies. The bulk of his empirical data involves occurrences of gesturing in conversational settings. He is perhaps most well known for a long-running series of studies where people are shown a 'Sylvester and Tweety' cartoon and then asked later to recount the action from this for a second person that didn't see it. Accordingly, much of his analysis highlights the narrative and storytelling functions that gestures play and usually involves one person who is the primary source of gesticulations and speech (the story-teller). Studies of gestural activity involving object manipulation or shared manual activity are noticeably absent from his work.

The focus on speech also plays out in McNeill's work in form of the transcription of instances of gesturing for analysis. Like most gesture researchers, McNeill adapts transcription conventions from conversation analysis. These transcription methods are highly developed with respect to the detail of utterance that they can record. Researchers into human gesture have been successful in augmenting them with transcription conventions for recording details of gesture. However, there are not equally developed methods for transcribing other aspects, such as positions in space or coordinated tool use.

My purpose here is to highlight that just as particular kinds of movements get framed as gestures within gesture interface research according to the kinds of movements that are available to conscious reflection, or technically feasible to detect, so to do gesture researchers frame movements as gestures according to the particular research motivations and constraints (such as access to suitable empirical material) that they work with. It is important, if gesture interface research is to borrow from gesture research that we are aware of these frames and the reasons they are set as they are.

2.5.3 Looking for broader conceptions of gesture

Within the research on human gesture that I have reviewed so far, there is a common focus across researchers on gestures on *communicative* gestures. As I showed, it is common to distinguish and separate different types of movements, leading to dichotomous definitions.

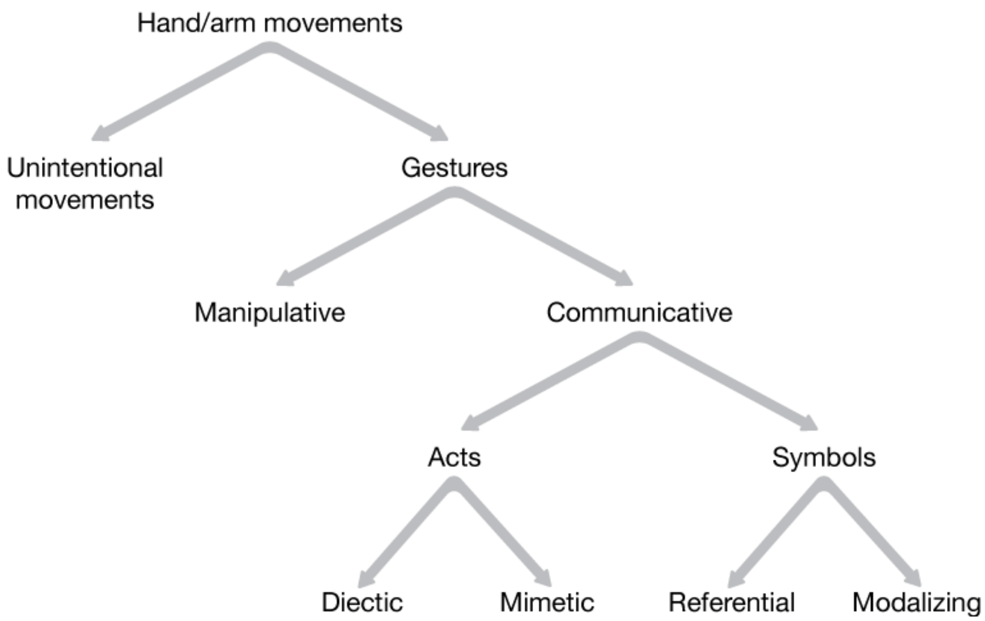


Figure 11: Taxonomy of gestures (Pavlovic et al., 1997).

This occurs both in gesture research (as we have seen) and in gesture interface research. For example, Figure 11, based on a taxonomy of gestures from within gesture interface research depicts the way that dichotomous definitions of gesture separate out different kinds of movements (Pavlovic et al., 1997). In this taxonomy, unintentional movements are defined as movements that do not convey any information (at least about intention). Communicative gestures are gestures that have an inherent communicative purpose, while manipulative gestures are ones that are used to act on objects in the environment. Communicative gestures are further distinguished into symbols or acts. In symbolic communicative gestures, the gestures play a linguistic role. Acts, on the other hand rely for their meaning on the interpretation of the action itself, for example by mimicking an action.

A popular metaphor for thinking about our interactions with computers is as a communication partner (as reflected in Cassell's quote above). Working from this metaphor, it makes sense to focus on communicative gestures. However, the communication metaphor alone is not rich enough to cover all kinds of interface. We can also conceive of the role of computer interfaces as communication media and as tools (Bødker, 1990). Consider the example of the 'Tailor' system from the first part of this chapter in which users were able to drive a speech-synthesis program through the movements of their bodies (Pausch & Williams, 1990). Here the computer interface serves as a tool for producing sound and at the same provides a medium for communication. Another example of a gesture interface as a medium is the ClearBoard in which gestures are not used as direct interactions with the system but are relayed through the system to distant collaborators (Ishii & Kobayashi, 1992). It is also possible to think of gestures interfaces from a tool metaphor. Though the system for generating robot movements described in the first part of the chapter being used to make the robot dance (Nakaoka et al., 2003), we could also imagine a technique such as this being used to robot movements for more object manipulation-type tasks. In this case, the robot could become like a tool that was controlled by the gestures of the user.

Focusing exclusively on communicative gestures is limiting for exploring these other metaphors for gesture interface design, particularly the metaphor of gesture interfaces as tools. Though the idea that only communicative movements should be considered as gesture is entrenched within the gesture research we have seen so far, it would be to the benefit of gesture interface research to look for broader conceptions of what gesture could be. As it turns out, there are strands of gesture research, which take a much broader view of what gestures are. Some of these might also be useful for gesture interface research.

Although the majority of research into gestures has concentrated on and defined gestures in relation to their communicative functions, other roles for gestures have also been identified. The developmental psychologist, Susan Goldin-Meadow has carried out a number of studies of the gestures made by children when they are working through math problems. These studies have shown that gestures play an important role in supporting the thinking processes of the person gesturing. In one study, children were shown two identical rows of checkers and then the checkers in one of the rows were spread out. The children were asked whether the number of checkers in the two rows were now different (a number conservation problem). Interestingly, some children exhibited a mismatch in between their gestures and speech in answering this question. Verbally, they answered the number had increased, but with their gestures they expressed the idea of a one-to-one correspondence by moving a pointing hand back and forth between checkers in the two rows (Goldin-Meadow, 2005, p. 28). Goldin-Meadow suggests that the children's speech and gestures convey different understandings of the problem because they have not yet developed a framework that would allow them to perceive the relation between their gestures, speech and the problem. Gestures are therefore key to the way that people explore meaning and gain information about the world through a process of learning. By allowing learners to express knowledge that is still forming, gestures allow listeners (such as teachers or parents) to respond to these gestures and support learning (Goldin-Meadow, 1995, chap. 9). Goldin-Meadow has also shown that gestures also support the thinking of the gesturer. People continue to gesture even when they are aware that a listener cannot see them and people gesture as a part of their problem solving processes (Goldin-Meadow, 2005). Roth and Lawless propose that gestures provide a link between sensorimotor experience and language (Roth & Lawless, 2002). Drawing on a large corpus of video data of high school students engaged in physics experiments, they show how gestures, which begin as action sequences, can become abbreviated and stylised as students incorporated them into a gestural and verbal discourse. They propose that this could provide a basis for theories of embodied cognition. The authors work from a perspective that sees cognition as an outcome of physical human experience in a thoroughly practical world.

Goodwin provides a perspective on gestural activity that highlights the way gestures are linked to the actions of people within a mutually constructed participation framework (Goodwin, 2000). He shows how gesture and other semiotic resources are brought into play by interactants for the construction of action within situated contexts and are simultaneously responsive to the larger activities and relevant phenomena within which they are situated. This provides a much broader analytic frame for understanding gestures. As Goodwin states, '…I argue against the usual analytic and disciplinary boundaries that isolate language from its environment and create a dichotomy between text and context' (Goodwin, 2000, p. 1490). Goodwin provides an analysis of a dispute between children engaged in a game of hopscotch. One of the players had thrown a beanbag into the fifth square and was preparing to hop to the other end. At this, another child stepped forward to challenge her, objecting that the beanbag had been thrown into the incorrect square. A number of semiotic fields (Goodwin's term to describe the deployment of signs within particular encompassing media) are brought into play. These include the words that are used to characterize the actions of the player ('cheater'), the location of the squares on the hopscotch grid, the rules of the game and the immediately preceding action of throwing the beanbag. In particular, Goodwin draws attention to the way the challenger holds up a hand showing four fingers while simultaneously saying 'this is the four and you go in the four, not the fifth'. This gesture is somewhat different to the gesticulations studied by McNeill where gestures tend to display information not contained in the speech (Goodwin, 2000). Instead, the gesture provides a visual version of the spoken numbers. In an analysis which focussed only on the spoken language, this gesture might be seen as providing a redundant versions of the numbers in the talk, but when seen within the wider context of action of the game, Goodwin shows how through the gesture, the challenger actively brings her body into a particular posture in relation to the hopscotch grid and the path of the player and in this way structures the environment within which subsequent action can unfold.

Kendon's studies of gesture follow a quite similar analytic orientation in situating gestures within a participation framework rather than analysing them with respect to existing taxonomies or theories of underlying cognitive processes (Kendon, 1990). However, his focus is more closely tied to communicative gestures themselves rather than situated conduct more generally. Another relevant body of work in a similar vein comes from the field of workplace studies, especially in relation to computer supported cooperative work. In studies of line control rooms within the London underground, Heath and Luff have explored the ways in which operators communicate information to each other and coordinate their tasks and activities (Heath & Luff, 1992). A finding from this research is that the close collaboration that is characteristic of this work is achieved through organizing conduct so that while people are engaged in one activity, they are simultaneously able to monitor the conduct of their colleagues. Also, participants design their own actions so that they are available and visible to their colleagues. Gestures have been shown to play an important role in this, including explicit deictic gestures to point out particular pieces of information (Heath, 2000) and less direct gestures such as snapping the fingers to call attention (Heath & Luff, 1992). But also other actions, such as glancing at a shared video monitor, consulting a timetable, or readying a telephone receiver can be seen as not just actions but also 'socially organised and communicative practices' (Heath & Luff, 1992, p. 86) and in this sense may take on a gestural character. In such practices, more familiar gestures can also take on unusual characteristics, as in a study of coordination between anaesthetists where it was observed that pointing gestures were performed without an associated coordinating glance, indicating an assumption of availability of the deictic reference and intelligibility of action between colleagues (Hindmarsh & Pilnick, 2002).

Clearly, we are starting to move away from a conventional understanding of gesture here. The objection may be raised, that if we consider any action as gestural, the term loses any meaning. This is a danger, but as I will show, there is a strand of research within which gesture is conceived of in very broad terms while remaining conceptually useful.

Within anthropology, there has been a long-standing interest in human movement. However, recently, there has been a shift 'from an observationist view of behaviour to a conception of body movement as dynamically embodied action' (Farnell, 1999, p. 341). This is a radically different view of movement (including gesture) the communication-focussed gesture research described in the previous sections. Whereas the work described in the previous section relies on dichotomous relationships (such as those represented in Table 1) to separate gestures from other kinds of movement, this view explicitly rejects this in favour of a holistic view. As Farnell writes:

> Older dualistic divisions of such intelligent embodied activities into practical and expressive, instrumental and symbolic, technical and ritual, verbal and nonverbal,

> and the notion of 'discursive and practical consciousness' … have proved unhelpful in understanding the range and complexity of human action (Farnell, 1999, p. 343).

Working from a similar perspective, Ingold has developed a conception of skilful action, which rejects divisions between mind and body, language and action, art and technology (Ingold, 1997, 1999, 2001). Reading Ingold's work for a precise definition of gestures is a frustrating experience. He writes often of 'gesture' but never gives a precise definition of it. Clearly, he includes more than purely communicative gestures when he discusses gesturing, as when he writes that gesture flows '…in and out of vocal discourse, serving (as in a conversation over dinner) at one moment to reinforce or illustrate an utterance and at another to manipulate utensils such as knife and fork' (Ingold, 1995, p. 36).

Elsewhere, he writes of gestures in relation to movements through the landscape, the marks made by storytellers as they trace out the lines of journeys and the inscriptive practices of writing (Ingold, 2006a), as tool use (Ingold, 2006b), as musical performance (Ingold, 1995), and as the shaping of materials through rhythmic technical activity (Ingold, 1999). What then could gesture mean, when it is used in such a broad way?

What distinguishes gesture from mere movement in Ingold's work is the notion of skill. Gesture in Ingold's writing can be thought of as 'skilled movement' and it is through this relation to skill that the term gains its conceptual usefulness. A fuller treatment is beyond the scope of this chapter, but Ingold does make three points in relation to skill that bear mention here (Ingold, 1997):

1. Skill is a property not of the individual, but of the total field of relations constituted by the person in a richly structured environment.
2. Skilled practice is not just the application of mechanical force to exterior objects, but entails qualities of care, judgement and dexterity.
3. Skills are not learnt through the transmission of a corpus of representations, but through the introduction of novices to contexts, which afford selected opportunities for perception and action and by providing the scaffolding that enables them to make use of these affordances.

According to Ingold, recovering an appreciation of skill as 'both practical knowledge and knowledgeable practice', will allow researchers to move beyond dichotomous conceptions to a 'more satisfactory account of the socially and environmentally situated practices of real human agents' (Ingold, 2001, p. 20). Broadening the conception of gestures from purely communicative movements to skilled embodied movement suggests that gesture interface research should consider a much wider range of movements, practices and relations than has been the case until now.

2.6 Chapter Conclusion: Responding to the gap in the literature

In the introduction to this chapter, I presented a working definition and framework of gestures that was (deliberately) very broad (Figure 2). I defined gestures as 'skilled embodied movements' and suggested that gestures could be produced for several purposes, including expressing meaning to another or oneself, exploring meaning or gaining information from the world, and manipulating objects and effecting material changes in the world. I also stated that gestures should be seen as situated in a social and environmental context, which influences and shapes their production and makes them intelligible as such. This chapter has largely been an attempt to explore the different aspects of this definition in relation to existing research on gesture and the field of gesture interface research.

I began with an overview of the field of gesture interface research and a presentation of some of the different kinds of gestures that have been employed in gesture interfaces. I next gave a brief introduction to a body of work on human gesture, which has a focus on communicative gestures. I presented some of the key distinctions between different kinds of gesture that have been identified within this work, including Kendon's continuum of communicative movements and McNeill's taxonomy of gestures associated with gesticulation.

Comparing back to the kinds of gestures that have been focussed on in gesture interface research, I took up Cassell's observation that there has been a gap in conceptions of what gesture is between these two fields. However rather than following Cassell's call for a focus on gesticulation, I argued that gesture interface research would be better served by a more critical attitude towards theory. This argument was based on a critique of the notion of 'naturalism' as the overriding objective for gesture interface design and the suggestion instead that gesture interface research should seek to create systems that are a good fit for particular contexts of use.

In relation to theory, I argued that that gesture interface research should look beyond categories and frameworks of gesture and enquire into the purposes of gesture research in order to understand the taxonomies and definitions of gesture that gesture research provides. The work of one gesture researcher (McNeill) was taken as a point of focus here, due to his prominence within both the field of gesture research and his familiarity to many gesture interface researchers. I also argued that gesture interface researchers should look to a broader range of conceptions of gesture than the communication focussed gesture research that has been the main point of reference until now. Gestures were discussed in relation to their role in learning, exploring meaning and thinking, structuring social action within contexts of situated action, and in relation to the notion of embodied skill.

The topics that have been covered in this chapter allow us to 'flesh out' the working definition and framework of gestures somewhat. The communication-focussed gesture research of McNeill and others provides a lot of information on the detail of gestures at the left-most end of the continuum, which concerns gestures that are employed for the purpose of expressing meaning to another. Research that has looked at the role of gestures in relation to learning and thought helps to understand the ideas of expressing meaning to oneself, and of exploring meaning or gaining information from the world. Work of researchers such as Goodwin highlights the connection to the social and environmental situation within which they occur and shape. Finally, work from anthropology such as Ingold, encompasses a wider range of human gestural activity including tool manipulation (the right-most end of the continuum) and connects to notions of skilled practice.

This is not a neat or coherent framework for understanding gesture. It is more akin to a 'conceptual marketplace' (Rasmussen, 2000) containing diverse and even contradictory views on what gesture might be. The aim of this dissertation is to begin to explore the alleyways of this messy marketplace and reflect back on how gesture interface research could benefit from and contribute to its development.

Chapter 3: Design-Engaged Research

This dissertation seeks to address the following research question: *What is the appropriateness of existing research into human gesture for the design of a gesture interface within an authentic context of use?*

This question sets up a relation between (1) understandings of human gesturing and movement as they relate to interaction and (2) the processes and products of design that these understandings might inform. The two sides of this relation provide the 'what' and 'how' of this dissertation respectively. The appropriateness of understandings of human gesturing and movement are the main topic for the research (the what) and the processes and products of design are an integral part of the method by which I enquired into this (the how). This arrangement stems from a key methodological decision I made early in the research project. I reasoned that since my research question was one of relevance to design, the best way to proceed with the research was (a) to engage in design as part of the process and (b) that this process of design should take place within an authentic context of use. As it turns out, this decision had a profound effect on the organization, methods and outcomes of the research and gave rise to an approach that challenges conventional notions about the role that design has to play in HCI research.

Design-Engaged Research, as I call it, is research involving both an engagement *with* design as part of the research question and an engagement *in* design as an integral part of the research process. This chapter examines some of the methodological issues arising from involving design as a part of the research process. I look to the field of design research as well as some recent thinking on this topic from within HCI to guide and situate my approach. I begin with an introductory discussion of the way that design has figured in the field of HCI followed by an examination of the often-cited distinctions between research *into*, *through* and *for* design. The value of this set of distinctions is not that they provide a categorization of approaches to design research to choose between, but that they highlight the potential pitfalls and likely critiques that design research will face.

The notion of engaging in design as a part of a research approach still highly contested, and presents special challenges for carrying out research. It should be acknowledged that the decision to employ design in the research process is risky and should not be taken lightly. I argue that design supports the research undertaken here in three respects: by prompting questions that would otherwise remain unasked; by allowing researchers to enquire into research questions involving processes of change; and by providing a grounding to support detailed analysis of interactions within a context of interest.

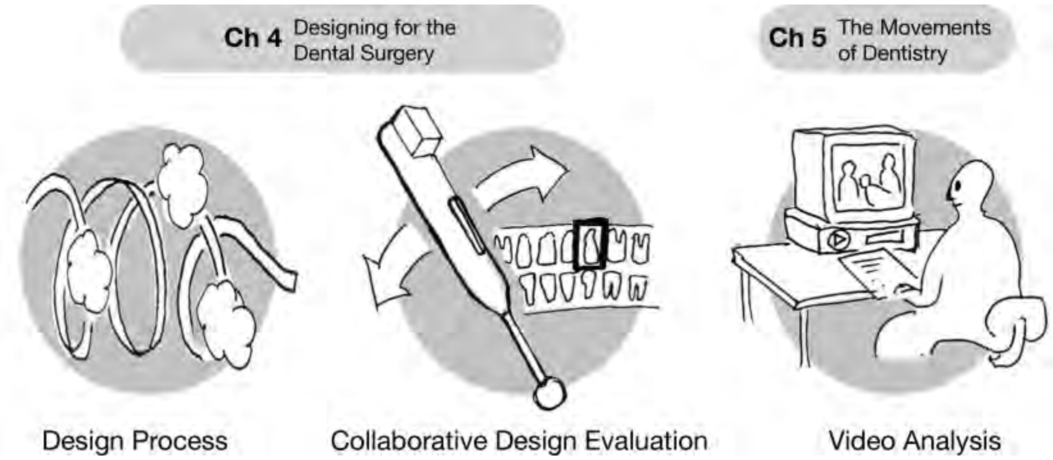


Figure 12: Key research activities that relate to the issues discussed in this chapter.

In concrete terms, the issues discussed in this chapter can be seen as relating to three groupings of activities from the research, the results of which are presented in detail in the next two chapters (as illustrated in Figure 12). These issues can be summarised as follows:

- **Artefacts of design:** What research role do the artefacts of design play? This is especially relevant to the design concept and evaluation as reported in the later part of chapter 4.
- **Process of design:** How can the design process be employed as a way of enquiring into a research question? This relates to the reporting in chapter 4 of the design project I engaged in.
- **Design and analysis:** Do the activities of the design process provide sufficient grounding for subsequent detailed video interaction analysis of the context under study? This relates to the detailed analysis of the movements employed in a dental examination presented in chapter 5.

The research area that this dissertation explores sits at the nexus of questions concerned with: the role that gestures play in an authentic context of use; the possibility for supporting practices within that context through the design of gesture interface technology; and the appropriateness of existing research into human gesture for gesture interface design. It is clear that design forms a central concern of the research. Whether it can also form part of the means by which the research is carried out and how it relates to other research activities are the questions explored in this chapter.

3.1 The 'problem' of design in HCI research

Design occupies an ambiguous position in the gesture interface research presented in the previous chapter. Results are typically presented through demonstrations and tests of working prototype systems, yet accounts of the design processes by which these artefacts are created rarely appear in the literature. Gesture interface research has mostly been concerned with the underlying technical problems of detecting, interpreting and responding to gestures, or with exploring new interaction possibilities opened up by technical advances. For those researchers who have looked to theories of human gesturing as a source from which to inform gesture interface development, the process of design is also underplayed. The focus for this research is on how informing theoretical frameworks relate to final system implementations, rather than on the process by which the finished system was designed to fit a context of application. Because accounts of the process of design are omitted from the research literature, one is almost left with the impression that systems emerge as straightforward applications of underlying technology or theory. This underreporting of the design process is not peculiar to gesture interface research, but is also characteristic of the wider field of HCI:

> "…when it comes to reporting work in [HCI], there is a tendency to present it only in its final state, losing the complexity of the creative design or iterative process and effectively treating wicked problems as if they were tame" (T. V. Wolf, Rode, Sussman, & Kellogg, 2006, p. 524).

If design has been underreported as a topic of research in HCI, then the question of how design might constitute a *mode* of research is even less understood. The field of HCI is conceptually diverse and encompasses several distinct research paradigms (Harrison, Tatar, & Sengers, 2007). The dominant research paradigm of HCI research remains with its roots in the traditions of positivist science and engineering (Boehner, Vertesi, Sengers, & Dourish, 2007). Positivism holds that the scientific method is the best approach for uncovering the processes by which both physical and human phenomena occur. Recent years have also seen the increasing use of ethnographic methods within HCI. Ethnography promises an alternative to the positivistic paradigm, however the relation between ethnography and HCI is still not fully worked out. The prevailing view within HCI towards ethnography has been to see it as a method for building an understanding of user practices that can inform design decisions. Several authors have noted that this is a rather limited view of the potential relations that could exist between ethnography and design. Anderson suggests that a more productive contribution for ethnography may be "…to enable designers to question the taken for granted assumptions embedded in the conventional problem-solution design framework" (R. J. Anderson, 1994, p. 170).

Design, in contrast, is far from accepted as a paradigm for HCI research, even though it has become integral to the professional *practice* of HCI (Zimmerman, Forlizzi, & Evenson, 2007). When design does feature as a part of HCI research, it is usually in a limited role. The kinds of design methods that gain currency in HCI research tend to be those that provide a clearly delineated procedure and can promise predictable outcomes. Design methods have a long history within design research (Jones, 1992) and obviously there is value in design methods such as these for HCI, but there is also an over-emphasis on them at the expense of other aspects of design that are less delineable. In design processes, findings often emerge gradually over time and may relate to a whole range of design engagements, such that they are impossible to trace back to one particular design method. These syncretic and holistic aspects of design tend to be ignored in HCI research.

An instructive example in this respect is provided by the uptake of the 'cultural probes' method in HCI. When first introduced, cultural probes were explicitly intended *not* to arrive at a predictable outcome, but rather as an approach that would serve to inspire designers with deliberately ambiguous and subjective material (Gaver, Dunne, & Pacenti, 1999). The probes approach (in various forms) has become a popular method in the HCI community in the years since its introduction, but the way it has been adopted and used has diverged from the way it was originally presented. In many cases it has changed into a more targeted and outcomes-focussed method. As (Boehner et al., 2007) have observed, the patterns of probes adoption in HCI are "…driven by a common desire to turn reflective, interpretive research methodologies into formal, packaged, and ideally objective methods" (Boehner et al., 2007, p. 1078).

A similar observation can be made for the uptake of 'design patterns' in HCI. The idea of design patterns as adopted by HCI originates from the work of the architect Christopher Alexander, who used patterns as one part of a holistic approach to the design and construction of buildings. The presentation of this concept was originally made in three volumes, as follows:

- 'The Timeless Way of Building' presented a philosophy and approach to the design and construction of buildings (C. Alexander, 1979).
- 'A Pattern Language' contained a collection of interrelated 'patterns' documenting recurring solutions to specific design problems at a variety of scales (C. Alexander, Ishikawa, & Silverstein, 1977).
- 'The Oregon Experiment' presented a case study of the practical use of the approach (C. Alexander, 1975).

In the process of being adapted into HCI, many of the original ideas of Alexander's approach have been overlooked. What researchers have tended to focus on and adopt is the notion of the 'pattern' itself and have left behind the general philosophy for design, which laid out how patterns should be mobilised in a design process. In Alexander's work, patterns were textual and graphic documentations of commonly recurring design solutions in the built environment. Patterns were presented at a variety of granularities, from the city-scale of urban planning to the room-scale of doors and stairs. These different scales of patterns were inter-linked in a hierarchical structure.

The idea of patterns seems to have appealed to HCI researchers as a way of packaging and communicating discursive design knowledge (e.g. Borchers, 2001) or design relevant findings from ethnographic studies (e.g. Wakkary & Maestri, 2008; Crabtree, Hemmings, & Rodden, 2002). Again, there is a clear benefit for HCI in being able to communicate this kind of knowledge, but what I want to highlight here is that the *other* parts of Alexander's approach, those more philosophical, processual and holistic aspects, are seemingly more difficult for HCI research to integrate. The relation between HCI and design continues to evolve (Wright, Blythe, & McCarthy, 2006), but in many respects, design presents a 'problem' that HCI research is yet to fully come to terms with.

3.1.1 Research into, through and for design

The relation between design and research is a central (and hotly debated) question for the field of design research, which brings together researchers from a broad range of design disciplines including HCI. Though there is far from consensus within this field on the question of how (or whether) design can contribute to research, there is a history of thinking and debate in this area that is worth considering here. I will start with the set of distinctions between research *into* design, research *through* design, and research *for* design. These distinctions are well known and often referred to within design research, but unfortunately there is rarely critical examination of their origin and details or of how applicable they are as a model for organizing design research. Unfortunately, they are often discussed as if they are straightforward categories into which a particular piece of research either belongs to or not. The real value of these distinctions is that they serve as signposts marking out potentially tricky terrain that design researchers must navigate. This requires that we return to their original presentation and examine the concerns that authors were trying to raise with them.

The earliest citation and the source usually given for these distinctions is Fralying, who at the time was a professor at the Royal College of Art (Frayling, 1993). His original phrasing for the distinctions was as follows: research into art and design; research through art and design; and research for art and design. Another paper worth noting was published by Archer at around the same time (Archer, 1995). Archer worked with Frayling at the Royal College of Art as Director of Research. Though he dealt with a similar set of distinctions, he had more of a design focus than Frayling. His distinctions were phrased as follows: research into practice; research for the purposes of practice; and research through practice. Though Archer states that he means to include any kind of practitioner activity in his distinctions (giving as examples teaching, medicine and business), his argument is clearly addressed to design researchers.

Table 3: Ordering of distinctions from Frayling and Archer.

Frayling			Archer
Research into art and design	**Into**	**About**	Research about practice
Research through art and design	**Through**	**For**	Research for the purposes of practice
Research for art and design	**For**	**Through**	Research through practice

Notice here that despite the similarities in the distinctions of Frayling and Archer, there is a subtle difference in the *order* that the distinctions are presented. This is an often overlooked, but important difference and I have summarised it in Table 3 to make it easier to see. The significance of this ordering is that it shows how each author is using the categories of research into, through, and for design as a way to highlight *one* of these categories as problematic.

Of the three categories, the first (research into art and design/research about practice) is the most comparable between the authors. This encompasses established research fields, where art or design is the object of study, such as research into the history of art or design, research into aesthetic or perceptual aspects of art or design, and research into theoretical perspectives on art or design. Research carried out in these fields is unproblematic, according to the authors, if it adheres to the standards of the wider field to which it belongs.

Each author then introduces a second category, which is in both cases rather broad and vaguely defined. In each case, the second category includes research approaches that are less conventional than the established fields included under the first category, but this is not presented as especially problematic by the authors. For Frayling, research *through* design describes research where design is the vehicle of the research. That is, research that results as a consequence of carrying out a design process and which is documented in a suitably communicable form. Examples provided by Frayling include materials research such as the development of metal colorization processes, communication of the results of development work, such as the customisation of technology for a novel purpose, and Action Research (which he describes as simply the keeping of a research diary and subsequent production of a report to communicate in a step-by-step way the undertaking of a practical experiment in the studio). Archer's second category, research for the purposes of practice, is defined as research conducted for the purposes of contributing to other practitioner activities. Archer does not provide illustrative examples of this kind of research, writing only that it can fall into any branch of science or the humanities, providing it is carried out according to the principles of its field and has communicable knowledge as a goal. Rhetorically, the second category of each author serves as a kind of catchall between what is accepted (the first category) and what is contested (the third category).

It is to the respective third categories of each author to which we should pay the closest attention. These are the areas of research that each author wants to raise specific concerns about and highlight as problematic. Frayling and Archer actually highlight quite different areas of design research as problematic, so I will deal with each in turn.

Frayling defined his final category, 'research for art and design', as research carried out in order to produce an artefact where the artefact was itself intended as the embodiment and communication of the research contribution. This would mean, for example, that a painting would itself stand as a research contribution and its exhibition in a gallery would constitute publication. Frayling admitted the possibility for such a research practice to exist (in his opinion most probably emerging from the 'cognitive tradition of fine art'), but he did not provide specific contemporary examples beyond referring to "artists who explore the doors of perception such as op artists – or computer artists – or artists as semiologists" (Frayling, 1993, p. 3). Frayling was clearly sceptical about the possibility and worth of this kind of research, worrying that it would open up for the awarding of higher degrees to "every painter since the renaissance" (Frayling, 1993, p. 4) and noting that with respect to higher degrees in Fine Art, the opinion at his institution was that "the goal is the art, rather than the knowledge and understanding" (Frayling, 1993, p. 5).

The category of research that Archer found tricky is 'research through practice'. This is research that is carried out through the medium of practitioner activity. Archer identified a dilemma for design research that although there are occasions where engaging in practice is the only way to enquire into a phenomenon of interest, design practice does not automatically equate to research practice. Therefore, he argued, it is necessary for design researchers engaged in research through practice to find a research approach that allows their practitioner activity to stand as research. His proposal in this regard was to adopt Action Research as a framework for organizing research through practice. In contrast to Frayling, who treats Action Research as a rather straightforward example of what research through art and design could be (a diary study and report in communicable form), Archer sees Action Research as a complex, multi-layered approach to research that offers one possible way to legitimise practitioner activity as research.

The picture that these two papers leave us with is quite confusing. They were published at around the same time, their authors had worked together, and the distinctions they present are broadly similar. The key to getting something out of them for actually reasoning about how to organize design research is to look past the categorisations, and focus on the key problem that each author raises. These are the issues that I take up in the next two sections, specifically:

- **Artefacts of design:** That design artefacts do not automatically equate to research contributions (Fraying – research for art and design).
- **Process of design:** That design practice does not automatically equate to research practice (Archer – research through practice).

3.2 Relating design artefacts to research contributions

The question of what the proper role for designed artefacts is in design research continues to be debated. Frayling's paper was published at a time of change for art and design higher education where art and design institutions were being integrated into the university system and funding was becoming tied to research outputs. This change motivated the need to reconsider the relation between art and design practice and more established academic research disciplines. Whether and how the art and design practice of researchers could be counted as a research contribution was as a much pragmatic political question as a purely academic one (Frayling, 1993).

Within this context, the argument that art and design practice *is already* a kind of research practice and that the artefacts of art and design *themselves* embody research contributions is an obviously advantageous one for art and design practitioners to make. However, as Newbury noted, this is a less than satisfactory response and seems merely to attempt to "…claim credit for existing practice without wishing to change that practice in any way" (Newbury, 1996, p. 215). It is this kind of shallow and politically expedient response that Frayling was arguing against. His concern was that to automatically consider a designed artefact as itself a research contribution fails to appreciate both the requirements of a research contribution and the ultimate purpose of art and design.

Unfortunately, compared to Archer's identification and discussion of the problems, pitfalls and possible ways forward for engaging in research through practice, Frayling's paper is somewhat lacking with respect to suggestions for strategies for actually carrying out research. In fact, considering the prominence that Frayling's set of distinctions have gained in the design research community, it is surprising to read Frayling's paper and see how vague it is in terms of suggestions for the practical organization of research.

In a commentary on Frayling's paper, Newbury argues that the analysis is based purely in an analysis of the current situation and is therefore underpinned by (and risks reinforcing) existing institutional divides between theory and practice. It thus evidences a failure of imagination for what future forms of research could be cultivated for art and design (Newbury, 1996). Indeed, to engage design as part of a research project and then to leave the resulting design artefacts out of the story of the research seems a rather anaemic pursuit. Nevertheless, the issues and concerns raised by Frayling are far from resolved and are still deserving of consideration.

In the field of HCI, design artefacts (typically in the form of prototype systems) are often an essential part of the research contributions that are made, even though their position within the research is an ambiguous one. HCI research can be seen as a design-oriented research discipline in which the design and construction of prototypes plays an important role (Fallman, 2007). In HCI research, prototype systems are often designed and constructed, but usually not to the level that would be in a commercial product development process. Prototypes only need to be 'finished' to the level that is necessary for them to be used to answer particular research questions. Consequently, interactive prototypes used in HCI research will often only implement a research-relevant subset of the functionality and leave other parts of the system unimplemented. It can also be sufficient for a prototype in HCI research to rely on Wizard of Oz (Maulsby, Greenberg, & Mander, 1993) or paper prototyping techniques (Rettig, 1994) where functionality is not implemented, but rather acted out by a researcher.

Prototypes in HCI research are usually a means to an end, which is the study of the interactions between people and these prototype devices and the study of the contexts into which they will be deployed (Fallman, 2007). From this perspective, prototypes can be thought of as analogous to the instruments that researchers working in the natural sciences must sometimes build in order to study a phenomenon of interest. A key difference is that natural science deploys experimental instruments in highly controlled laboratory situations to develop generalisable claims, but prototypes in HCI research are often deployed into open and uncontrolled social situations in order to reveal contextually specific insights (Fallman, 2007). The criterion for success for design prototypes in HCI research is that some new knowledge was arrived at through the use or testing of the design prototype, rather than the quality of the design prototype itself (Fallman, 2007).

Compared to 'engineering design', the question of how 'creative design' can contribute to deciding what needs to be built in user-centred design remains marginal in the field of HCI (T. V. Wolf et al., 2006). According to this distinction, creative design is as concerned with understanding the problem as the design response to it and conceives of the design process as a tight interplay between problem setting and problem solving, which is inherently unpredictable and which progresses along many parallel tracks. In contrast, engineering design assumes that the purpose of design is to address an existing well-defined problem that can be solved step-wise through a progressive series of partial solution refinements. It should be noted here that the term engineering design here is intended as a label for a particular *ideal* of design and not as a characterisation of the kind of design that takes place in authentic engineering design practice, which in actuality contains many aspects of so-called creative design (McGarry, 2005).

Within HCI, the dominant ideal for the design process has been engineering design (Wright et al., 2006). This is perhaps not surprising given the strong positivist legacy within HCI. This, combined with the focus of HCI research on final products of design rather than reports of the processes that lead to them has meant that many of the important roles that design artefacts play *within* the design process from a creative design perspective are under-reported. Two such functions are to further design activity, and to communicate design ideas (T. V. Wolf et al., 2006).

Through the function of furthering design activity, prototypes provide a way of working through design judgements (T. V. Wolf et al., 2006). The process of making a prototype requires the maker to engage in a series of specific decisions about the form that the prototype should take. This requirement to be specific is important in pulling the design researcher in to a closer consideration of the situation at hand. One is forced to say *something* and in so doing, ones understanding of the design situation crystallizes a little more. This echoes Schön's description of design as a process of listening to the 'backtalk' in a reflective conversation with the materials of a design situation (Schön, 1992). Design prototypes and artefacts in this way can become 'things to think with' supporting designers in working through a design process (McGarry, 2005).

The function of design artefacts to communicate design ideas allows others to draw insight or build upon the design thinking that the artefacts embody. Design artefacts can embody a range of design thinking that might be more difficult to obtain from other field materials. Often, user-centred design processes involve collaborative design sessions and evaluations of design concepts realised in prototype form (Brandt, 2007). In these situations, prototypes serve as 'boundary objects' that allow participants from different knowledge traditions perceive their own meanings while maintaining a common identity and point of reference (K. Henderson, 1991). The communication that prototypes support is not a one-way presentation of what designers have in mind, but rather a two-way opportunity for dialog between users and designers with the prototypes serving to provoke reflections on a design from different perspectives. This can support participants in 're-seeing the design' in a way that gives new meanings (Brandt, 2007, p. 182).

There is one further area in which design artefacts play an important role for HCI research that I have hinted at, but not yet addressed directly. Considering the many demonstration systems of gesture interface research, it does seem that presentations of design prototypes are often central to how this research is communicated. One reason is that these design artefacts demonstrate the *design-relevance* of particular knowledge in a more compelling way than a conventional textual medium (such as list of design recommendations). Design artefacts and prototypes help make the story of the design process more comprehensible to a reader. This is an important consideration for the topic of the next section, where I turn to the question of how design process might contribute to research.

3.3 Relating design practice and research practice

Can design practice also stand as a kind of research practice? This is the issue that Archer pointed to for design research. The issues raised by this question are closely related to those discussed in the previous section, but the focus here is on the processes of design which bring design artefacts into being, rather than the design artefacts themselves. Just as Frayling was concerned that design artefacts do not necessarily equate to research contributions, Archer was concerned that design practice does not necessarily equate to research practice. Archer saw that this presents a conundrum if engaging in design activity is the only way to enquire into a phenomenon of interest, which is a common situation for research related to design.

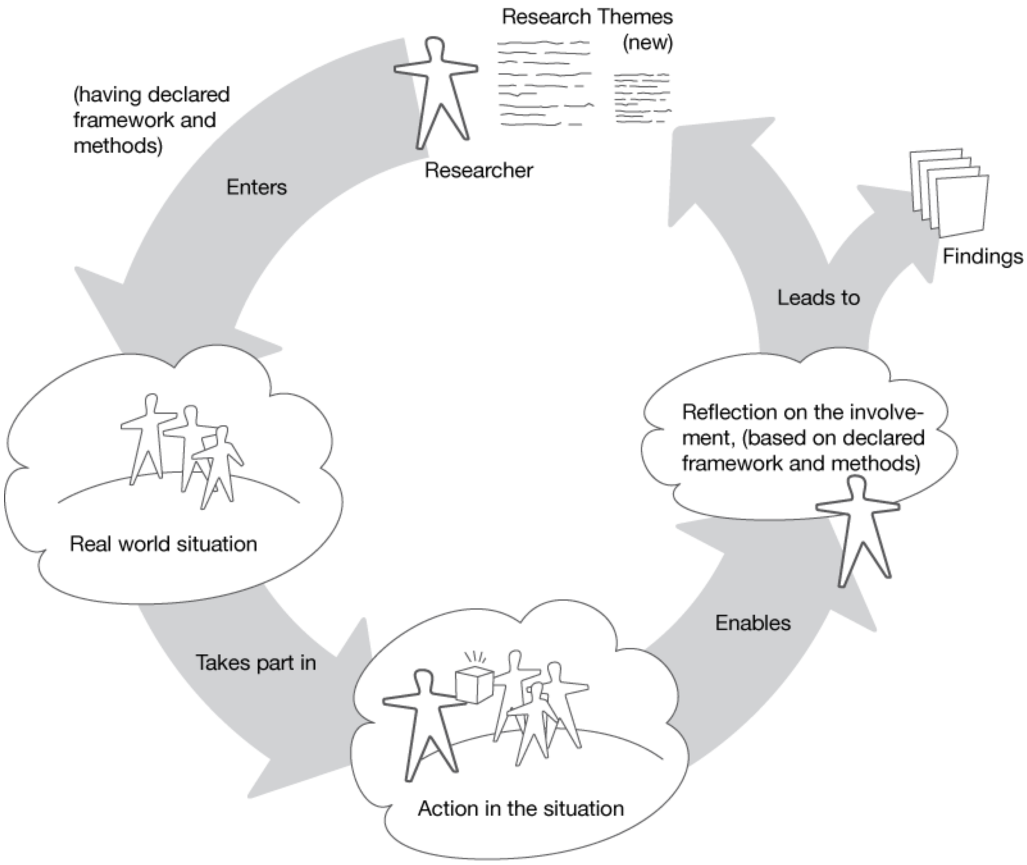


Figure 13: The Cycle of Action Research (after Checkland & Holwell, 1998).

Archer's suggestion for escaping this conundrum was to adapt the tradition of Action Research to the needs of design research. Action Research is an iterative research method in which researchers follow cycles of theorising, engagement, and reflection to develop and refine their research findings. Archer defines Action Research as "systematic enquiry conducted through the medium of practical action, calculated to devise or test new, or newly imported, information, ideas, forms of procedures and to generate communicable knowledge" (Archer, 1995, p. 11). The component of 'practical action' is what allows design practice to be integrated into an Action Research project.

Unfortunately, Archer's paper only presents a broad overview of the Action Research process. A better starting point for understanding Action Research is provided by (Checkland & Holwell, 1998), who present a model of the cycle of Action Research, compare it with more traditional positivist research paradigm, and discuss several important principles for carrying out successful Action Research. In their model (Figure 13), researchers begin with an established epistemological framework and some initial research themes that they wish to pursue. They then enter in to a real world situation and take part in action in that situation. Eventually, the researcher withdraws their engagement from the action and takes time to reflect on the outcomes of the action in relation to the research themes and epistemological framework that they started with. Based on this, they are able to draw out findings from the research, establish new research themes, and adjust their framework in anticipation of subsequent cycles of engagement (Checkland & Holwell, 1998).

A conventional view of different kinds of research might distinguish between basic and applied research, where the purpose of basic research is the generation of foundational principles and the purpose of applied research as the application of these principles to specific problems (Friedman, 2003). From this perspective, gesture interface research would probably be seen as an example of applied research and McNeill's theoretical framework of human gesturing as an example of basic research. However, the relationship between basic and applied research that this relationship posits is too simplistic for our purposes. Applied research can also provide new insights, overturn existing understandings and suggest new avenues for enquiry, while basic research can also give rise to practical outcomes context of study. Action Research can also seen as complementary to more traditional modes of research, since the results of Action Research can provoke new lines of enquiry, or propose research hypotheses to be investigated further. By engaging in an Action Research project involving design of a gesture interface in an authentic work context, it is my aim to open up for discussion of the appropriateness of existing research into human gesture for gesture interface design.

Action Research presents several difficult challenges for researchers. By engaging in action directly as part of the research process, a researcher must forsake some of the ideals of a positivist paradigm. First, given the researcher's direct involvement in the situation that is at once topic of research and arena for action, the ideal of objectivity cannot be maintained. Second, the aim of reproducibility of results is also not maintainable, because the conditions that give rise to results cannot be separated from the specifics of the situation or a researcher's own activity. Third, the idea of declaring and then testing hypotheses also cannot be maintained, because of the elusiveness of any objective criteria for success to judge an hypothesis as refuted or upheld. Rather than testing hypotheses, a researcher engaged in Action Research develops and enquires into research themes, which may evolve as the program of research progresses. Action Research must aim for contextually specific insights, rather than generalisable claims.

These issues can be mapped to a process of design relatively easily. Design is, by its nature interventionist. It brings subjective decisions and values into play within the design process and in judgements of a design's success. Introducing design interventions into a setting is likely to change the nature of that setting and the practices that occur there. This works against the ideal of reproducibility of results. Design also relies on a complex of interdependent factors such as the designer's own skill, access to suitable sites for design enquiry, technical means for implementing design solutions, and a background of design-relevant knowledge to inform the design process. This works against the ability to separate out and test individual hypotheses about influences on the design process (such as that the use of a particular theoretical framework is beneficial for design).

In the face of these challenges, there should be a good reason for researchers to choose an Action Research approach. One compelling rationale that engaging in practice is sometimes the *only* way to enquire into a phenomenon of interest. This is often the case for phenomena that change through time, especially social processes of change (Checkland & Holwell, 1998). The research questions I am interested in for this dissertation are a good example of such social processes of change. In particular, my interest in how gesture interface technology could be designed to support an authentic work context implies some direct interaction and intervention in the context of interest and would be likely to change the way that work is carried out in that setting. Since such gesture interface technology does not currently exist, some process of design must take place, which requires engaging with existing social relations and establishing new ones.

3.3.1 The ideal of recoverability and principle of a declared-in-advance framework

Although researchers engaged in an Action Research approach must forsake many of the ideals of a traditional positivist approach, engaging in Action Research does not mean that 'anything goes'. One core ideal that researchers engaged in Action Research should aim for in place of the ideals of a positivist scientific approach is *recoverability* (Checkland & Holwell, 1998). The notion of recoverability expresses the ideal that if an interested person wanted to critically examine the results of an Action Research project, the reported record of that research should allow them to *recover* sufficient detail about the process that they could make an informed assessment about the quality of the research or even try the process out themselves (though there would be no guarantee that they would reproduce the same results).

This ideal leads to a key principle for carrying out Action Research. Namely, that the researcher operates within a declared-in-advance methodology and framework of ideas (Checkland & Holwell, 1998). It is important to declare this framework in advance because (a) it provides a reference point against which subsequent learning can be defined, and (b) it allows other researchers to make sense of the ensuing activity. Without such a framework Action Research can quickly become indistinguishable from mere action (Checkland & Holwell, 1998). This is illustrated in Figure 13, where the researcher declares their research themes, their method and epistemological framework before entering into the change situation and then revisits them later when reflecting on what happened in the change process. As described by (Braa & Vidgen, 1995), a researcher first adopts a theoretical framework and methodology, then applies the framework and method in the field and assesses and refines the theoretical framework and method in light of the outcomes.

3.3.2 Addressing the ideal of recoverability

In this section I want to describe how I relate the Action Research approach to my research project, specifically addressing the idea of recoverability and how I have chosen to present my process in this thesis. I want to begin by returning to an illustration that I developed early in my research project expressing my understanding of Action Research in relation to a design process, which I have found useful in helping me conceptualise the relationship between design and research activities (Figure 14).

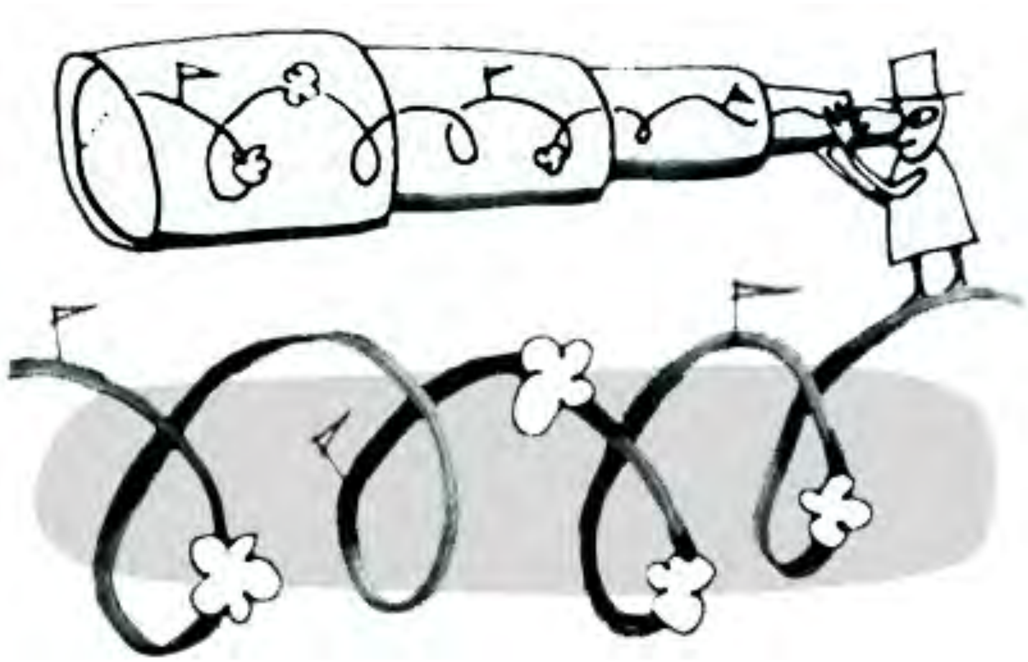


Figure 14: Relation between Action Research and a process of design

The illustration shows a spiral, with flags and clouds placed on it and a person looking back over the spiral. The spiral with the flags and clouds is meant to evoke an iterative design process that proceeds through a number of phases of engagement (the loops) marked by emerging expressions of understandings (the flags) and punctuated by events such as prototyping sessions, field-studies and role-playing activities (the clouds) that serve to drive the design process forward (Binder, Brandt, Horgen, & Zack, 1998). The diagram does not specify what the different phases of a design process might be, or how they might relate to one another in terms of the progress of the design project, but the looping is meant to imply some amount of back-and-forth in the process where the results of earlier phases can be revisited based on the outcomes of later phases. This means that the overall shape of the project can be adjusted in response to the unfolding process as new questions and possibilities for action emerge. An example of this could be where a design concept built around an existing tool raises questions about current use of that tool that earlier phases of fieldwork had not examined in detail, necessitating a return to the field for further investigation.

The person looking back over the spiral is engaged in a process whereby reflection is made on the process undertaken and the results gained and some understanding of this is articulated. The metaphor of the telescope is not meant to imply precision in the act of looking back, but instead a *telescoping* of events. When one looks back in this way, one sees patterns and connections between events that are not always apparent in their midst. This process of stepping back from immediate events is necessary in order to extract research insights from the hurly-burly of the process. Additionally, each time one looks back, the view changes, because the stories and events keep shifting with you (Lanzara, 1991).

The little flags stand for other places along the way where the researcher has articulated an understanding in this way. In the terms of the model of the Action Research cycle presented in (Figure 13), these are equivalent to the iteratively developed research themes and declared framework and methods. There are many ways to raise such a flag, from recording preliminary findings in a research diary, to explicitly planning the objectives and agenda for a design encounter, to writing a research paper about a particular method or result, to presenting preliminary results at workshops and colloquia. It is important to raise these flags regularly, because as time goes on, the immediacy of events fade and it becomes impossible to reflect on them in depth.

In addition to the records of the 'flags', there is also the question of how to record what happens in the 'clouds', which is equally important for the ideal of recoverability. In my case, I made heavy use of video for recording of design activities, because it allows for the recording of details of subtle shifts in gaze, posture, gesture and position in a spatial context that are all potentially salient to the enquiry, and which are difficult to record in other ways. Along with video I also took audio recordings, photographs, hand-written notes, and made models and prototypes with participants.

A challenge for meeting the ideal of recoverability is how to present all this material in a way that is coherent and concise enough for a reader to actually make sense of it. Within the confines of a dissertation, it is not possible to recount everything that happened over the course of a PhD research project. One must make choices about what is essential to the story and what can be left out while still allowing the reader to form an accurate sense of what was undertaken and what was learnt. That is what I attempt to do in the next chapter, which tells the story of engaging in the design of a gesture interface for the dental surgery context. There, I draw on these materials to present a story of how the design process unfolded and what I learnt along the way. I concentrate in particular on:

- Framing the design problem that I sought to address

- The overall structure of the design project and its relation to two other significant projects that I engaged in
- Activities I engaged in to find out more about the context and develop a design concept
- The collaborative design evaluation of a design concept in working prototype form

Many presentations of design in HCI research concentrate on a final design concept and evaluation. For the ideal of recoverability, it is important to also present a story of the framing and unfolding of the design project through time. By including these other aspects in the next chapter's description of the design process, I aim to give the reader sufficient detail that they can form an accurate impression of the work that was carried out through the whole design process and how this related to the underlying design problem and evolving understanding of the design context. This description should be sufficient for the reader to form a judgement of the character of the work that was carried out and of veracity of the claims that are made from that work. There is also sufficient detail given, such that it would be possible to plan and carry out a project along similar lines to investigate how the claims hold up across different design contexts.

3.3.3 Participatory design as an organizing framework

In this section, I want to address the principle of a declared in advance framework of ideas and methods in my research. For me, this was provided by the design approach that I took to the project. Design approaches could be thought of rather narrowly as a set of methods that can be drawn upon in order to 'do' design. However, we can also consider at design approaches in broader epistemological terms. From this perspective, a particular design approach not only provides a set of methods for doing design, but also entails ideas and assumptions about:

- The nature of knowledge required for design
- How that knowledge is constructed
- The nature of use-practice and user expertise
- The kinds of relations that are required between stakeholders and designers

- What kinds of design interventions should be sought
- Criteria for judging the success of those design interventions

In deciding how to approach the design process for this project, I have worked from the belief that if the aim of my research is to help create interfaces that enable people to maintain and enrich their bodily experience of the world when interacting with computer interfaces, then it is important people who would be affected by such interfaces should be asked to contribute to design process. I decided to draw on the tradition of participatory design as an organizing framework for my design approach.

The most prominent distinguishing characteristic of the participatory design approach is that prospective users of new technologies (and other affected stakeholders) should be directly involved in the shaping of those technologies throughout the design process – that is, they should *participate* in the design process (Greenbaum & Kyng, 1991). This is sometimes mistakenly taken as meaning that users replace designers (Lloyd, 2004), but this is not the case. Participatory design does not replace designers with users, but it does require users and designers to enter into more collaborative relationships. The role of designers is still very important, but it expands from that of an expert who works separate from the users to a facilitator who also collaborates with people to ensure that they can contribute their skills and ideas to the design process. Establishing and maintaining a relationship of collaboration is a challenging task that requires sensitivity and skill on the part of designers (Ehn, 1993).

Participatory design cannot be boiled down to a straightforward method or generally applicable set of tools. One reason for this is that participatory design involves forming close relations with real people and paying attention to the detail of actual work settings, which means that it is particularly shaped by the situations in which designers and participants find themselves (Greenbaum & Kyng, 1991, p. 21). Participatory design calls for a pluralist approach to methods and tools and designers engaged in participatory design must assess for themselves, based on the particulars of the design situation, how to proceed.

Participatory design practice commonly uses techniques that emphasise designing by doing. In participatory design, prototyping is typically used from the early stages of design. This not only allows designers to work out problems early on, but also provides an alternative to more rigidly requirements-focussed approaches, because subsequent prototypes themselves constitute evolving versions of the final system (Floyd, Mehl, Resin, G. Schmidt, & G. Wolf, 1989, p. 313). Prototyping can give participants access to the possibilities and limitations of technology, thereby allowing them to contribute to the design process at a deeper level. Prototyping activities can also be conducted in the field, thereby further reducing the separation between the designers' and users' worlds (Pedersen, Buur, & Djajadiningrat, 2003). Drama-inspired techniques (Brandt & Grunnet, 2000), or activities based on game metaphors (Matthews, Brereton, & Buur, 2001) have also proven effective as ways of engaging users in exploring their visions of future technology use.

The participatory design approach is best understood as a sensibility and set of principles concerning the way in which designers should seek to relate to potential users and the roles that those people should be given in the design of the technologies that they will work and live with. There is a great diversity of approaches to participatory design, but despite this there is a core of agreement within which several common elements can be found. (Greenbaum, 1993a) lists the following principles:

- Computer applications should be better suited to the actual skills and work practices of the people that use them.
- Work is a social activity involving interactions of different groups of people.
- Building effective communication during the design process requires lowering barriers between technical specialists and end-users.

Floyd et al. identify the central principles of participatory design as democratisation and humanisation. Through the principle of democratisation, participatory design aims to integrate the interests and values of all people affected by a design, while through the principle of humanisation, participatory design aims to recognise and support human strengths (Floyd et al., 1989).

Nevertheless, despite this core of agreement, there is not a single philosophical, political and theoretical position that defines participatory design. Although the origins of participatory design lie within a fairly narrow historical social and political context, arising out of collaborations between computer scientists and trade unions in the countries of Scandinavia during the 1970s, it has always contained a diversity of views and has developed differently as it has spread to new contexts (Floyd et al., 1989). In broad terms, whereas the Scandinavian tradition of participatory design has been more politically motivated, for American practitioners, the pragmatic motivations have been more prominent, such as the desire to bring domain expertise into the design process or to help ensure a good fit with existing practice (Greenbaum, 1993b). Participatory design also continues to evolve in response to the emergence of new computing paradigms such as ubiquitous computing and the involvement of other kinds of stakeholder groups, such as self-employed participants (Brereton & Buur, 2008).

In considering my own approach in relation to the ones that other practitioners have taken, I see myself as more within the pragmatic tradition of participatory design. The participants I worked with were professionals and in many cases owners of their own businesses. Further, the purpose for setting up and carrying out the project was in order to investigate into the design of gesture interfaces, in particular in relation to an existing technology prototype that researchers in my group had made. My attitude towards this technology in going into the project was with a provisional acceptance, I was prepared to abandon development of the technology for this context if it seemed inappropriate, but at the same time, I was actively seeking places within the work where it might be put to good use. Such an attitude to technology could fairly be described as 'technology-driven' participatory design (Carroll, 1996) and in this respect, my project shares some similarities to the project described by (Blomberg, Suchman, & Trigg, 1996) where the researchers also started with an a-priori commitment to a particular technology, of which they were not the original developers, but for which they were seeking to find applications within a particular context of use.

Reflecting back on the issues raised by Frayling and Archer about whether and how design artefacts and design practice can contribute to research, it seems to me that there is one important area that has been overlooked. It is, how to bring *people* into a design research process. This is a particular strength of the participatory design approach. The principles of participatory design are built around and relate directly to the people that we design for, not as abstract entities but as active agents. Ultimately the criteria for determining the success of a design rest with these people and how they judge it to support or extend their practices of use.

3.4 Design as a grounding for analysis

So far in this chapter, I have been concentrating on particular issues that are important to consider for design research, namely how design artefacts and design practice can contribute to research. The discussion of these issues has shown, I hope, that design can provide a suitable approach for enquiring into research questions such the one I address in this dissertation. I now want to turn to the question of how design research can be related to other research approaches. In particular, I want to describe how the design process I engaged in gave me an understanding of the design context sufficient for me to carry out a further detailed analysis of one episode of work. The results of this analysis are presented in a chapter of their own (Chapter 5) and constitute a core contribution of this thesis.

Design research is still a hotly contested as an approach to research. Because of this, when arguing for a design research approach, it can be tempting to try to create a separation between design research and other research approaches. While it is important to strengthen design research as a viable approach, creating a false separation from other approaches is ultimately detrimental, because doing so obscures possibilities for new relations between design and other forms of research. As Newbury suggests, rather than accepting institutionalised divisions for design research, we should look for a more "…interactive and interdisciplinary approach, which will be to the benefit of all" (Newbury, 1996, p. 219).

An interactive and interdisciplinary approach to design research is especially important for HCI, which is a multidisciplinary field that incorporates aspects both from the natural sciences and design professions (Mackay & Fayard, 1997). The phenomena of interest for HCI is the interaction between people and artificially created artefacts, an interaction which evolves and changes through time and is heavily dependent on the specifics of the context. At the same time, as a discipline it has an interest in producing general knowledge and has borrowed many attitudes and approaches from the natural sciences. As Braa and Vidgen note, such research:

> "…is situated in an uncomfortable space in which a variety of research methods are needed to reflect the relative objectivity of technical artefacts and the subjectivity of purposeful activity" (Braa & Vidgen, 1995, p. 50).

I certainly experienced this kind of 'uncomfortable space' within my research project. I was at once seeking to build an understanding of a particular design context, engage in a design intervention within that context, and reflect back on the appropriateness of existing research into human gesture. A particular tension I felt was that in design, there are many design directions that one *might* pursue, but there are only so many that one *can* pursue. Accordingly, the final design concept I arrived at for the project is a response to a partial and particular facet of the complexity of the design context and there was much that I had learnt from having worked through the detail of the design process that did not 'end up' in this final design concept.

Without jumping too far ahead, this was particularly problematic with respect to my aim to comment back on the appropriateness of existing research into human gesture for gesture interface design. Something that came to trouble me more and more as I worked through the design process (and became familiar with a wider range of approaches to the study of gesture) was the definition made by McNeill of gestures as 'spontaneous idiosyncratic communicative movements accompanying speech'. It seemed to me that this served to separate out communicative gestures from other kinds of movement that might be useful to consider for gesture interface design and which might be encompassed by a broader view of gesture.

3.4.1 A further step of video analysis

To better understand and communicate what such a view might entail, I resolved to undertake a further step of detailed video analysis based on one 40 minute video recording of a dental examination. In brief, the analysis I undertook can be seen as within the broad tradition of workplace studies in HCI that focus in on the detail of interaction in work. I transcribed the entire video and chose a series of vignettes, which showed a range of the different kinds of gestures and movements that occurred in the dental examination and the important roles that these play in the work. These vignettes were analysed in greater detail and are presented and discussed within the body of chapter 5 (which also contains a more detailed account of my analytic approach).

It is worth stressing here that this further step of video analysis was only carried out *after* the design project had finished. From working through the design project, I discovered that there things I wanted to say about the role of gestures and movements in the design context which I could not support with a presentation of the final design prototype or a description of the design process alone. I found that the detailed video analysis allowed me to tell another kind of story about the role of gestures in relation to the design context. One way of looking at this is as a form of 'Triangulation' where different research methods are deployed in a complementary manner to address a common research question (Mackay & Fayard, 1997).

The design process I had undertaken can be seen as serving as the grounding for this analysis in at least two respects. First, it provided me with a detailed understanding of the work involved in the design context, including knowledge of the spatial, social and professional relations. Over the course of the design project, I had also developed a detailed understanding of the role that gestures and movements played in the work along with an understanding of the possible relevance of these for my design project. Engaging in design had allowed me to form an opinion about my research question that I wanted to articulate through the analysis. I got to *know* the context and *know* what I wanted to say about it from a *design* perspective. Without having gone through the process of design, it is unlikely that I would have analysed the material in the same way.

This also establishes a novel relation between design activities and analysis of field studies. I also did not attempt to relate the findings of my analysis back to the final design concept either as a justification for the design decisions made or as providing implications for further design, which would be a more conventional way to use field studies in HCI (Dourish, 2006). Here, it was the design studies that provided the grounding and motivation for analysis and the purpose of the analysis was squarely on being able to comment back on existing theories of gesture, which is the main research question that I set out to enquire into with this thesis.

3.5 Chapter Conclusion: My approach to design research

This chapter has been an exploration of the methodological issues that arose from the decision to engage in design as part of the research process. As I have outlined, these issues have fallen in three main areas: the contributions that design artefacts can make to research; requirements for mobilizing a process of design as an integral part of the research process; and a rethinking of the relation between design and analysis such that design serves as grounding for subsequent detailed analysis.

Design artefacts play a number of important roles in contributing to HCI research. Drawing on recent work within the field of HCI, I identified and discussed several of these in the chapter. Design artefacts, especially design prototypes are often employed in HCI research as a way of enquiring into the interactions between people and interactive technologies within particular contexts. Prototypes in HCI often have a particular character; they are 'finished' only to the degree that is required to support the enquiry. Design artefacts also serve an important role in furthering design (and by extension research) activity by drawing the design researcher into a reflective conversation with the materials of design and particulars of the design context. Finally, design artefacts play an important role in relation to communicate design ideas and design dialogue. This is both within the design process between designers and other stakeholders by providing 'boundary objects' around which dialogue can take place and in the communication of the results of the design process to other researchers.

The process of design also needs to be considered as part of a design research approach. The suggestion made by Archer, and followed in this chapter is to draw on the tradition of Action Research as a framework for organizing my design research approach. Action Research was described as an iterative research method in which researchers follow cycles of theorising, engagement, and reflection to develop and refine their research findings. There are many similarities between the structure of an iterative process of Action Research and an iterative process of design, however this does not mean that 'anything goes' for Action Research. Two important criteria were identified and discussed in the chapter. The first, the ideal of recoverability, captures the idea that the reporting of an Action Research project should provide sufficient detail for interested researchers to make an informed assessment of the quality of the research or to run a similar investigation of their own. The second, the principle of a declared-in-advance methodology and framework of ideas, provides a reference point in terms of which subsequent learning is defined and against which other researchers can make sense of the activity. A detailed account of the design process is presented in the next chapter.

In the final part of the chapter, I described how I took one additional step of analysis following the completion of my design activities in order to help articulate the position that had emerged for me in relation to the theoretical framework. Although engaging in a process of design had led me to see there were things that I wanted to say about the role of gestures and movements in the design context in relation to existing theories of gesture, I found that I could not articulate with the findings of the design activities and artefacts alone. This realisation opened up for me a more nuanced view of the relation between design research and other kinds of research activity. Rather than attempting to separate design research out from other kinds of research, I came to see how design research could be brought into complementary relations with other forms of research. A detailed account of the result of this analysis is given in the chapter following the next.

Chapter 4: Designing for the Dental Surgery

A dental surgery presents a rich design context, dense with specialised professional knowledge, skilled instrument use, cooperative work relations, and careful spatial arrangement of material resources. Dentists make increasing use of computer systems in their work for a variety of purposes, such as to manage patient records, track material usage, handle billing, and support patient education. However, the conventional office PC configuration of keyboard, mouse and monitor is in several respects ill suited for the needs of the dental surgery: it interferes with the interaction between the dentist and the patient; it does not build on the existing skills of dental practitioners; and keyboards and mice are difficult to keep clean and integrate into infection control procedures. Within this setting, a gesture interface seems a plausible interaction approach for addressing some of the problems presented by current computer interfaces.

The purpose of this chapter is to present the design process that led to the development of a design concept to address these issues. Results from a collaborative design evaluation of a working prototype in three dental surgeries are also presented. The chapter follows the basic chronology of the project, and concentrates on the key events through which my understanding of dentistry and the requirements for a gesture interface for this context were developed. The chapter is told in three parts. I begin by presenting a vignette taken from a video recording of dental examination, which highlights the kinds of problems that current computer interfaces pose for dental practitioners. Following this, I give an overview of the structure of the design project along with a brief description of two related projects that I undertook during the thesis. The main part of the chapter reports on specific activities carried out during the design process and the findings that emerged from these. The chapter finishes with a description of the final design concept and the results of collaborative design evaluations of a working prototype in three separate dental surgeries.

4.1 Interaction problems with current computer interfaces in the dental surgery

The following vignette demonstrates a typical example of the kind of interaction problem that dentists, assistants and patients must confront with the use of office PC based input devices such as keyboards and mice during a dental examination. It is taken from about half way through a video recording of a 40-minute examination at the point where the dentist and assistant were about to record some initial observations about the patient's teeth in an electronic patient record.

Excerpt 1: Pressed escape.

Frame 1.1  D: (turns to the patient and looks at her teeth,) "Just close together" D: (looks up to the computer screen. Removes hands from patient's mouth) "Okay, got class 1, class 1 molar. Please make a note..."	**Frame 1.2**  D: (looks over to the assistant) "Pressed escape"	**Frame 1.3**  A: "Should I just press cancel [and do it all again]?" D: (looking at the computer screen) "um," A: "might be easier" D: "Yeah". (dentist continues looking at the computer screen while the assistant moves the mouse and clicks).	**Frame 1.4**  P: (The patient looks up too.)
Frame 1.5  D: (Reaches up and adjusts the light (because it is now shining in the patient's eyes?). Maintains his gaze on the computer screen during this time.	**Frame 1.6**  D: (to the patient) "When [assistant] pulled the keyboard out, it just brushed on the escape key, so it just went out of the [thing], so we're doing this [...] (while he's saying this, his hands mime the pulling out of the keyboard and the brushing of the escape key)"	**Frame 1.7**  D: (coughs)	**Frame 1.8**  D: "Okay" D: "Okay, ummm, (glances at assistant) pro gnathic, that's g-n-a-t-h, pro-gnathic pattern with retro-cline lower anteriors giving class 1 anterior occlusion." (looking at the computer screen).

The electronic patient record is a screen-based form showing a diagram of the teeth in the patient's mouth. On it, information such as locations and types of fillings on surfaces of teeth, missing teeth and cavities can be recorded. In addition, typed notes may be entered for more specific observations. In this surgery, the electronic patient record was displayed on a computer monitor mounted on a swing-arm above the legs of the patient, where it was visible to both the dentist and assistant. In order to update the electronic patient record, the dentist would dictate observations to the assistant, who sat with a wireless keyboard and mouse to enter the information into the computer.

At the outset of this vignette, the patient was reclining in the dentist chair while the dentist and assistant sat in wheeled stools to either side of her. From the camera's point of view, the dentist was to the left of the patient and the assistant was to the right. The dentist had just been checking the bite of the patient before looking up to the computer and asking the assistant to make a note. At this point, the assistant reached behind herself to the bench to retrieve the wireless keyboard (Frame 1.1). As she brought the keyboard back to sit on her knees, she accidentally pressed the escape key, which exited the screen-based form into which she had been entering information.

The dentist and assistant conferred over what had happened and what to do next. The dentist looked over to the assistant and remarked "Pressed escape", thereby confirming the cause of the problem (Frame 1.2). The assistant suggested that it might be quicker to just press cancel and fill out the form again and the dentist agreed with this (Frame 1.3). As the assistant moved and clicked the mouse to reset the form, there was an extended and rather awkward silence. The dentist sat motionless with his gaze fixed on the computer screen. Eventually, after 15 seconds the patient also lifted her head to look at the computer screen (Frame 1.4) and the dentist gave her an explanation of what had happened (Frame 1.6). Finally, the assistant re-set the form and they continued on with the examination (Frame 1.8).

This vignette presents a concrete example of the kind of practical problem in using current computer interfaces that dentists and assistants encounter in the context of a dental examination. This can be described as a *breakdown situation* where the normal flow of an activity is disrupted by an unexpected problem and focus shifts from the object of the work to the artefacts employed to carry out the work (Bødker, 1990, p. 80). In the case above, the accidental pressing of the escape key shifted the focus of the dentist and assistant from the task of recording an observation about the patient's teeth to the accidental pressing of a key on the keyboard and how the interface could be restored to its prior state. This breakdown also drew the patient in, when she lifted her head up to look at the computer screen in response to the extended pause in interaction. Her focus shifted from participating in a dental examination to trying to see what had happened to the computer, which motivated the dentist to offer an account of what had happened. Because of the breakdown, the focus of all participants shifted away from the patient and her teeth to the computer and its problem.

4.1.1 Current computer interfaces are a poor fit

When presented with such a concrete example of an interaction breakdown, one can imagine several possible solutions that might help prevent it, such as adopting a different placement of computer peripherals within the surgery (indeed in my observations of other dental clinics, it was apparent that there are a number of approaches to the arrangement of computers within the space of the surgery). However, there is a deeper problem at play here, which is that interface devices such as keyboards, mice, and monitors are designed for an office environment and are in several respects a poor fit for the specific needs of the work of the dental examination.

One striking way this was manifested in the excerpt above is that it was the assistant who typed on the keyboard and moved the mouse while the dentist dictated the observations to be recorded. The reason for this interaction arrangement was the need to follow infection control procedures, which regulate the way that objects and people may interact and move between various zones of cleanliness in the surgery. Because the gloves worn by the dentist come into contact with the mouth of the patient (a dirty zone), they cannot touch items sitting on the bench, such as the keyboard and mouse (a clean zone). This is why the dentist was forced to dictate his observations to the assistant, who had removed her gloves in order to 'drive' the interface.

Another force acting on the style of the interaction between the dentist, assistant and computer interface, is the specialized language of dentistry. The 'tooth numbering' system is a formalised designation of the space of the patient's mouth. The dentist and assistant use a numbering system to name individual teeth in the mouth as well as a specialised vocabulary to indicate planes and faces of teeth. In this way, "1-3 L" refers to the lingual plane of the third tooth in the first quarter of the mouth. That is, the inside of the upper right canine (from the patient's view). There is also a specialised terminology of dentistry for describing aspects of the teeth (e.g. 'pro-gnathic retro-cline pattern'). The tooth numbering system and specialised terminology of dentistry provided a means by which the dentist could succinctly and precisely dictate observations about the patient's teeth to the assistant for entry into the computer, but are also difficult for a patient to relate to.

The spatial arrangement and characteristics of the dental surgery present another series of impediments to interacting with an office computer. Consider an idealised arrangement of a keyboard, mouse and monitor one might expect in an office setting. The user sits at a desk with hands extended out over the keyboard and the mouse positioned to one side with sufficient space around the mouse for it to be moved across the surface of the table. Behind the keyboard, the monitor is positioned at eye-level close enough for the interface elements and text displayed on it to be easily legible. In the example above, in contrast, the monitor was placed above the eye-level of the assistant and dentist and further from them than a normal monitor would be. There was no horizontal surface between the assistant and the monitor for her to sit the keyboard and mouse on. She was forced instead to reach back to the bench behind her to use the mouse and to rest the keyboard on her thighs when typing, requiring her to replace it on the bench when not in use.

Unlike the usual single user of an office computer, there were two simultaneous users of the interface in the excerpt above (the assistant and dentist) and a third interested observer (the patient). The single-user dynamic of an office computer presents a particular kind of problem for dentists and assistants that is especially apparent if we compare their cooperative use of the computer with the other kinds of cooperative activities they undertake throughout the examination where they coordinate overlapping and parallel streams of activity. With the computer, their actions are forced into a sequential and linear stream of interaction. The computer changes the work from a stream of overlapping beginnings and endings to a series of starts and stops (Ingold, 2006b).

To summarise, there appear several clear problems with the use of standard computer input/output devices in the context of the dental examination. They are:

- They are challenging to integrate with infection control procedures

- They are difficult to use within the spatial constraints of the surgery
- They are optimised for single-user interaction but are being used in a multi-user context

4.1.2 Dentists see value in the use of computer systems in their work

Despite the obvious problems with the use of computers in the context of the dental surgery, it bears emphasising that dentists and assistants are overall *successful* in appropriating this technology into their work. Besides the electronic patient record, computer systems such as the one used by the dentist in the example above include functions for storing images taken with intra-oral cameras and x-rays, preparing treatment plans, tracking material use, recording appointments and handling billing. Evidently, dentists receive sufficient benefit from the use of their computer interfaces to bear with the problems of using them and appropriate them into the work.

A preparedness to incorporate computer technologies into the dental examination was not restricted to this surgery. In my research project, I visited a number of surgeries where computers were in use. I observed in these surgeries a variety of different ways that computers were positioned in the space of the surgery and the interaction with them divided between the dentists and assistants. This suggests both that the potential benefit of computers is not restricted to this single surgery and that dental practitioners are still experimenting with different ways of integrating computers into the work. Many dentists that I spoke to over the course of the research had experimented with different approaches to interacting with computers. Several had experimented with speech input, which would seem attractive as an input modality given the infection control constraints described above, or with foot-controls. Also, many were using new specialist devices such as intra-oral cameras or were considering the switch to digital x-rays.

For me, the apparent ability of dentists as 'artful integrators' (Suchman, 2002) of technology into their work, their preparedness to experiment with and bear with the shortcomings of current interfaces provided one motivation for choosing the dental surgery as the context in which to carry out my research. It seemed reasonable to assume that dentists might be receptive to alternative interaction modalities, such as gesture.

Indeed, from the beginning of the project, dentists met the proposal of gesture as an input modality positively and were generally interested in the concept.

4.1.3 Gestural interactions, skilled instrument-use and cooperative work

Beyond a pragmatic focus on the problems with current interfaces and the willingness of dentists to adopt new technologies into their work, the dental surgery was also a fascinating context to design for given my interest in gestures, as well as with respect to aspects of skilled instrument use, cooperative work and the structuring of the space to support the work. One of the features of the work of the dental examination that immediately drew me to it was the dentist's use of gestures when explaining aspects of the teeth to the patient (Figure 15).

Figure 15: Dentists use gestures to explain aspects of the teeth to the patient.

This was especially the case with the dentist from the excerpt above, who employed an extraordinary repertoire of gestures when describing aspects of the teeth to the patient. He could mimic the functioning and relation of the jaw using his fist and cupped hand, or describe the inner structure of the tooth by holding his hand inverted with his thumb, index and middle fingers pointing down representing the three roots of a molar tooth. There was an important social dynamic to the work of the examination in how the dentist interacted with and explained things to the patient within which gestures appeared to play a key role. These explanatory gestures about the structure of the teeth and jaw are described in more detail in section 5.3.

In addition to the dentist's use of gestures in his explanations about the teeth, there were other aspects of the dental surgery context that I found intriguing from a design perspective. Dentists and assistants employed a variety of specialized dental instruments in their work and they exhibited a high degree of physical dexterity and skill when working with these tools. The physical space of the surgery also seemed highly structured and organised toward supporting the work of the examination. Information resources such as x-rays were positioned within the space so as to be available to draw up on in discussions with the patient, and the arrangement of drawers, benches and the materials upon them was supportive of the flow of items into and out of the examination.

Figure 16: Dentist and assistant employ instruments in close coordination.

The work of the dental examination also had a collaborative character, which was interesting to me. I have already discussed how the dentist and assistant coordinated their actions to update the electronic patient record and I have hinted at the coordination involved in setting up the workspace, bringing instruments and materials into it as required. There was also a particularly striking instance of cooperative work with the use of delicately coordinated movements of hands and instruments when the dentist and assistant were working together in the mouth. At times, this would involve as many as four instruments simultaneously in use in the patient's mouth (Figure 16). From my starting interest in gestures, these finely coordinated movements were especially interesting because of the way that they seemed to flow smoothly without explicit verbal communication. Movements associated with these instances of finely coordinated work are discussed in more detail in section 5.4.

4.1.4 Framing questions to explore within the dental surgery context

The preceding presentation already suggests a relatively well-defined problem in the work of dental surgery that could potentially be addressed through the design and use of gesture input technology, that is, the difficulties encountered by dental practitioners when accessing electronic patient records in the course of a dental examination because of the need to follow infection control procedures and maintain social interactions with the patient. However, it was not the case that upon encountering the dental surgery I found this problem waiting to be solved. My initial impression of the dental surgery was that it seemed a promising setting within which to explore further with respect to my research interest in the design of gesture interfaces. Rather than a readily apparent problem calling for the design of a gesture interface, it was more that I encountered a series of intriguing questions that seemed worth exploring further in light of my research question, such as:

- What role do gestures play in the work of dentistry?
- How do gestures relate to instrument use and other movements in the surgery?
- How do gestures relate to the space of the surgery?
- Would gestural input technology provide a benefit for dental practitioners and if so, in what form and for which part of the work?
- How could dental practitioners be engaged to discuss the possibilities of gesture as an input modality?

The process of engaging in design was as much concerned with becoming sufficiently familiar with the work of dentistry in order to be able to begin to respond to these questions and frame a problem to be solved as it was with following a ready-made problem through to resolution. This aligns closely with Schön's discussion of how problem *solving* relates to problem *setting*, in which he argues that problems are usually not given, but must be constructed through processes of *naming* and *framing* (Schön, 1983). As he writes:

> "…although problem setting is a necessary condition for technical problem solving, it is not itself a technical problem. When we set the problem, we select what we will treat as the 'things' of the situation, we set the boundaries of our attention to it, and we impose upon it a coherence which allows us to say what is

wrong and in what directions the situation needs to be changed. Problem setting is a process in which, interactively, we *name* the things to which we will attend and *frame* the context in which we will attend to them" (Schön, 1983, p. 40).

In relation to the notion of *recoverability* articulated in the previous chapter, as well as the argument presented there that a process of design can provide sufficient grounding to inform further detailed analysis of the work of a dental examination, the processes of coming to understand the design context (of naming and framing in Schön's terms) is equally as important as the articulated problem and final design response. Therefore, in my presentation of the design process in the main part of this chapter, I give a detailed report of the exploratory design activities I undertook in order to understand and develop a design response for the work of dentistry.

4.1.5 Timeline of activities in the design project and two related projects

Before proceeding to a description of specific design activities and outcomes from the design project, it is worth stepping back to get an overview of the project as a whole and how it related to two other design projects that I engaged in during the thesis. This is shown as a diagram in Figure 17. In the diagram, time runs from top to bottom and coloured backgrounds are used to indicate periods of project involvement, with darker shading indicating periods of more focussed work.

Running down the centre of the diagram is a series of call-outs that identify groupings of activities from the projects. These are intended mainly as a structuring device for presenting the work through this chapter; each is presented in a separate section. As such, they should not be read as showing clearly delineated phases of project work but rather as indicating a general progression from initial observational studies informing design, exploration and development toward a final concept that could be evaluated with potential users. This progression of activities is typical of what one would expect from a participatory design project and many of the methods and activities are familiar within participatory and user-centred design approaches. Rather than go into detail with a description of already well-known design methods in this chapter, I focus in particular on how the question of designing for *gestural* interaction came into play in relation to each of these activities.

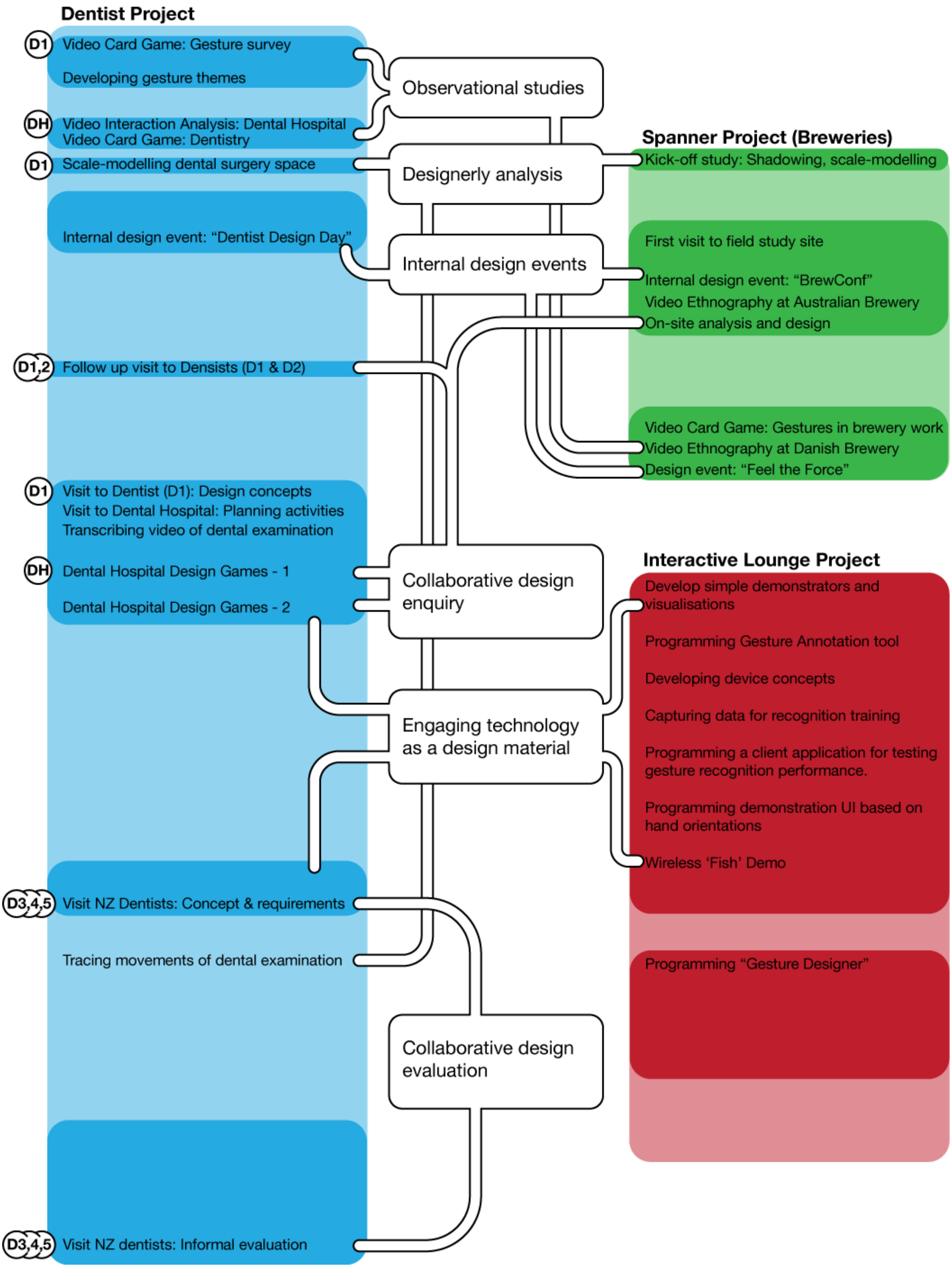


Figure 17: Timeline of activities and projects engaged in during the thesis.

The blue column on the left side of the diagram indicates the dentist design project, which I have already introduced. This was the longest running of the design projects that I took part in during my thesis and the most complete in terms of moving from early observational studies through to final concept development and evaluation. I worked on the project with two other PhD students, Brett Campbell and Tim Cederman-Haysom and my thesis advisor, Margot Brereton. While working closely together on the day to day running of the project, we also developed individual research questions to pursue. Campbell became interested in questions of agency relation to context aware computing (Campbell, 2010) and Cederman-Haysom became interested in the role of engineering expertise within a Participatory Design project for ubiquitous computing (Cederman-Haysom, 2009). When I refer to 'we' in the description of the design project, it is to Cambell, Cederman-Haysom, Brereton and myself that I refer, unless stated otherwise.

A number of different dental practices were visited over the course of the project. Occasions where these different dentistry practices were visited are identified on the diagram with white circles. These are labelled 'D1 to D5' for the five private practices and 'DH' for the dental hospital that were visited during the project. Engaging with these different dental practitioners was especially important for the project because it broadened my view of the variety of approaches to dentistry and brought more perspectives into the development of the design. Each of these dental practices also presented particular advantages for different parts of the design process. The first two (D1 and D2) were private dental practices where dentists known to members of the design team worked. This allowed us to get rapid access to the site of the dental surgery so we could begin our studies and initial design explorations. The dental hospital (DH) was a teaching hospital connected to our university in which some initial field studies and later some collaborative design games were undertaken. As a teaching hospital, it gave a view on a group of dental practitioners still at the early stages of developing their expertise and it lent itself to these more experimental and exploratory design activities. The final set of sites visited (D3, D4 and D5) were three dental surgeries in different cities in New Zealand. Our access to these surgeries was arranged through a contact at a dental technology company who had become interested in our work. They were suggested by our contact at the dental technology company as dentists who were open to experimenting with new technology in their work. Therefore, they were a good fit for the later stages of the project for collaborative design and evaluation sessions.

In addition to the dentist project, the diagram also shows two other projects that I took part in during my thesis. These projects played an important role in helping to develop my design approach and understanding of gesture interfaces more broadly. Shown at the top in green is the 'spanner' project, which was concerned with investigating possibilities for pervasive computing in the context of an industrial brewery. Below this in red is the 'interactive lounge' project, which was concerned with designing a gesture interface for interactive television.

The spanner project was carried out in collaboration with two other PhD students (Jesper Pedersen and Mads Vedel Jensen (2007)) and was supported by a manufacturer of industrial control equipment. The rationale for the project was driven by a pervasive computing vision that control components in industrial settings are becoming increasingly networked and control architectures de-centralized. The research question we set out to explore was how process workers and technicians could be supported to make sense of the network aspects of the systems that they were interacting with.

I was involved in this project during two main phases of the study, which consisted of field studies and design explorations in both Australia and Denmark. For my part in the project, I took as a main interest the question of how the gestures and movements of the people who work in breweries relate to the way they do their work and how this might be used to inform the design of interfaces for pervasive computing systems. Though breweries and dental clinics are clearly different as work contexts, my involvement on the spanner project proved beneficial for the development of the dentist project for two main reasons: First, both projects were at the early stages or observational studies and exploratory design work, so there was a good fit in terms of the general kind of design process activities that were taking place – especially questions around how gestures and movements could be recorded and analysed for design; Second, the brewery context highlighted for me how gestures and movements relate to the spatial context of the work and I was able to try out ways of analysing and working with this that I later employed in the dentist project. This is described below in the section on space modelling of the dental surgery. It is also reflected in the diagram, which shows the links between the brewery project and the dentist project at the early stages of workplace studies, designerly analysis, and internal design events.

The interactive lounge project had the aim to assess the applicability of gesture interfaces for interactive television. The project involved participants from three universities and one partner organization. The plan for the project was for two of the university partners to develop a gesture interface device and screen-based interaction for the context of an interactive museum exhibition at the partner institution and for the third university partner to carry out a usability evaluation of this with respect to an interactive television application. The project has been reported on previously in (Varan et al., 2006).

I worked on the project as part of the group that designed and implemented the gesture interaction device and accompanying screen-based interactions. This involved working closely with industrial and interaction designers from a partner university and with pattern recognition researchers from my own university. In comparison to the spanner project, my part in the lounge project was less focussed on observational studies and early stage design development and more on technical development and specific gesture interactions for a gesture interface. As such, it was a good fit for the later stages of the dentist design project, where I was able to make use of the development I had done with the technology in the interactive lounge project for the purposes of engaging dentists in design discussions of the possibilities for gestural interactions in the dental surgery and for practical tasks such as recording and annotating data for possible gesture interactions. Again, this is highlighted in the diagram, which shows how the work in the interactive lounge project helped in engaging technology as a design material, which was particularly helpful as the project moved towards a final design concept.

The dentist project was the longest of the design projects that I engaged in during my thesis and the one that moved through a complete design process from observational studies to final concept development and evaluation. Therefore it is the project that I focus on reporting from in this thesis. However, as shown in the diagram shows, the 'spanner' and 'interactive lounge' projects were carried out in parallel with the dentist project with interleaved activities. This was beneficial to the development of the dentist project because it allowed work from one project to carry over into the other, but it makes it somewhat difficult to separate these other projects out from an account of the research. Therefore, in the description that follows, these other projects 'peek in', from time to time.

4.2 Observational studies

In order to start to build an understanding of the design context, it was necessary for my colleagues and I to leave our office and go out to visit dentists, watch them at work, and talk to them about the issues they faced and the values that were important to them in their work. In addition to wanting to know how the work of dentistry is done currently, I was particularly interested in understanding the role that gestures and movement play in the work of dentistry, how gestures and movement relate to the coordination of the work and how they relate to the resources of the physical environment of the dental surgery. Along with the other members of my research group, video cameras were used to record examinations and notes were also taken of the action as it was occurring. Before and after the dental examination, we also had time to describe our research project to the dentists and ask questions about aspects of the work. During this early stage of the project, we were able to conduct observations at two private surgeries (D1, D2) and the dental hospital (DH).

In carrying out the observational studies, there were also some additional considerations related to the particular circumstances of my project and research question. Firstly, the dental surgery is a medical context in which patients receive medical treatment and have their medical histories discussed. In this context, special consideration had to be given to how the study might impact on the medical treatment of patients and how their privacy would be safeguarded. In all cases, we explained the purpose of the research and what would be involved to participants (including patients, dentists and assistants) and made clear that they could withdraw their participation at any time in order that they could give their informed consent for the study to take place. In this way, it was possible to observe several instances of dentists working with real patients. When videotaping examinations with patients undergoing an examination, the method of videotaping that we employed was to videotape the interaction without intervening in the interactions, because it was important not to disrupt the examination. If questions arose, we waited until after the examination had finished to discuss these with the dentist or arranged a follow up interview where we showed segments of video that we wanted to know more about. As a supplement to these observations of 'real' patients, we also arranged to observe examinations with dentists where one or other of the project team sat in as a patient in the examination. Informed consent and ethical procedures were also followed in these cases, but we allowed ourselves to be more 'forward' in our observations – asking questions about what was happening if necessary.

Given my interest in gesture and how this related to the work of dentistry, a second relevant consideration concerned how to record details of gestural interactions observed during the field studies. Video was chosen as a primary medium for this, because it offers the advantages that gestural interactions can be captures that would otherwise be impossible to record and that video can be viewed repeatedly, which allows observations to be shared and discussed with colleagues and revisited later. It must be remembered that a video recording of a gesture is not the same thing as the gesture itself and that the act of recording with video inevitably involves choosing a frame and perspective for the image with a background, foreground and point of focus that might be quite different to that of the people performing the gesture.

4.2.1 Developing gestural themes of interaction with the video card game

When working with video as a medium for recording observational studies, it is easy to amass a large corpus of video material, that can then be very time consuming and difficult to sit through and analyse. A method that proved useful for dealing with video that we had collected during these early observational studies was the 'video card game'. This is a method for collaboratively analysing and producing themes from a corpus of video data (Buur & Søndergaard, 2000; Buur, Binder, & Brandt, 2000). Originally developed in the context of industrial product design, the method is loosely based on the metaphor of a children's card game called 'happy families', where players collect and trade cards in order to complete a set. In the video card game, participants instead trade custom made cards corresponding to video clips from a corpus of video data in order to build themes around a topic of interest. Each card has the title of its corresponding clip, a still image from the clip, and some space for writing notes.

The video card game progresses through a series of rounds starting from individual observation and ending at collaborative discussion and card trading. Participants begin by forming into pairs and each pair chooses a set of cards from a common pool. Each pair then goes and watches the clips corresponding to their cards and looks for possible themes. The group then re-forms around a table and each pair presents their themes. The other groups offer cards from their set that could fit each proposed theme. Each group then decides on a single theme, which they refine based on the contributions from the group. These are again presented in a round and each theme is recorded by sticking the video-cards for that theme onto a piece of A3 paper along with a title and the name of the owners of the theme.

The video card game was used twice during the dentist project. The first video card game we ran was at the very outset of the project and was used as a way of surveying gestural interactions across a range of workplace and everyday settings in order to get started thinking about possibilities for gestural interface design. Then about six months later, we ran another video card game to enquire into the work of dentistry, using additional video material that had been gathered from a dental surgery in the intervening time.

As a result of running the video card game on these two occasions, eleven separate themes were developed in the form of A3 posters with theme cards stuck on them, titles and names of authors. In addition to these theme posters, candidate themes that were proposed during the game but not developed further were also written down in order that they could be revisited if necessary. Following the video card game, I went back to the source video material for each of the themes in order to refine these themes and try to understand them in more detail. Clips that did not support the theme as originally proposed were removed and clips that had not originally been included but which were appropriate were added. The definitions of the theme were refined to be more precise and consideration was given to what the implications of the theme might be for design. I developed a common format in order to record these refined themes, consisting of the following components:

- **Short Title**: A short and memorable title is preferred over a long descriptive one.
- **Introductory paragraphs**: Describe the theme in general terms including the contexts of interaction in which it occurs.

- **Specific examples:** Selected specific examples of the theme from the source material. Each includes clip reference, still image and textual description. **Descriptors:** A list of short phrases describing characteristic qualities of the theme.
- **Implications:** Speculation on how the theme might be relevant for design.

The set of themes that was developed further from the outcomes of these two video card games is presented below. For the sake of brevity, I present only the title, introductory paragraph and a single example here. Several of the themes have been published previously with the full format (Brereton, Bidwell, Donovan, Campbell, & Buur, 2003). One interesting characteristic of the themes that resulted from having developed them across the two video card game sessions is that they related to different granularities of interaction.

There were several themes from the first video card game which related to particular kinds of gesturing (Table 4). These were: mirroring gestures, gestures as placeholders, preparatory gestures and commanding gestures. An interesting aspect of these distinctions is that they distinguish gestures based on the form of the gesture as well as based on the purpose the gesture serves. 'Mirroring gestures' describes the observation that when two people are conversing, they sometimes mimic one-another's gestures. In the example, the dentist made a gesture to his own jaw when describing a dental procedure, which the patient immediately repeated. These gestures seem to serve the purpose of confirming a common understanding. The 'gestures as placeholders' and 'preparatory gestures' are more related to the way that people make gestures for their own benefit either by pointing to a position that they need to keep track of or by gesturally rehearsing an action. The 'commanding gestures' themes describes gestures made explicitly to direct the actions of another person.

In terms of the existing research into human gesture presented in the literature survey, only the first of the themes (mirroring gestures) fits with McNeill's focus on spontaneous idiosyncratic communicative movements accompanying speech. The example of the commanding gesture was performed without accompanying speech probably closest to an emblem in the terms of Kendon's continuum (Figure 9). The other two themes (gestures as placeholders and preparatory gestures) describe gestures a person performs for their own benefit, to support their own actions.

Table 4: Themes about kinds of gestures

Theme: Mirroring Gestures

When we watch two people communicating we often see them mirror each other's body posture and gestures. People are seen mirroring gestures to confirm what has just been communicated, sometimes slightly adapting the gesture to modify the meaning. They are used as a substitute for or supplement to spoken language when words can't be found or do not seem sufficient to convey meaning. In this situation gestures act as concept-tokens that other people in the conversation can use to attach meaning to, expand on, or change. The ability to mirror the original gesture is central to this process.

Example clip: Dentist explains the surgery

The dentist used his hands to describe the sequence of a particular dental procedure to the patient. First he indicated with both hands where the gums would be lifted and the bone cut. Then with one hand he described how the upper palate would be free to move around. At this point the patient used a very similar gesture and indicated both verbally and with a nod of the head that he understood. The patient's use of the same gesture made it clear *what* it was that he understood.

Theme: Gestures as placeholders

Gestures may be physical, temporal and/or mental placeholders. Such gestures are characterised by being relatively temporally extended rather than of short duration. Although these gestures might arise in communication, most of the instances we observed and described involved only one person. It is interesting to observe that such gestures occur around information of very different granularities. They range from pointing to identify a single object to using several fingers to hold attention to and compare several objects. When gestures are engaging in place-holding fingers are seen to spatially 'home-in' on or seek an information object.

Example clip: Dentist uses the mirror

The dentist was performing a routine 'tooth-by-tooth' examination. He held a mirror in one hand and a probe instrument in the other. As he moved from tooth to tooth through the mouth the mirror and probe seemed to help him hold his place as he worked.

Theme: Preparatory Gestures

Gestures are sometimes used as a way of preparing ourselves to undertake a task. These tasks are either ones that require being done right first time, and or ones that require a high degree of motor coordination. Preparatory gestures may rehearse the action to come, such as when a golfer makes a practice swing, or when we are using a new piece of equipment for the first time. Alternatively they may be typical gestures that precede an activity.

Example clip: Trainee with auto screwdriver

The trainee adjusted her grip on the pneumatic screwdriver and then practiced pressing the activation switch. Only when she had completed these initial gestural interactions that gave her a feel for the tool, did she shift her focus to the task at hand, screwing the flow meter case together.

Theme: Commanding Gestures

Commanding gestures are used to direct another person to do something. These gestures are typically simple, short, recognisable, and relatively independent of speech. They tend not to be used for everyday interactions; rather they are used in situations where there is some extenuating factor, such as noise level which impedes effective verbal communication, a need for urgent communication of danger, a need for discretion when a dentist wants to direct an assistant without alarming a patient etc.

Example clip: Boy on gangplank

On the ferry a young boy attempted to disembark across the boarding plank before it was completely secured. The deckhand held his palm out flat signalling to stop and wait until safe to proceed. The boy did not receive further verbal guidance – it is clear that the gesture caused him to wait. In this situation the extenuating circumstance is that the deckhand needed the boy to stop immediately for his own safety. There was also the possibility that verbal instructions could be lost with the wind.

Table 5: Themes about interpersonal aspects of dentistry

Theme: Interaction with the patient

The dentists we have observed seem to try to maintain good communication with their patients and be attentive to their feelings and needs. They take time to explain complicated procedures and conditions in a lot of detail, explaining the meaning of any terminology. When working in the patient's mouth they pause from time to time to allow the patient to rest. They also engage in personal conversation with the patient and ask them how they are feeling.

Example clip: Dentist explains flat teeth

The dentist had just finished his initial examination of the patient's teeth and was explaining his findings. Although his explanation included terms such as 'cusps', 'inter-cuspation' and malocclusion' the meaning was clear because he either re-phrased the words in simpler language or used hand gestures to clarify the meaning. For instance, when he used the term 'inter-cuspation' (the way the teeth fit together) he accompanied it with a two-handed gesture where he spread and inter-locked his fingers and moved them back and forth slightly. This was then explained further both by elaboration and an additional gesture.

Theme: Articulation Work

This theme is about the importance of doing small tasks for completing the big task. When doing articulation work, there is a need for coordination between the small tasks and the big one. When there are different people doing the small tasks they need to cooperate to be able to complete the big task. They have to articulate their individual work to make the others aware that the small tasks are done.

Example clip: Dentist tells assistant what is needed

The dental student instructed her assistant on what she needed him to do for the next stage of the treatment. Although she turned her attention back to the patient she later looked back over to the assistant to see what he was doing and provide more instructions.

Theme: Shared Tools, Shared Workspace

The theme of "Shared Tools, Shared Workspace" arises when two or more people undertake different tasks but do so within the same space or using the same objects. In all instances of the theme each person is familiar with the other's task and intentions to some extent. It reminds us of the interweaving actions of dance partners or tennis players without the elements of shared movement or competition.

Example clip: Dentist and assistant cooperate

The dentist and the assistant were cleaning the patient's teeth with the ultrasonic scaler. The dentist held the scaler in one hand and the mirror in the other. The assistant held the suction instrument. As the dentist moved around the teeth with small precise movements, the assistant maintained a space between her hands and the dentist's but positioned the suction instrument so it was in the right place. Only when the dentist removed his hands from the mouth to let the patient have a break did she use larger hand movements to apply suction to other parts of the mouth.

The second set of themes related to interpersonal aspects of the work of dentistry (Table 5). They were: interaction with the patient; articulation work; and shared tools, shared workspace. The inclusion of these themes clearly reflects the cooperative nature of the work of dentistry and the importance that dentists place on their interactions with the patient. From a gesture perspective, these themes are also interesting with respect to the role that gesture appears to play in supporting these different relations. In the first case, with the interactions between the dentist and the patient, we saw clear use of communicative gestures by the dentist when explaining aspects of the teeth to the patient. With the articulation work theme, we see how maintaining a shared understanding of the work depends on and is supported by a mutual awareness of tasks and this can be communicated through gestural interactions. Finally, in the theme about shared tools and shared workspace, an example is presented which suggests that the movements of the dentist and assistant mediate the coordination of the work.

Table 6: Themes related to physical interactions

Theme: Customisation of Objects in the Workspace

Typically we customise/personalise objects in a workspace to make ourselves more comfortable, organised, and efficient. Customisation refers to the arrangement of objects in a space to suit an individual's particular needs or desires while personalisation encapsulates the act of taking an object and manipulating it in such a way that its use is unique to the individual. Customisation can occur in a varied scale ranging from the way tools are arranged in a small space to the way larger objects in the workspace, such as furniture and benches are used and manipulated. Personalisation is often intrinsically linked to customisation.

Example clip: Dentist waits for assistant

While the dental student was waiting for her assistant she reached over and rearranged the instruments and moved the stand closer to her.

Theme: Different Foci of Attention

In general when we are attempting to work, we focus our attention on one particular object. However in an environment that involves a lot of different activities, it is necessary to vary our attention. It was observed that generally there was a moment of readjustment when the change of focus was made. It was as if there were two areas of attention being kept in the mind and the changeover took a bit of time. This allowed for good concentration on the task at hand, whether it be in the confines of a mouth or the expanse of a desk.

Example clip: Dentist polishes and tests the bite

The dental student was polishing the new filling. Her head was bent forward, eyes concentrated on where her hands were working in the patient's mouth. After a little while she looked up to the right to the tool tray and replaced the polisher, then looked quickly left to the bench, leaned over and retrieved something. Then she attended to the patient again, but this time her focus was not as concentrated as at first as she alternated between peering closely into the mouth and glancing up to get things from the tool tray.

Theme: Barrier of Sterility

A big constraint on the dentists is the need for them to maintain sterility while in surgery. We often saw how the dentist's interactions with their tools and environment were hampered by the fact that they could not touch un-sterile things. We also saw several occasions where dentists and assistants circumvented sterility protocols, presumably in order to work more efficiently.

Example clip: Dentist asks for journal to be opened

The dental student was wearing gloves and examining her patient when she needed to refer back to the patient record. Rather than take off her gloves or wait for the assistant to return she motioned to the cameraperson and asked for the record to be opened. Once the cameraperson had opened the record the dental student made a circular motion with her hand and said "next page". She did this three times until she was looking at the page she wanted. Then she pointed with her finger as she read the record without touching the page before finally returning to the patient.

The final set of themes related to the physical constraints and environment of dentistry (Table 6). They were: customisation of objects in the workspace, different foci of attention, and barrier of sterility. The interesting aspect of these themes from a gesture perspective is that they point to some of the physical constraints and opportunities for action afforded by the context of the dental surgery. The customisation theme would probably relate to many work settings, but it is particularly interesting to observe at work in the dental surgery context, because the bracket tables, chair, lamp and stools that the dentists and assistants use are optimised for a wide range of adjustments. Watching dentists and assistants at work during an examination, one notices that they are constantly adjusting and readjusting their work environment to suit the task at hand. The 'different foci of attention' theme picks up on the way that the dentist's focus and attention moves around the workspace as the procedure progresses. From a gesture interface design perspective, it raises the question of whether a gesture interface would require the direct attention of the dentist and if so, where that attention should be placed within the range of other foci that currently compete for attention. The sterility theme picks up on a major constraint on the way that dentists are able to physically interact. This is at once a possible motivation for gesture interface design because current interfaces are challenging to integrate into infection control procedures, but also a constraint that a gesture interface would need to work within.

4.2.2 Using video to understand the role of gestures

Setting out to try to build an understanding of the role of gesture in a context such as the dental surgery presents particular challenges for an observational study. Video observation techniques have the advantage that they can record occurrences of gestural interactions with a high level of fidelity, capturing details of posture movement and rhythm, which would not be possible with other field recording media such as pen and paper or audio recordings. However, this extra fidelity comes at a cost, which is that video can be unwieldy to analyse and communicate the findings from to others.

I found that the video card game was an effective way to work against this problem and still end up with themes that captured some of the richness of gestural interactions in the setting of the dental surgery and several other contexts. The themes of interaction were an effective way to record and communicate the findings of the video card game activity.

There are clear similarities between these themes of interaction and the notion of patterns as it has been used in interaction design (Crabtree et al., 2002). However, I consciously decided against using patterns, both because the link between the themes and particular design solutions was unclear and because our understanding of the themes themselves was still forming. An important difference between these themes and the general categories of gesture presented in the literature survey is that the themes are tied to a particular context of activity with which the members of the design team had *direct personal contact*. Indeed one of the key benefits of engaging in observational studies from the perspective of gesture interface design is that as designers we take our own gestural abilities out into the world that we seek to observe, understand and design for. There is also a benefit in being able to explore ideas that may not be generalisable, but are nevertheless interesting for design.

4.3 Designerly analysis

In a process of design, designers move between reflective moments of appraisal, episodes of engagement with a design problem, and reflection-in-action where processes of action and reflection are closely intertwined (Schön, 1983). When carried out within the context of a research project, such as the dentist project, it is possible that this kind of reflective design practice could also serve an analytic purpose. Making design *moves* and listening to the 'back-talk' that results (Schön, 1983) opens up for the possibility of *designerly* analysis, which can serve as a useful complement to other kinds of analytic research activity.

This is not to set up a false dichotomy between this and other kinds of research, such as that described in the previous section. In fact, the video card game method was proposed explicitly as a way of taking video beyond 'hard-data' in user-centred design toward something more akin to a design material (Buur et al., 2000). Nevertheless, it does seem reasonable to highlight a difference and suggest that there may be a continuum of possible analytic stances. Designerly analysis emphasises actively engaging the design problem and responding with processes of making, drawing, and working with materials.

Two activities from the dentist design project stand out in this respect and proved useful in developing my understanding of gestures in dentistry. The first, building a scale model of the surgery, was particularly helpful in opening up for consideration of the spatial context of the dental surgery and the second, tracing the gestures of the dental examination, was helpful in building an awareness of how gestures are arrayed in time in relation to the unfolding events of the examination.

4.3.1 Modelling the space of the surgery

A particular challenge in designing for the dental surgery was to develop an understanding of the spatial relations within the setting, especially with respect to the activities and movements of the dentist, assistant and patient. One way to engage with this complexity was to go out and experience and observe the context directly as described in the previous section. Such activities were effective for giving an overall picture of the work of dentistry and we could begin to see how the arrangement of the space related to the work of the dentists. However, because of the constraints of the time of dentists it was only possible for my colleagues and I to spend short periods in the actual context of the dental surgery. A challenge for us was therefore to keep a hold of the richness of the design context that we had experienced first-hand at the dental surgery when we were back in our office at the university.

Facing similar issues in a project aimed at investigating the design of networked products within a pervasive computing project, (Lehrdahl & Pedersen, 2002) have suggested activities involving space modelling of a design context as one way to hold on to the richness of the setting when designers are back at their studios. In these activities, physical models are made of the spaces that are being designed for. Models can be made at a range of different scales, from full size to small scale and support designers in a number of different ways, depending on the scale and level of detail at which they are created. Full-scale models of selected parts of the setting can support designers in developing empathy for the people in a design context by acting out scenarios of use. Smaller scale models of the overall space can help to give an overview of relations and show how relations fit together within a spatial context.

As mentioned previously, I was first introduced to the scale modelling activity during the spanner project, where I used it with Pedersen to help understand the relation of brewery workers to the space of the bottling line and the activities of their work colleagues. The scale modelling activity worked well for this, so Campbell, Cederman-Haysom and I decided to try this approach to help understand the spatial relations within one of the dental clinics we had visited (D1) by building a scale model of the various rooms it contained. We were interested in modelling not only the surgery, with which we were already familiar from our previous visits, but also the other rooms and spaces in the clinic that we didn't know so much about. In order to build the model, we arranged for the dentist to give us a guided tour of the spaces of the clinic as part of our next visit. As the dentist showed us through each room we made a plan sketch in our notebooks as well as notes about the purpose of the room and who worked there. Then we went to a café next door and combined our separate observations and drawings into a single larger version on a piece of cardboard. When we were agreed on the form of this larger plan, we took it back to the dental clinic and checked with the receptionist to verify that we hadn't made any mistakes.

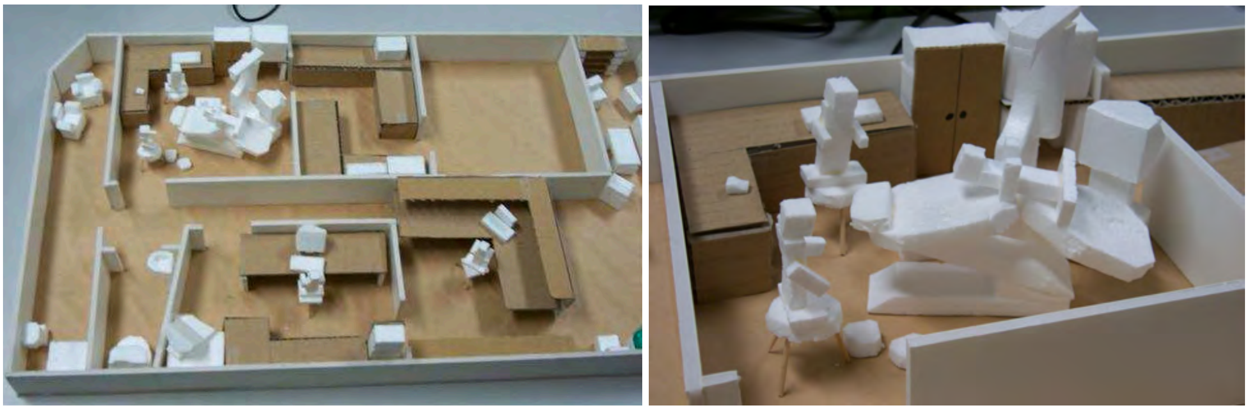


Figure 18: Scale model of a dental clinic (left) and detail showing the surgery (right).

We then went back to our office at the university and used the plan drawing on the sheet of cardboard as the basis to create a better quality scale model of the surgery. For this, we used simple modelling materials (cardboard, foam core, polystyrene and toothpicks) to turn the plan we had made into a model with walls dividing the rooms. Figure 18 shows a picture of the model of the whole clinic as well as a detail showing the surgery of the dentist we were working with. As can be seen in the picture, models of the furniture and equipment inside the rooms were created along with models of people to stand for the dentist, assistant, patient, clinic manager and receptionist. Once we had created this model we took it back to the clinic on our next visit and presented and discussed it with the dentist in order to again check and verify our understanding.

In order to more easily present the different rooms in the clinic, Figure 19 shows a labelled plan diagram of the space. On the right hand side, the entrance to the clinic opens on to the reception area, which has a desk staffed by a receptionist and a waiting area with chairs. A corridor runs the length of the clinic to a narrow room used as a staff area and for storage. On one side of the corridor is an office room where the management functions of the clinic are carried out as well as a bathroom. The two surgeries that the clinic contains lie to the other side of the corridor, separated by a laboratory. The surgery on the left ('surgery 2' in the diagram) was the surgery of the dentist that we collaborated with for this study and which we had visited previously. The other surgery belonged to another dentist who was not a participant in the project. During our visit this dentist was seeing a patient, so it was not possible for us to observe this room so we left it empty in the model.

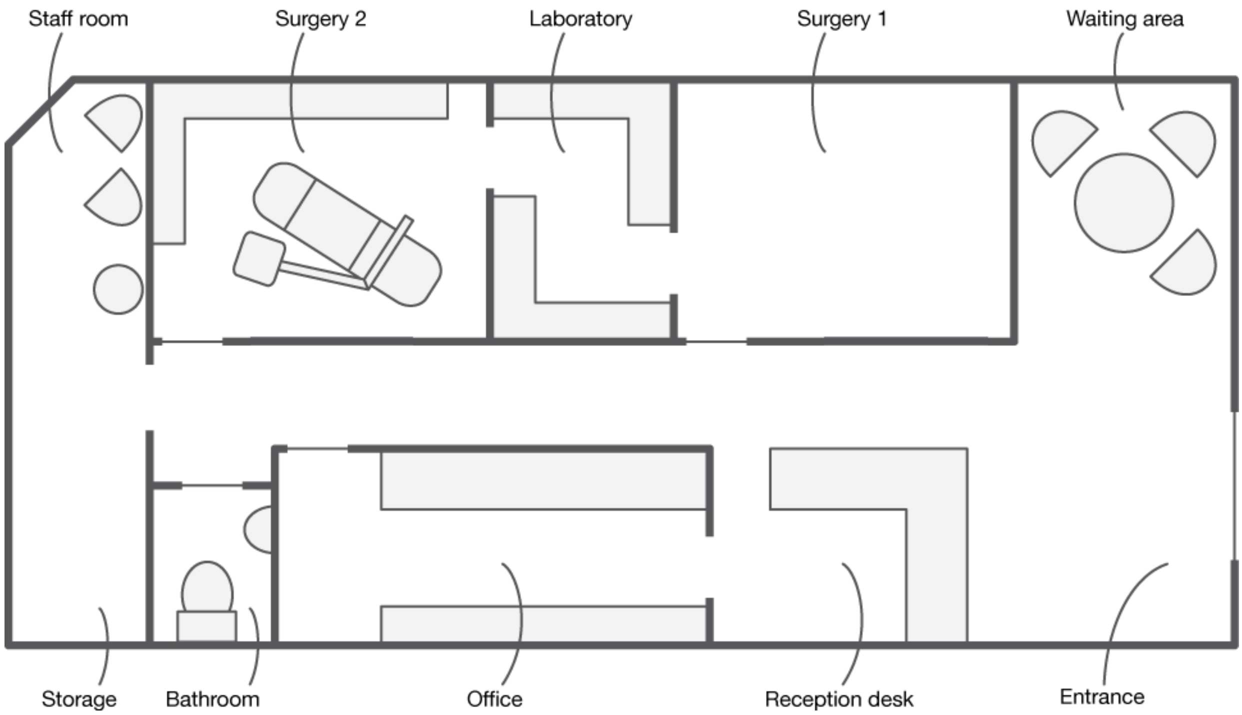


Figure 19: Plan of the dental clinic.

The process of mapping the space of the clinic, building a model of it together, and verifying our understandings with the dentist and receptionist at the surgery was an important step in developing our understanding of the work of dentistry. Prior to building of the model, we had mainly paid attention to the space and activities happening *within* the surgery. Building the model forced us to attend to other parts of the clinic and the activities that happened in them and how these related to the work done in the surgery.

We got more of an appreciation for the fact that a dental surgery is a business, as well as a place of medical treatment. In the office, we saw where the office manager carried out the work of accounting and record keeping for the clinic. At the reception desk, we learnt that the job of the receptionist is not only to welcome patients into the clinic and advise them when it is time for them to go into the surgery, but also to handle sending out letters to remind patients that it is time for a check-up, in this way maintaining contact to patients over time. This also gave us a better understanding of the software that the dentist used in the surgery. Previously, we had seen the dentist using this software to access the electronic patient record and treatment plans, but he had told us that the software also supported a range of other functions related to the business side of dentistry, such as allowing for tracking usage of materials, billing and appointments. During the guided tour of the surgery, we paid particular attention to the various places where people were using computers to access the system. We included this information in the scale model of the surgery by making small polystyrene computer screens in the surgery, office and reception areas (Figure 18). In this way, we saw the same computer system from (literally) different standpoints. We came to see the different screens of the software program as connected to the different spaces in the clinic, each with its own view on the system. Whereas the focus in the surgery was on the treatment plan and patient records, the focus from the office was on management and reporting functions and from the reception desk it was on the view of appointments reminders.

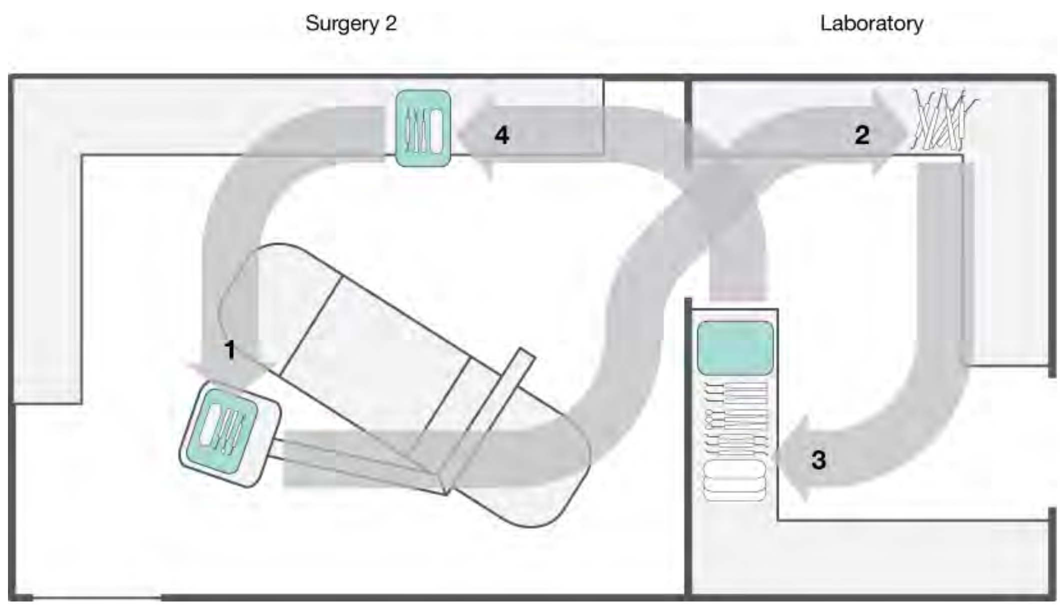


Figure 20: Flows of instruments and materials between the surgery and laboratory.

The modelling exercise also helped us to clarify our understanding of the flows of instruments and materials into and out of the surgery. The dentist had previously described to us how the instruments were cleaned in an autoclave and we had seen the instruments in use in the examination, but we didn't have a picture of the whole process by which the instruments were used, cleaned and then prepared for use again. A particularly interesting aspect of this was the use of instrument trays, which is illustrated in Figure 20. These trays (represented by the blue rectangles in Figure 20) were prepared to contain the instruments and materials commonly required for a procedure. Since different procedures require different combinations of instruments and materials, a number of different trays were prepared for the common procedures encountered in the surgery. These trays were stored in the cupboards above the bench next to the entrance to the laboratory. In setting up for an appointment, the assistant would choose the tray for that procedure from the cupboard and place it on the bracket table ready to be used by the dentist (arrow 1). When the procedure was complete, the used materials would be discarded and the tray and dirty instruments were taken into the laboratory where there was an autoclave, which is a device that uses high temperature and pressure to sterilize the instruments (arrow 2). Once a batch of instruments had been sterilized, they would be sorted back into the different kinds of instrument trays (arrow 3) and returned to the cupboard in the surgery ready for use (arrow 4).

This was interesting for my design project, because it lined up with a shift in my thinking from the idea of designing a generic gesture interface towards the idea of designing a 'gesture instrument', which would be a device made specifically for dentists that would sit alongside their other instruments in the bracket table and they could use to interact with the electronic patient record. Such a gesture instrument would need to fit within the existing flows of instruments between the surgery and laboratory described above, which presents several requirements and relevant questions for this concept:

- A gesture instrument would need to be able to withstand the temperatures and pressures of the autoclave
- The issue of charging would need to be addressed. This could possibly be integrated into the existing cleaning process

- Would a gesture instrument be inexpensive enough that a clinic could afford to purchase a large number as they do with other dental instruments or would each surgery only purchase one or two, as they do with intra-oral cameras?
- Would gesture instruments be packed into trays according to procedure along with other instruments? If so, could this information be used to make the gesture instrument respond to different gestures based on procedure?
- Should a gesture instrument be a dedicated instrument, or should it be built into an existing instrument such as the mirror or probe? Could it also be packaged so that it can be clipped on to other existing instruments?

The scale model of the surgery was also useful in supporting the collaborative aspects of our own design process. It provided a shared tangible reference to the spatial layout of the dental clinic that we could use to ground our design discussions when we were working back at our office at the university. The model was small enough that it could sit on top of a bookshelf near our desks where we could easily pull it down and refer to it during discussions. This was useful not only in supporting discussions within the design team, but when describing the space of the dental clinic to other researchers who had not visited the space. It was also brought to the internal design event described in the next section. The model also supported us in communicating our understanding to the dentist when we took the completed model back and verified it with him. As a tangible representation of our understanding of the space of the clinic, the model was more accessible for the dentist to interpret and comment upon than field notes and sketches written in a notebook for example. A less obvious aspect in which the scale model supported the collaborative aspects of the project was in the process of *making* the model. By bringing together the individual notes and observations of researchers about the space of the clinic and building these into the form of the scale model, we were also building a shared understanding of the space. We had to agree on the overall form of the model, what was important to include in each room, and the appropriate level of detail. This was particularly important given that we were each in the process of developing our individual research interests in the project.

4.3.2 Tracing the movements of a dental examination

The space-modelling activity described above proved to be a useful way of analysing the spatial relations of the dental surgery and how it related to the larger dental clinic. Later in the dentist project, I engaged in another instance of deisgnerly analysis, which was helpful for analysing the temporal and spatial relations of the gestures and movements within the dental surgery during a dental examination. At this time, I was working through the more conventional analysis that is presented in the next chapter. Whereas most of the video that we had collected during the dentist project was hand-held, the video that I was mainly working from had been taken from a tripod-mounted camera positioned at the foot of the dental chair, which meant that there was a stable framing of the image from the start to the end of the examination. At some point, it occurred to me that I could take advantage of this and make a tracing of the video that might show how the dentist, assistant and patient moved over the course of the examination.

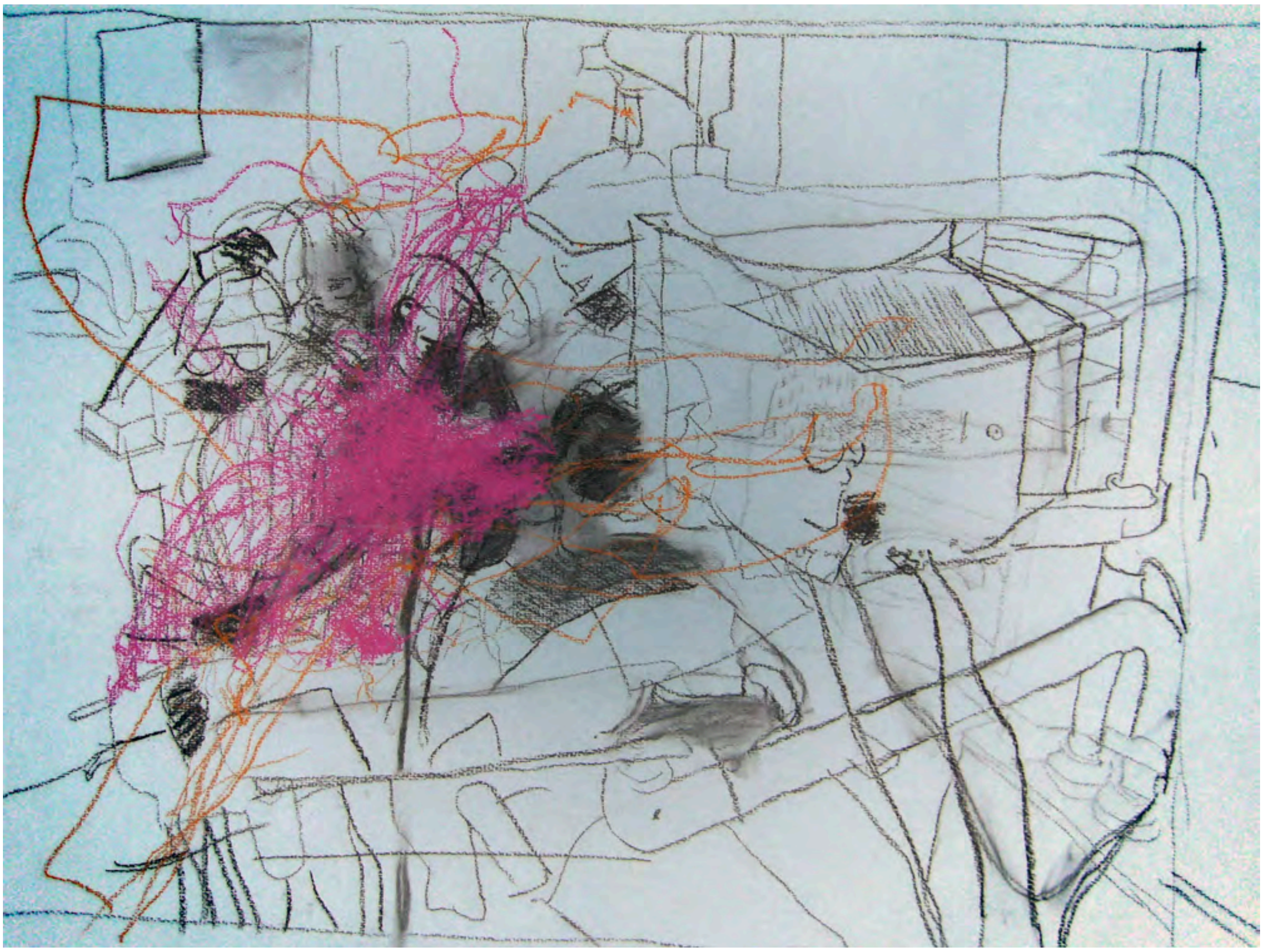


Figure 21: Tracing of the movements of a dental examination.

In order to do this, I took a large (approximately A0 sized) sheet of paper and taped it up on a wall. Then I projected the video of the examination onto the paper with the projector positioned so that the image filled the paper. I played the video through at normal speed and traced the movements with a chalk as it played. I allowed myself to vary between tracing the line of movement of a single part of the dentist's body (his right hand), outlining the bodies of the dentist, assistant and patient as they changed posture, and drawing the furnishings of the room that were visible on the image. I simply tried to keep drawing the whole time. Once the tape had played through (approximately 40 minutes), I rewound it and played it again. This time tracing with a different coloured chalk. A version of the drawing that resulted is shown below in Figure 21. The colours of the original drawing have been inverted in this version in order to print legibly.

One way of presenting this drawing would be as a visualisation of the movements of the dental examination, but this would miss the real worth of the activity. From the image above, we can see a large scribble of pink lines concentrated on an area to the left of centre. There is also a less-dense orange-line that ranges out from the same central spot, but over a larger area. Several outlines of people can also be seen, as well as the outlines of the furnishings of the room, some rubbed out and re-drawn in a different position. Clearly, there is a relation between the drawing, the video that was projected, and the examination that was recorded, but what we really see in the drawing are the traces of *my movements* as I held the chalk out to the paper and struggled to draw along with the running video.

For me, the real worth of this activity was in the *process* of drawing, not in the drawing that resulted. The drawing reflects some accumulation of temporal activity. This helps you remember while you are drawing, but it does not let us see the shape or structure of that temporal activity in the drawing that results. We cannot see where the line starts or ends, or whether it moved quickly or slowly, or in what direction it moved. Whereas the drawing is a flattening of forty minutes of video into a single image, the *process* of drawing took place in real time and allowed me to experience the rhythms and regularities of my own movement as I followed along with the video.

Because of my familiarity with the setting, I had a strong feeling for how the movements that I saw in the video related to the layout of the surgery. As I traced the movements of the projected video, I was struck that the movements and gestures of the dentist and assistant are *located* such that particular kinds of movements and gestures occur in predictable places within the surgery. The dentist moved in close behind the patient and leaned in when examining the teeth, sat straight-backed focussed on the computer when making a note, and moved to the side of the patient when explaining something about the teeth. In retrospect, this is a rather obvious observation, but it had not occurred to me up until that point. Though I could see this in the video as I was drawing it, I could see that the drawing did not show it, especially because of the perspective from which the video was taken, which flattened the dentist's movements into one plane.

I set out therefore to try and draw another picture, which expressed my understanding for how the movements I had seen in the video fitted within the space of the surgery. This is shown in Figure 22. This picture is drawn as if looking down from the ceiling onto the middle of the dental surgery. On the left is a blue shape for the movements of the dentist and on the right side is a green shape for the movements of the assistant. In the middle is a smaller orange shape for the movements of the patient. On the assistant's side, there is a long green blob extending down the right edge. This corresponds to the bench at the back of the surgery where the assistant brings in and prepares materials for the examination. There is also a smaller blob in between this and the central area, which corresponds to where the assistant types on the keyboard. On the dentist's side, there are several tendrils reaching out in different directions. These correspond to where the dentist reaches to adjust the position of the bracket table and light, where he stores and retrieves his instruments and where he points to the x-ray on the wall behind him. The shapes of the dentist and assistant also overlap in several places. One is in the centre of the drawing, where a small circle is drawn. This shows the area of the patient's mouth where the hands of the dentist and assistant work together when performing a scale and polish. Another is at the top of the picture, corresponding to the area behind the patient's head, where the dentist and assistant passed things to each other out of view of the patient.

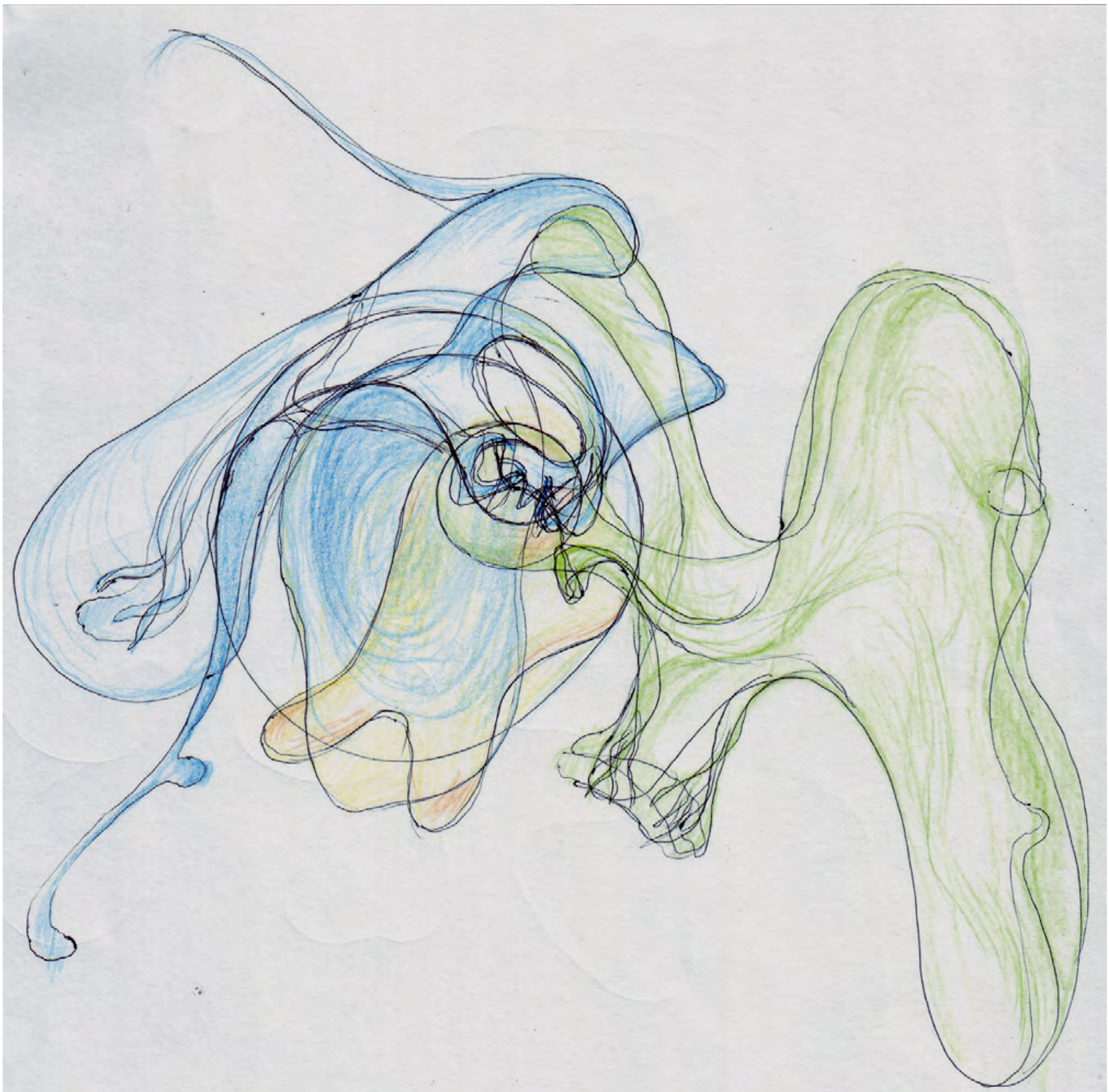


Figure 22: Impressionistic diagram of the locations of movements.

In drawing this picture, I struggled with how to indicate some of the different kinds of movements. With the lines curling around the mouth and the lines reaching out to the keyboard, I tried to give an impression of the way the hands were held and the quality of the movements, but with other movements, such as making explanatory gestures for the patient, it was less clear how to do this within the format of this picture.

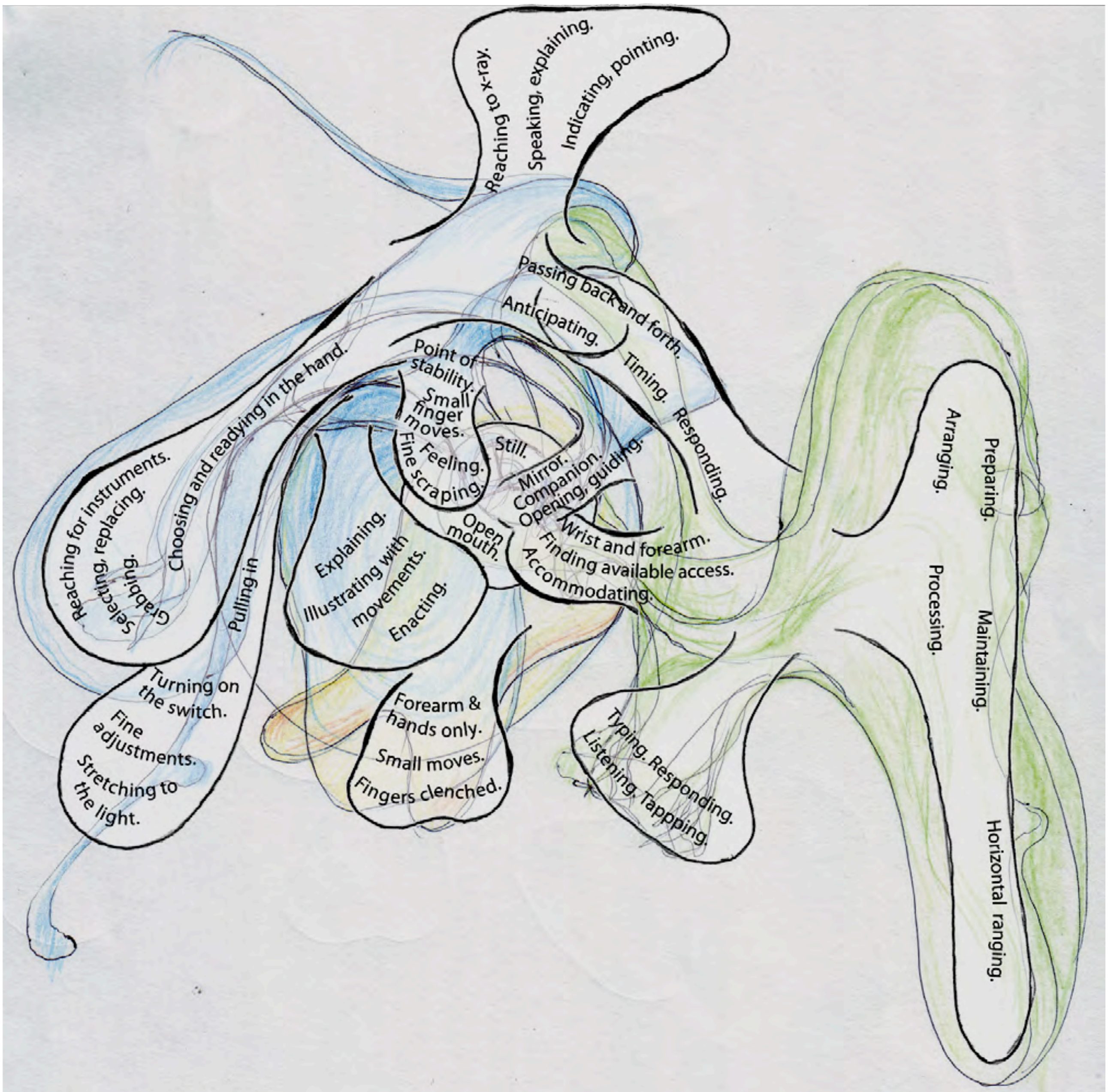


Figure 23: 'Movement bubbles' of a dental examination.

To address this, I decided to draw another diagram and try a different way of indicating the movements. To make this second diagram, I took a piece of paper and laid it over the first diagram of the locations of movements, so I could trace through the paper. Then I drew bubbles indicating where I felt that the different areas of movement were. Inside these, I wrote words and short phrases describing the movements. I thought of these 'movement bubbles' as something like speech bubbles in a cartoon. A version of the diagram is shown in Figure 23 superimposed on the first diagram and with the words re-typed for legibility.

4.3.3 Designerly analysis and understanding gestures

In terms of developing my design thinking in the dentist project, the activities of designerly analysis described in this section played an important role. In a very literal way, they helped me *locate* my thinking about gestures. This changed the way I saw the problem of gesture interface design from a question of what kind of gestures to use, to one of what kind of gestures to use, and *where* and *when* in the space of a dental examination. They are not just analytic observations, but also design moves, because they reframe relevant aspects of the setting for consideration in the design process. In reflecting on the reason that these activities were successful, it seems to me that a key ingredient is that they required an active engagement in a concrete activity of creation.

The notion of designerly analysis challenges conventional distinctions between design and other kinds of research activities by suggesting that the processes of design for a setting and analysis of a setting can be tightly bound rather than separate activities. As such, it is very much in line with one of the main themes of this thesis, that gesture interface researchers engaged in design can also make contributions back to broader understandings of gesture based on knowledge gained through their design activity.

4.4 Internal design events

Another area in which gestures were engaged with in the design project was through collaborative design events within the design team. To kick this off, Campbell, Cederman-Haysom and I organised a daylong design workshop in order to further develop our understandings of the work of dentistry from the earlier phases of field study and shift focus to design responses. The design day was particularly useful for us in generating new design ideas, opening up the design space and building a common understanding within the team for the kinds of issues we were dealing with. Much of the activities from this design event have previously been reported from a perspective of how the multiple representations that were created and employed during the process provided different views on the design space and served as a 'springboard' into the design process (Campbell, Cederman-Haysom, Donovan, & Brereton, 2003).

In this section, the activities from the day are presented with a particular focus on how they related to getting a feel for the way gestures relate to the work of the dental surgery. In addition to the members of the design team, we also invited several other researchers from our research group. These guests came from a variety of backgrounds including engineering, neurophysiology, and user-centred design. Counting the design team, a total of eight people participated in the day.

Table 7: Timetable for the dentist design day

Warm-up, Video Mirror	Brainstorming	Morning tea, Ideas Market	Model-making, Demonstration	Lunch	Visualisation, Story-telling	Afternoon tea, Acting	
9:00	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**
Orienting	Ideating		Prototyping		Enacting		

The timetable for the workshop is presented in Table 7. Overall, the timetable for the day was designed to begin with an introduction to the field study material so that participants could orient themselves to the findings that had emerged up until that point. It then shifted to an ideation phase, where participants could begin to respond to the field study findings with design ideas, and a prototyping phase where participants were asked to give tangible form to their ideas. The day finished with a phase where participants developed their ideas into scenarios and enacted these for the rest of the group. Participants were presented with a folder including a booklet detailing the timetable and activities for the day as well as materials that they would use in the various activities. The scale model of the dental surgery was also brought along and presented to provide a reference to the spatial context of the dental surgery. A conscious decision was made to focus on movement and gesture throughout the activities of the day.

4.4.1 Video Mirror Activity

To begin the day, following a brief gestural warm-up activity, we introduced participants to some of the findings from our field studies about the work of the dentists through an activity called the ‘video mirror’. This activity was designed to allow workshop participants to get a direct physical and bodily understanding of the findings. To run this activity, each participant was given different ‘theme card’, which was an abbreviated version of the themes of interaction that had been developed from the observational studies. Theme cards were printed on A5 sized paper and consisted of a title, a brief summary and a written description of the action on an example video clip from the field studies (Figure 24).

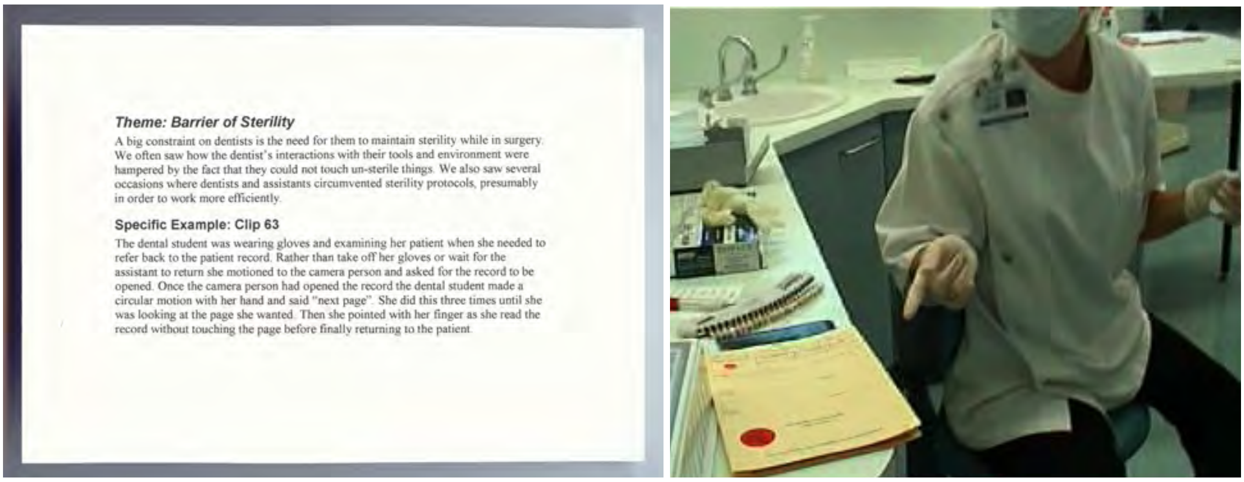


Figure 24: Theme card with reference to example video clips.

Participants were asked to read out their theme cards for the rest of the group, including the written description of the video clip. Following the reading of each theme the example video clip for that theme was played and projected onto a wall within the space of the workshop. The whole group was asked to watch the clip and try to mirror the action that they saw there with their own gestures (Figure 25).

Because it is difficult to follow and mirror the interaction in a short clip upon first viewing, the clips were repeated several times, with the group watching and mirroring each time until everyone felt satisfied that they had been able to follow enough to get a feeling for the clip and the theme. At this point, we took a round to discuss our experiences and observations about the theme in the light of the video clip. If the participants felt it was necessary, the clip could be replayed with participants watching or mirroring the action in the light of their discussion. This process was repeated until all of the themes had been presented.

Figure 25: Mirroring gestures of dentists from short projected video clips.

The video mirror activity seemed to be a worthwhile approach for introducing the themes from earlier research to the participants for the design event. A majority of the participants had participated in previous collaborative analysis activities and therefore already had some familiarity with the themes that were presented. It might be expected from this that there would not be many new insights into the themes, but this was not the case. A big surprise was how *difficult* it was to mirror the gestures in the clips. This seemed due to the fact that whereas we were attempting to perform gestures that we saw projected on a screen, the people who had been video recorded were performing gestures situated within a context of activity. This highlighted aspects of the context that we had not previously paid a lot of attention to in terms of the role they play in structuring the actions and gestures within the dental surgery. Specifically, we became aware of and discussed the following points:

- **Posture:** Whereas the dentists were usually sitting in low stools, and the patients were usually lying down, the workshop participants were standing. Posture has a significant effect on how it feels to perform a gesture.
- **Direction of gaze:** Whereas participants stood looking at the video screen while mimicking the actions they saw there, the people portrayed in the clips directed their

gaze at the person they were talking to, towards the place where they were working, and so on. Gaze and gesture are intimately linked in interaction.

- **Instruments and artefacts:** The dentist often held instruments in his hands while working and also while gesturing to the patient. For the participants, who did not have these artefacts, it was difficult to know how precisely to make their gestures. Instruments and artefacts help shape gestures.
- **Positioning in relation to others:** When the dentist made a gesture towards another person, or passed the instruments to someone else, the location of that other person gave a direction for them to orient to. Gestures are made in relation to other people and locations.

When presented in list form, as above, these observations may not seem so surprising. One can easily agree, for instance, that a person's positioning in relation to others has an influence on how they perform their movements and gestures. However, there is a difference between reading and agreeing with such an observation and getting a bodily experience of the difficulty of mimicking the movements and gestures when one or other of these aspects was lacking. It seems that the fact that the video mirror exercise allowed for a bodily exploration and experience of gesture (and the difficulties associated with that) was key to its effectiveness as a way of highlighting to participants the importance that these aspects play in the dental surgery.

Indeed, most of the themes that were presented already mentioned these aspects in the descriptions of the example clips, but they passed with little comment when first introduced. For instance: the 'different foci of attention' theme deals explicitly with the way people move their attention around in their workspace and the example describes the shifts in the dental student's gaze as she looked from the patient's mouth to the bracket table; the 'shared tools shared workspace' theme describes the way that the dentist and assistant hold and adjust the position of their instruments in when working in the mouth of the patient; and the 'articulation work' example describes how the dental student positioned herself in relation to the assistant and patient.

In developing these themes, we had *seen* these aspects, but we had not *felt* them until we tried to move our own bodies in the same way. A pertinent factor in this is probably that, our engagement with the video data had been more traditional analytic modes of either solitary viewing and logging of video data or collaborative watching and listening to the video while making written notes and then discussing our observations around a table. Of course, when engaged in these modes of analysis participants also engage in gestures as a part of their normal communication, however, we had not put our abilities for gestural mimicry and movement in the foreground. Another important aspect of the activity was that it projected the theme into the physical space in which our design event was being held. Both in the literal sense that the example video clips were projected onto the wall of the room where we would design, but also in the sense that this was done at the start of the day and served as a warm-up exercise for our bodies. We rendered the theme with our bodies, the bodies with which we would subsequently design, build and demonstrate our models.

4.4.2 Ideation, prototyping and scenario acting

Following the video mirror activity, participants were split into groups of three and asked to brainstorm design ideas that might support the work of the dental surgery. Workshop participants were asked to use the theme cards as a starting point from which to brainstorm, either by thinking of the theme as a ‘problem’ that they could try to solve or as something that they should try to address. At the end of the brainstorming, groups were asked to pick their six favourite ideas and copy them onto ‘idea cards’. These idea cards were then presented and traded to the other groups in a circle (Figure 26).

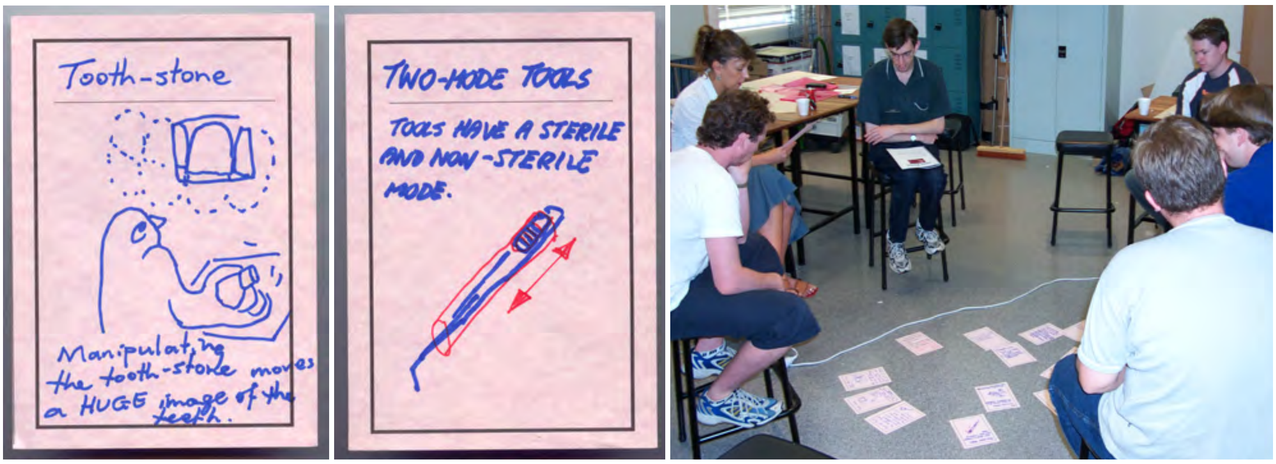


Figure 26: Two of the idea cards, which were traded among workshop participants.

These ideas were then used as the starting point for a session where participants were asked to model their ideas with simple modelling materials such as foam board cardboard, blue foam, polystyrene, marker pens and toothpicks. Participants were told not to worry too much about making a model with a perfect finish, but to instead concentrate on developing the model to a stage where they could use it to explain the idea to another person. Participants were encouraged to use the physical properties of the modelling materials to help them think about how the ideas might be made tangible and to begin modelling immediately rather than spending time analysing and discussing the problem (Figure 27).

Figure 27: Participants modelled ideas using inexpensive modelling materials.

The final phase of the workshop was focussed on getting participants to develop and act out a scenario of use for their design concepts (Burns, Dishman, Verplank, & Lassiter, 1994; Buchenau & Suri, 2000). The purpose of this was to draw together the work that had been built up over the course of the day and communicate it to each other in a coherent way. It was also intended as a test of the ideas that had been modelled to see if they made sense once they were incorporated into a scenario of use.

We were mindful that design scenarios sometimes tend to function merely as vehicles for technological design concepts, rather than as ways of exploring the experiences of people in relation to a design concept. Therefore we began this part of the workshop with a visualisation activity, where participants were asked to recall their experiences from their most recent visit to the dentist. Participants were also reminded of the other information that had been presented during the day, such as the themes, video clips and the scale model of the dental clinic and told that they could draw on these also. Workshop participants formed back into their groups, and worked to develop a scenario of activity in the dental surgery.

When all the groups were finished with developing their scenarios, it was time to act them out. All members of the group were asked to participate in the performance, either by taking the role of one of the people in the dental surgery (dentist, patient or assistant) or by acting as a narrator for the action. A ‘stage’ was prepared at the front of the room with a chair for the patient and a stool for the dentist. Each group also ‘dressed’ the stage with the models that they had made as props for their performance. In order to focus the performances, action was kept to less than 5 minutes and the performances were video recorded, with an improvised ‘clapper board’ used to signal the start of the action.

Three scenarios were presented in all and none of the scenarios incorporated an explicitly ‘gestural’ interface. Rather than describe all these scenarios in detail, I will just briefly mention the first two before giving a fuller description of the third. The first scenario was mainly about the ways that the dentist could be supported in making a patient feel less stressed during an uncomfortable procedure such as a root-canal filling. This surgery featured an augmented reality display that that the patient could wear to watch a calm and relaxing scene and take her mind of the stress of the procedure. In the scenario, an anxious patient was also given a sort of ‘stress-ball’ by the dentist, which she could use to indicate if she was feeling uncomfortable during the procedure. The second scenario dealt with a case where the patient had a tooth ache, which the dentist did not think warranted treatment. In the scenario, the patient convinced the dentist to treat the tooth and it eventuated that there was decay that the dentist hadn’t been able to see. This scenario featured a ‘tangible display’ with which the patient could feel with his fingers what was happening in the mouth.

In the third scenario, a young boy visited the dental surgery for a check up. It dealt with the idea of how the dentist could be supported in educating this boy about dental hygiene and how to make the visit to the dentist more enjoyable for the boy. This surgery had a lot of features that would appeal to children. When the patient sat down in the chair, the dentist’s first question was, “What flavour would you like today?” In this surgery, it was possible to choose instruments that taste like chocolate, vanilla and raspberry. These flavoured instruments were seated in the bracket table in colour-coded holders. The patient said that he would like raspberry (Figure 28).

Figure 28: A young boy gets a sticker showing where to pay attention in brushing.

The bracket table also held a small display on a swivel stand. The dentist pointed to this and showed the patient a picture of what his teeth looked like at the last visit and asked if anything had changed since then. To this the patient replied that he had lost one and that another had been getting a bit sore. The dentist said that he would look at that and then began to clean the teeth. The instruments in this surgery were somehow guided by electromagnetic force and the patient could look on the screen to see live video from the instruments while they were working. The lights on the bracket table would also indicate the progress to the patient.

When the procedure was finished, the assistant printed out a sticker for the patient and said, "Here's your new sticker. Look. You can put that on the mirror in your bathroom back at home." Then he explained that the patient needed to be a bit more careful with his brushing in a particular spot and that he should remember to tell his Mother about it too. The group explained that the sticker was produced for a particular patient's teeth by a special instrument that could add 'virtual marks' to the teeth in the mouth and which could then be printed out as stickers.

4.4.3 Internal design events allowed us to step back from the current situation

The aim for the design day event was to make a first step towards being able to articulate a design response to the findings from our initial field studies. Therefore, we sought to run the day with an open and explorative spirit. A danger with such an attitude is of course that the results become totally unhinged from reality, but this was not the case here. The scenarios that were presented clearly lean more to the fanciful and provocative than the feasible and pragmatic, but they are not unhinged. In fact, later when discussing some of the ideas with a dentist at a feedback session, we discovered to our surprise it is already possible to get cleaning compounds in banana and mint flavours, which isn't so far from the concept of flavoured instruments presented in the scenario above.

More importantly than remaining linked to a technical feasibility is that the scenarios manage to maintain a link to a believable human experience. The experience of being an anxious patient in a dental chair and wanting a respite from a stressful situation is familiar to many. Upon reflection, some participants wondered whether we might have tried to put too many ideas into the scenarios. However, each of the scenarios did managed to have central 'story', which in all cases was based on the experience of the patient, so it seems that groups were able to use the visualisation and storytelling activities to move beyond the design concepts developed and modelled earlier in the day.

Without stepping away from my commitment to a participatory design approach, I believe that it is important for a design team to sometimes hold internal design events away from direct user involvement. Reasons for this include the pragmatic, such as limited availability of time when running activities with busy professionals, as well as the tension between needing to understand and respect the current situation and step back from it and imagine alternative ways of working. Activities such as those described here allow us to explore ideas that are a bit 'further out' from the current situation than we might if we were in a focussed design encounter in the dental surgery. We can also experiment with novel ways of working and making sense of gestures, such as the video mirror activity and learn from these lessons that we can take back to the field when we return. A concrete example of this from the use of the video mirror activity in the design event was that I became very conscious on later visits with dentists to try to use the context and their embodied knowledge of the work as a way of scaffolding discussions about gestures.

4.5 Collaborative design enquiry

A core feature of a participatory design process is the involvement of the people who would be potentially affected by a design as active contributors to the development of the design concept. Collaborative design activities serve a whole range of purposes in a participatory design process. In addition to developing, discussing and evaluating design ideas, collaborative design activities can also be a way to enquire into current practice.

In my presentation of the dentist project, I highlight two facets of the collaborative design process. This section deals with 'collaborative design enquiry', which is geared toward engaging practitioners to understand current practice. The other distinction I make, 'collaborative design evaluation', is discussed later. Of course, these distinctions should not be seen as mutually exclusive. Many collaborative design activities support one to enquire into aspects of current practice even if that is not their main aim. For instance, the way that potential users discuss prototypes of possible *future* designs can tell us about what is important to them about their *current* work. Nevertheless, it is useful to distinguish between whether the emphasis of particular activities of collaborative design work is toward understanding current practice or envisioning possible futures, as a way of understanding the way that particular events functioned within the overall design process.

4.5.1 Meaning in Movement Activity

Following from the observational studies, initial designerly, analysis and internal design event, my colleagues and started to define our individual research interests within the project. My interest remained with gesture and designing gesture interfaces, Campbell became interested in issues around context aware computing, and Cederman-Haysom became interested in multimodal interaction and role of engineers in Participatory Design.

We had each developed some initial design concepts around these interests and taken these concepts back to dentists to get feedback and input on the design ideas. Though the response from dentists had been favourable and they had given some suggestions for additional ideas to explore, we felt that we needed to go a bit further in our engagements with them than a quick informal sit-down feedback session. Therefore, we decided to arrange and run a more focussed design activity aimed at exploring particular issues for our respective research areas.

Figure 29: The dental hospital clinic.

As a site for this engagement, we decided to contact students from the dental hospital (DH) where we had conducted previous observational studies. With this group of participants, we felt that there would be more flexibility in finding a longer period of time to run the activity than with dentists working in private practice. The dental school functions as a working surgery where students carry out procedures on real patients. The clinic was fully equipped with chairs, instruments, and so on (Figure 29). The main clinics are open-plan rooms containing multiple individual work areas, but on the occasions of our visits, we were also able to use a smaller single-chair room off the end of a larger clinic to run the activities. In addition to providing a working dental clinic, the dental school was attractive because there was the possibility for rehearsing our design events in the space of the surgery when it was not in use by students and patients.

For this engagement, we developed three separate activities aimed at enquiring into questions related to our individual research topics. These activities were conducted sequentially with the same participants progressing through each. Though we each had our own activities, we also assisted on the other games, for instance by recording video or taking the role of a patient. Campbell ran an 'agency game' where he asked participants to think about what aspects of their workplace could respond to a context-aware system and create a scenario and poster around this (Campbell & Brereton, 2004). Cederman-Haysom ran a Wizard of Oz style activity exploring the multimodal interactions that the dentists might use to navigate an electronic tooth chart (Cederman-Haysom & Brereton, 2004). I ran an activity aimed at exploring the question of how qualities of movement and gesture relate to professional values of dentistry (Donovan & Brereton, 2004).

The rationale for my game was that I wanted to explore notions of professional dental practice in terms of gestures, actions and movements. Because it was still rather early in the design process, I was not focussing on how movements would relate to specific interface actions, but rather just trying to find inspiration in the actions that arose and deepen my understanding. I acted as the facilitator for the activity while one of my colleagues videoed it. The activity itself was loosely based on a design exercise in which industrial design students were asked to create a pair of three-dimensional forms that were simultaneously expressive of three qualities (Djajadiningrat, Overbeeke, & Wensveen, 2002). Two of the qualities were to be common to both the forms and a third was to be opposite between them. In the 'Meaning in Movement' activity, this format was adapted so that participants worked to create a sequence of movements, rather than a three dimensional form, and they worked with words related to the work of dentistry which they proposed themselves.

Each participant was first asked them to write down ten words that describe professional dentistry on slips of paper. I said not to worry about relating the words to movements at this stage, just that they should be somehow important for dentistry. After about five minutes, the participants had finished writing down the words. They laid them out on a table and spent a little time discussing them and arranging them into three groups. One group consisted of words about how the patient should feel, another had words that described how the dentist should act, and the last one had words about the atmosphere of the surgery.

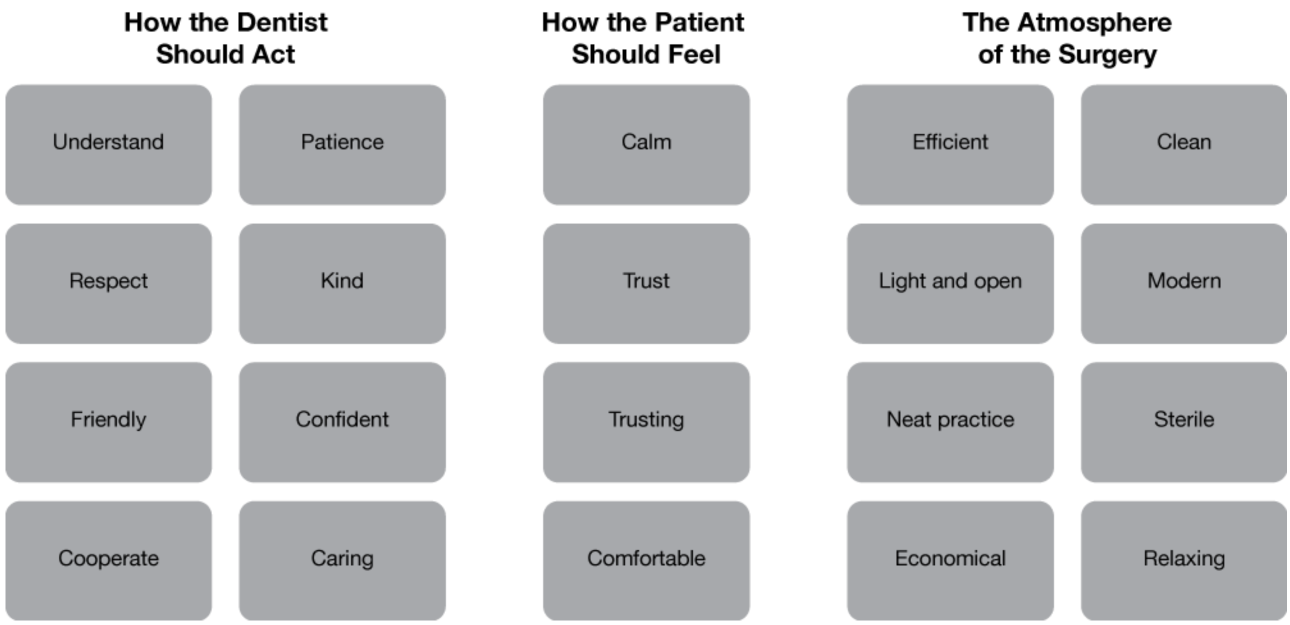
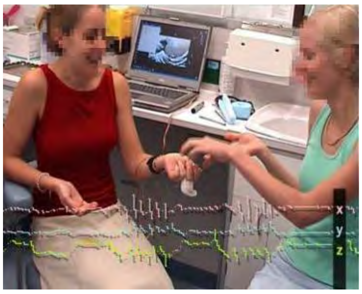


Figure 30: Groupings of words chosen by the participants.

Next, I asked the participants to choose three of the words from which they would make a sequence of movements. The participants decided to work with 'caring', 'efficient', and 'clean.' Initially, the participants seemed to find it difficult to know how to begin making movements for the words. For a few minutes, we just discussed the words and what they meant but we did not take the leap into expressing them with actions. My role as facilitator proved important at this part of the activity. In rehearsals with colleagues, I had discovered that acting out scenarios, using the space, and tools were good ways to begin expressing movements, so I suggested that the participants try this with one of their words. I had also discovered that having three words to work with was helpful because when participants got stuck on one combination, I could suggest that they continue on with a different one. This helped to keep the momentum in the activity.

Once the participants began drawing on their own experiences, the activity got moving again. The participants first acted out a scenario for the word 'caring' where one took the role of a patient and the other played the part of a dentist who was comforting them and trying to make them feel reassured. For the word 'efficient', they acted out the passing of instruments between the dentist and the assistant. For the word 'clean', they drew on the movements they would make when cleaning down the surfaces of the surgery. Three stills from the video I recorded of the movement sequence along with a description of the movements made are shown in Table 8. The still images also have the data from the prototype gesture sensor overlaid along the bottom of the image in graph form.

Table 8: Movement sequence for the words 'caring', 'efficient' and 'clean'.

		
Caring: One participant played the part of a patient and the other played the part of a dentist who was trying to comfort them. The dentist made slow downward motions over the arm of the patient.	**Efficient:** The participants mimed passing instruments back and forth between each other and performing actions with them. The jagged parts in the acceleration data are where the participant acted out using the instrument.	**Clean:** The participants acted out the process of wiping down the equipment in the surgery at the end of the consultation. They made steady side-to-side movements with open hands, imagining the surface of the chair.

Once the participants had developed each of these individual scenarios, we began a process of asking how the movements related to each other. First, I asked the participants to make gestures that were both caring and efficient. This seemed to take the exploration of the words to a deeper level. Suddenly, the question was raised as to whether one could simultaneously be caring and efficient. After a time, the participants would become stuck on one pair of words. It seemed that in focusing on two of the words, the participants would forget about the third. When this happened, I would remind them of the third word and try to play with that against one of the other words. This served to open up the dialog of gestures once again and move it in a new direction.

4.5.2 Outcomes of enquiring into gestures with participants

One of the aspects of the activity that I found interesting is that it takes words as its starting point and ends with gestures. This contrasts with other methods I have used for analysing gestures where I have tended to move in the other direction, from gestures to words. Using gestures to express and question words seemed to be a powerful tool. The process of expressing an abstract concept as a movement helped me see complexities and explore relationships that I might not otherwise have considered. An example of this is the notion of clean, which I had been thinking of in terms of as a state (i.e. that the surgery *is* clean) or in terms of what the dentist can or cannot touch, but the participants linked the notion of clean to the *movement* of cleaning. Similarly, the notion of 'caring', which might be seen as an internal mental attitude, was instead related to a particular bodily posture and *gesture* between the dentist and the patient. In seeing how the participants managed to work through the difficult task that I set them, I was again struck by the importance of the context for supporting people's ability to engage in gestural activity. They drew on their dentistry skills, instruments and the space of the dental surgery. This supports Ingold's view that skilled practice is not a quality of the individual that can be studied in isolation from the environment (Ingold 2001).

This design activity gave an initial insight into how dentists conceive of and reproduce the qualities of their movements in dental practice. The activity also appeared to help the dental students reflect upon the qualities of their movements. Both dentist participants and designers need vehicles through which they can draw out, discuss and reflect upon movement qualities before designing specific gestural interactions.

4.6 Engaging Technology as a Design Material

Existing gesture interface research has had a preoccupation with technical issues of sensing and responding to gesture interfaces or with demonstrating interactive possibilities through finished systems. This has been at the expense of understanding the detail of the role that gestural interactions play in actual contexts of use or understanding how the process of design might be organised to develop gesture interfaces. In my presentation of the dentist project so far, I have focussed on to these neglected issues in gesture interface research. However, issues surrounding the technology of gesture interfaces were still important for the project. In fact, technical considerations played an important role from the outset of the dentist project.

One of the starting points for the research was an earlier project carried out at The University of Queensland in which researchers designed and built a working prototype of a gesture interaction device called the GestureRing (Wyeth, Brereton, & S. Alexander, 2001). This wearable input device consisted of a ring and a wrist-mounted micro-controller, shown in Figure 31. The ring had two dual-axis accelerometers attached so that it was capable of detecting acceleration in three axes. The wrist-mounted micro-controller was programmed to analyse the patterns of acceleration from the ring and distinguish from a limited set of pre-defined patterns. The results of this analysis could then be wirelessly transmitted to a client application to be interpreted as a command.

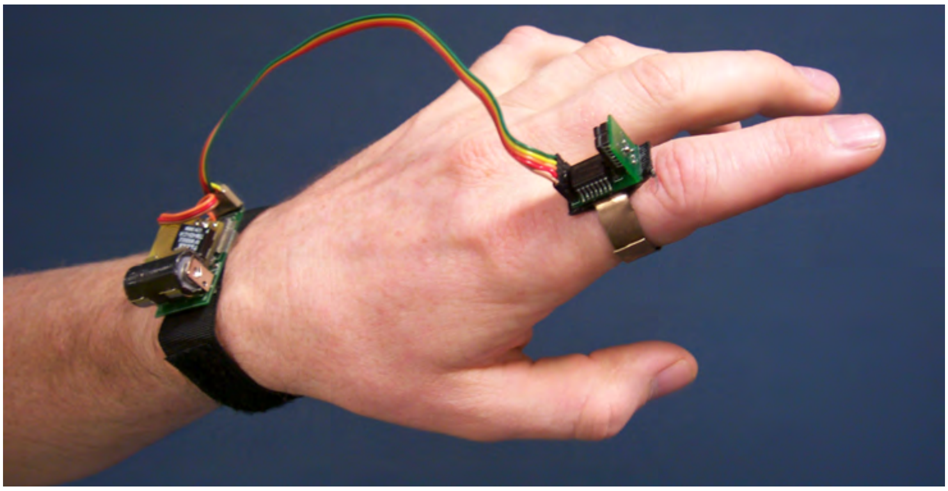


Figure 31: The GestureRing provided a technical starting point for my research.

From a technology perspective, this device was interesting as a starting point for my research in several respects. First, it was self-contained, in that it did not rely on external fields or cameras in order to sense movements, or on external processing to recognise patterns of movement. Second, (and partly as a consequence of its limited on-board processing power and sensing capabilities) it was intended to only recognise a limited pre-defined set of six to nine movement patterns. This raised an interesting design question as to what these pre-defined movement patterns should be. Third, it was not an entire system, but a general-purpose gestural input appliance capable of sending commands to client programs or devices. This raised another design question as to the nature of the commands sent and the feedback given by the client program. The device had been developed to working prototype stage, and the feasibility of on-board recognition and wireless transmission of results had been demonstrated.

My attitude towards technology throughout the project was to pursue strategies for opening up the ‘black box’ of technology and make it into something that design process participants could engage with and get a feel for in relation to their practice and the evolving design concept. In working with the accelerometer sensors that the gesture ring used, I realised that there are some subtleties in their functioning that make them difficult to map to a personal experience of moving.

Firstly, these sensors measure instantaneous acceleration, not movement as such. Acceleration results from changes in velocity over time. This means that the sensors can detect if the speed at which they are moving is changing, but not if they are moving at a constant velocity. They also detect a constant 1g of acceleration due to gravity regardless of whether they are moving or stationary. This is quite different to our bodily experience of movement. We can feel that our arm is moving from one position to another even if it is moving at a constant speed and we can experience it as stationary even when constantly accelerated by gravity.

Secondly, the sensors measure the accelerations acting at a single point (e.g. on the finger). In contrast, if I extend my arm and wave my hand back and forth, I can feel the forces of that movement acting along the whole length of the limb up into my shoulder. My experience of my arm moving is integrated from all of my senses. I can see the movement of my arm, feel the resistance of the air as it rushes over me, and hear the rustle of my shirt as it creases. I am also aware of the positions and postures of my body and limbs when I make a gesture. There is a bodily difference between clapping my hands at my chest and clapping them above my head. I can feel the difference between a movement made with tightly clenched fists and one made with open, relaxed hands. It may or may not be possible to distinguish these from sensor values alone.

This may sound rather philosophical, but it has a direct consequence for designing gestural interactions that rely on these sensors. In designing gestural interactions, it is important to find gestures that both are good fit for the use-context and also reliably detectable by the technology. From a participatory design approach, an obvious way to do this would be to run design activities where participants could explore what gestures would be most appropriate for them. As I showed in the description of the 'Meaning in Movement' activity in the previous section, participants can be supported to enter into design discussions about qualities and forms of gestures in relation to their work. However, it is less clear how they could be supported in an iterative process of gesture *refinement* when working with sensor data that does not relate to their own experience of movement.

Questions of materiality and the role that this might play in design have a particular resonance for the field of interaction design. Whereas established design disciplines such as architecture, product design and graphic design have a clear relation to their materials of design, for interaction design this relation is less clear, dealing as it does with the shaping of what have been described as *materials without qualities* (Löwgren & Stolterman, 2004). In this section, I give two examples of specific ways in which I worked to engage the gesture interface technology as a design material.

4.6.1 Giving form to the sensing technology

Physical sensors such as the accelerometers have a basic physical materiality that can be explored for design. The sensors I was using were relatively small and unobtrusive, but not invisible. They have a dimension and a weight and would need to be held or worn by the user. This opens up for an exploration of how sensors should be packaged into a form that guides the user in perceiving how to hold and gesture with them. Put more directly, it suggests the idea that form can afford gesture. The idea that form of an object can afford gesture is relatively easy to try out. If one picks up two dissimilar objects (e.g. a glass and a pen) and tries performing gestures while holding then in the hand, one will find that certain gestures are constrained and others are supported, due to the posture that the hand assumes, how the object is held, its shape, weight and so on.

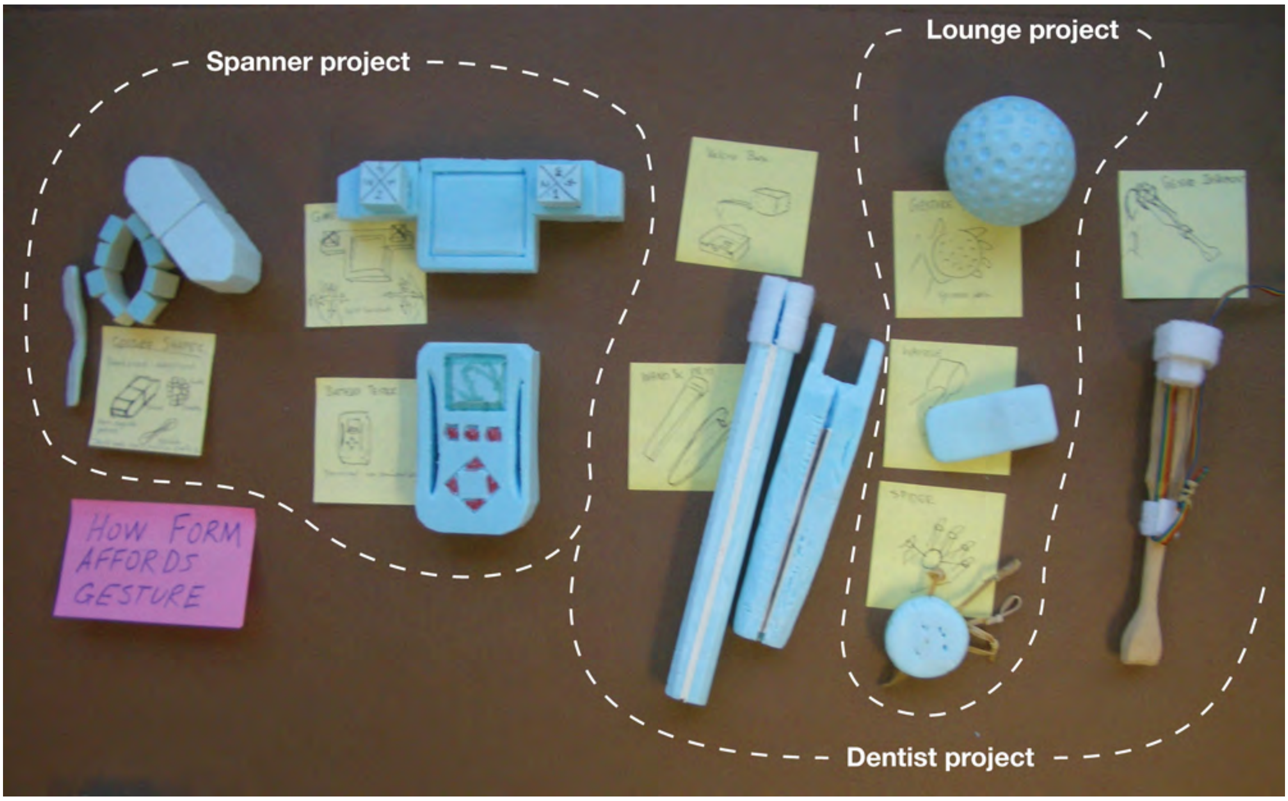


Figure 32: Explorations of device forms across the three projects.

The idea that the form of a gesture device can be designed with respect to the kinds of gestures that might be performed with it was one that I explored across all three of the projects that I engaged in during my PhD studies. I found that an easy way to do this is simply by carving the rough shape of a device out of modelling foam. It could then be picked up and played around with to see how one might gesture with it. At one point later in the dentist project, I made a poster to compare some of these different form explorations across the projects. I made the poster by arranging the mock-ups along with brief post-it note annotations in chronological order on a large sheet of paper. A photograph of this poster with dotted lines indicating which of the projects the different mock-ups came from is shown in Figure 32.

On the left side is a grouping of mock-ups made during the spanner project. The two right most of these are fairly conventional PDA form devices, but the ones on the left are more abstract forms explicitly intended to explore how form affords gesture. With these, I explicitly created a diversity of shapes. There is a thin stick that might be held between the thumb and index finger, or tucked behind the fingers. There is also a 'bracelet' of linked segments that can be curved and flexed between the fingers, and a larger 'block' that could be separated into two pieces and joined together again. This could be held by a full grip of the hand or between the thumb and fingers with the hand in a c-shape.

On the right-hand side, there is a group of mock-ups for gesture devices developed at an early stage of the lounge project. These were developed together with an industrial design student (Alf Fjelland). He modelled the bottom two mock-ups and I modelled the top one. The top of these mock-ups is a ball with divots in its surface. It is sized slightly smaller than a tennis ball, so that the hand can comfortably hold it, but not close entirely over it. It can also be gripped by the fingers and held out from the palm. Below this is a smaller rectangular shape, which is tapered at one end. This can be held between the thumb and the curled index finger with the other fingers curled under. At the bottom is the 'spider'. This has elastic bands, which can loop over the fingers of the hand and allows the user wear the device while opening the fingers on their hand so that they could make a grabbing gesture with it.

In the middle and on the far right are three mock-ups from the dentist project. Though these are all roughly the same shape, they do not invite the same kind of movements. The two on the left look rather like some kind of wand (especially the left most) held by gripping around the base and waving the other end aro0und. The form of the one on the right, in contrast looks more like an instrument, with the top-half providing a handle that could be held like a pen. The grip for this one can be changed so that the 'pointy' end of the instrument is held into the palm and the end of the handle points outwards.

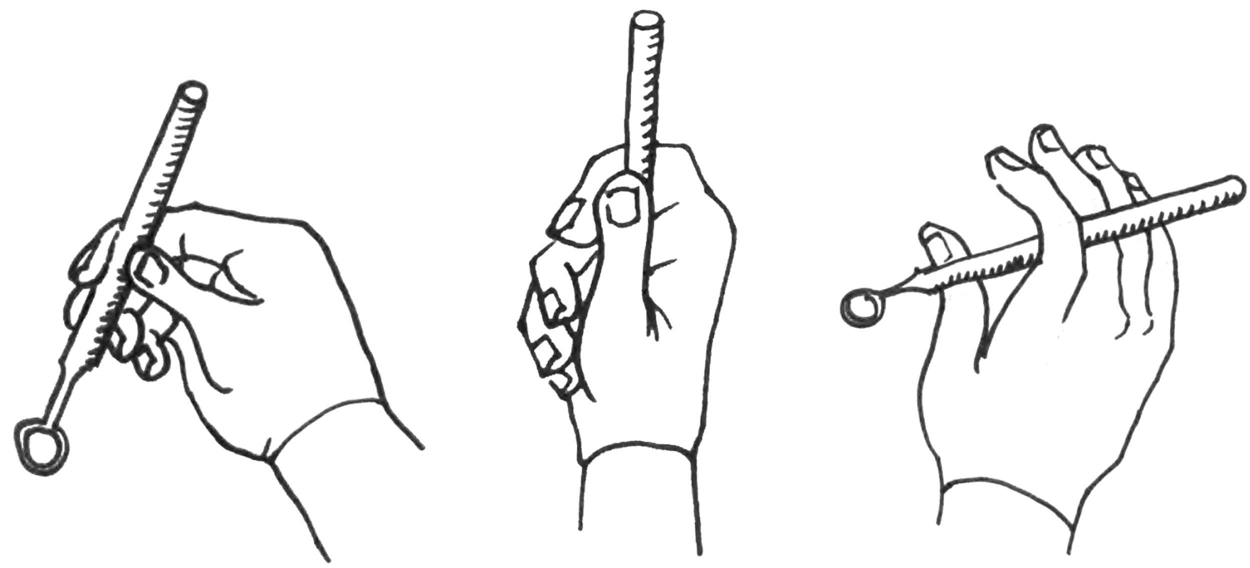


Figure 33: Hand postures with a dental instrument

This tracks the shift in my thinking from a general 'gesture instrument' to paying closer attention to the way that dentists hold their instruments in the hand when they are working. I noticed that there are a variety of grips that dentists employ when they hold an instrument. They may hold the instrument between the thumb and index finger like a pen, either pointed out from the hand or curled back in toward the palm. From this curled-in palm grip, it is relatively easy to switch to a 'wand' grip where the head of the instrument is held in the palm of the hand with the handle sticking out over the index finger with the thumb pressing down on the top. I also noticed that dentists would tuck their instruments behind the fingers when they were not using them and needed their hands to do something else, such some materials from the bracket table. I wondered whether this might make it possible to have a gesture instrument that 'switched modes' by switching grip.

4.6.2 Packaging gesture sensors and creating simple visualisations

Admittedly, carving a shape out of a piece of blue foam can only take one so far in terms of engaging technology as a design material. To take this line of enquiry further and start to investigate how the sensors would respond to different movements and device configurations, I separated the sensing components into a small package separate from the micro-controller. I covered this package in Velcro so that it could be attached to device mock-ups, or strapped to parts of the body.

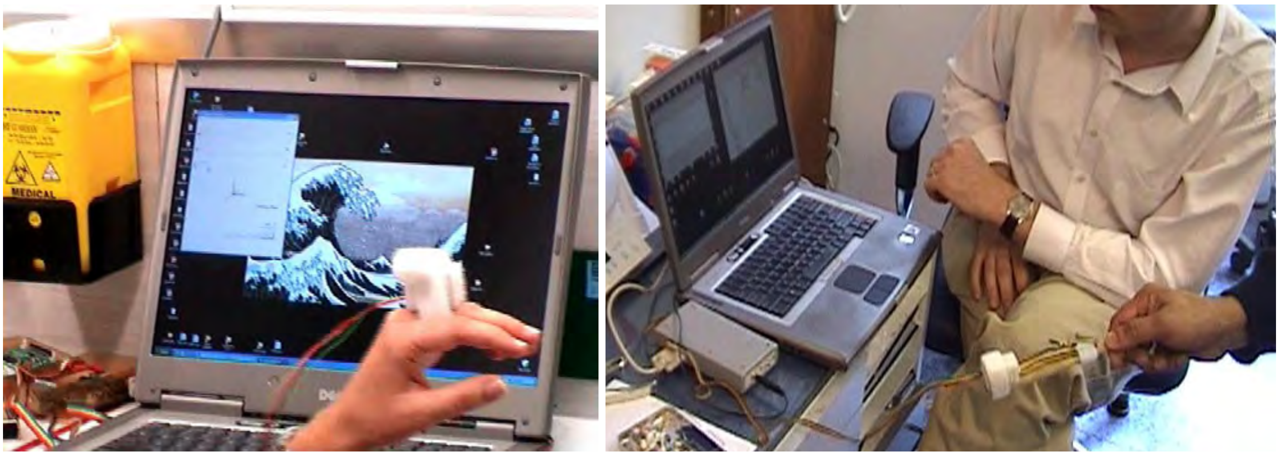


Figure 34: Attaching the sensor box to the hand (left) and device mock-up (right).

This was used in the meaning in movement activity described in the previous section to record the movements of the gesture performance that the participants made. In this case, the sensor box was attached to the finger of one of the participants in the same configuration as the original gesture ring (Figure 34, left). I also used this technique in my first visit to the three New Zealand dentist surgeries where I took a version of a 'gesture instrument' device prototype (shown on the right side of Figure 32) so that we could discuss where the sensors should be placed on the device and explore the responses that the sensors gave (Figure 34, right). Three surgeries were visited on this occasion (D3, D4, D5). I was accompanied by Cederman-Haysom and our contact at the dental software company, who had arranged the contacts with the dentists. Cederman-Haysom ran an evaluation of a speech interface for periodontal charting that he had developed and I ran an informal discussion of the basic concept of using gestures to interact with the electronic patient record and the functioning of the sensors.

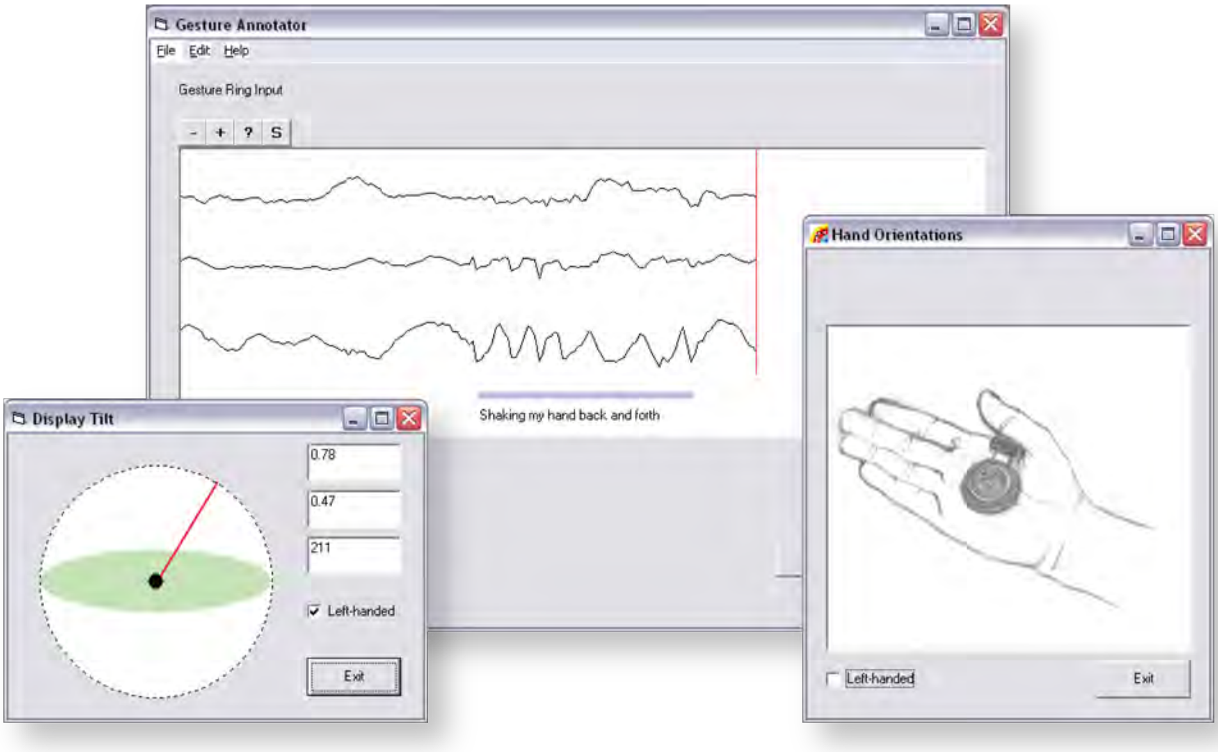


Figure 35: Three simple visualisations developed for displaying sensor data.

Another important part of this set-up was the use of simple on-screen visualisations of the data coming from the sensors. These programs ran on a laptop computer, which read data coming from the device over a serial port (either wired or Bluetooth). Three of these visualisations are shown in Figure 35. The leftmost visualisation, called 'DisplayTilt' maps the sensor data to the tilt of the red line and inclination of the green ellipse, so if the device is tilted to the left or right, the red line tilts the same way and if the device is tilted forward or back the green ellipse lengthens or shortens to look like a plane. The middle visualisation, called the 'Gesture Annotator' is one in a series developed that show the three axes of sensor data as line graphs with time running from left to right. In this version, it was also possible to highlight a segment of the data and make an annotation such as in the picture where it says 'Shaking my hand back and forth'. These annotations and the associated data could also be saved to file. The right-most visualisation, called 'Hand Orientations', was originally developed in the Interactive Lounge project. It interprets the sensor data as hand orientations based on an assumption about how the device is worn and displays a picture of a hand (wearing the device from the interactive lounge project) in the same orientation. In addition to these visualisations, I also created a simple sonification, by mapping the data from the sensor's x, y and z axes to a sound output. The axes were mapped to the pitch and sample duration of two overlaid sine-waves and played on a small speaker attached to the micro-controller.

The importance of these visualisations is not just that they allowed participants to see the data from the gesture device, but that they also encourage movement and exploration with the data. In respect to this, I observed that the different visualisations seem to elicit different kinds of movements from people. With the DisplayTilt visualisation, people would make slow tilting movements back and forth to explore the correspondence between the angle of their hand and the display of the line and ellipse. With the ‘Hand Orientations’ visualisation by contrast, people would flick quickly from one orientation to another, holding their hand steady at each one. With the ‘Gesture Annotator’, people tended to wave and move their hands more, trying to get the lines to react to their movements. In this respect, it was useful to have a number of different visualisations to try out, even if I was only testing a single device form.

In the case of the visits to the New Zealand dentists, several possible design directions were suggested from the use of these technology visualisations. One was to tap the gesture instrument on a tooth or on another instrument, because this tended to produce a distinct signal on the accelerometer data. A second was to explore the use of tilt, because the DisplayTilt visualisation suggested that reasonably fine control was possible with this. In discussing what kinds of pre-defined gestures might be appropriate, the Gesture Annotator was somewhat useful for getting an impression of the way the signals from various gestures varied across time. However this part of the discussion tended to stay at the level of what would make sense in the context of the work and the information demands of the interface. More detailed information on these aspects was gained in the final collaborative evaluation, which is described below.

4.6.3 Opening the black box of technology

This line of work of engaging with technology as a design material was essential for developing my understanding of how the technology of the GestureRing device could be made to fit with the work of dentistry. The explorations of the device forms helped me to explore what shape a device should take. These explorations took place across the three projects that I engaged in during my PhD. In the dentist project, starting with the idea of a ‘gesture wand’, I moved toward the idea of presenting the gesture device in the form of a 'gestural instrument' that the dentist could use alongside his or her other instruments during a dental examination.

By packaging the sensing technology of the gesture device into an easily attachable and adjustable form in the Velcro box, I was able to explore how the sensors would respond to their placement within a gesture instrument. I discovered through this that the ideal placement for the sensors was not at the tip of the instrument, as I had originally assumed, but at the base of the handle because this gave a larger movement when held by dentists in the way that they would hold it in an examination.

Developing simple visualisations of the data from the sensors allowed for an experience of subtleties in the qualities of the sensor behaviour that hadn't been apparent before that point. A particularly important outcome in this respect was to realise that the sensors can quite reliably detect fine tilting movements. With the 'DisplayTilt' visualisation, it was possible to bring dentists into a discussion of this quality of the sensors too and I found that such movements would fit with the other gestures that they perform when working around the mouth.

The attitude I have brought to engaging with technology in the dentist project is one that acknowledges the importance of technology for the design and implementation of gesture interfaces. At the same time, I have tried to look beyond technology as simply a means to an end that can be straightforwardly applied to solve particular gesture interface problems. Instead, I have sought to mobilise it as a *design material*: as something that needs to be played around with in an actual context of use to get a feel for its subtle quirks and modes of operation and as a resource for engaging others in the process of development.

4.7 Collaborative Design Evaluation

Over the course of the design project, the original design concept of the wearable GestureRing developed into the idea of having a graspable gesture instrument. I had introduced this broad concept to a number of dentists as part of the technology explorations described in the previous section and it was received favourably. I decided to develop the concept a little further and be more specific about the kinds of movements and gestures that would be involved and exactly how it would relate to the control of the electronic patient record. The revised design concept was called Tilt-Roll-Wave (Figure 36).

In this concept, the gesture device is not a stand-alone instrument, but an augmented mirror that the dentist could use along with all his or her other instruments to access and make simple updates on the electronic patient record while working around the mouth in an examination.

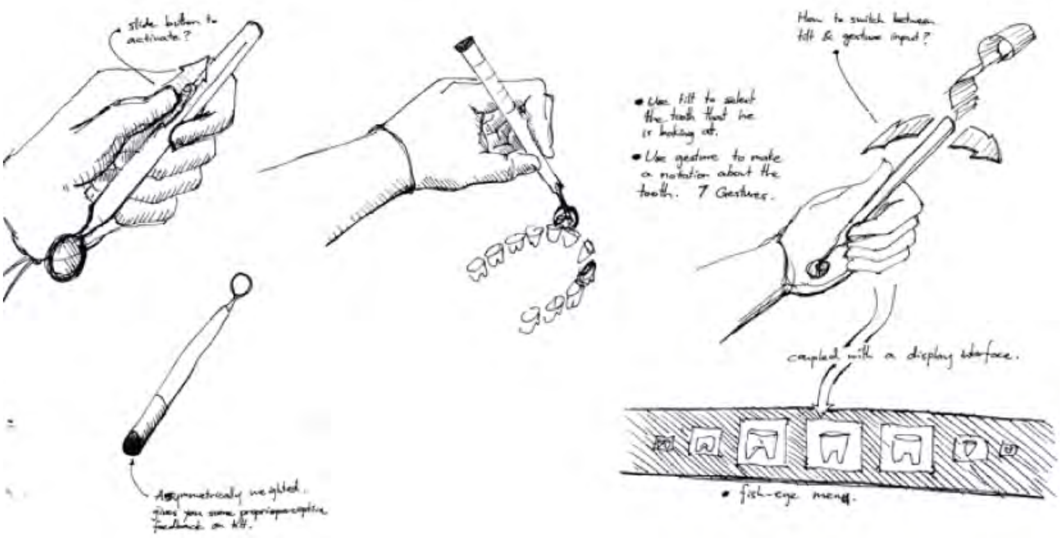


Figure 36: Tilt-Roll-Wave concept.

The purpose of this device was to allow the dentist to make simple selections and annotations in an electronic screen-based patient record. The patient record has a chart that consists of a diagram showing all the teeth in the mouth where all the information about the different teeth can be recorded. Figure 37 shows the electronic patient record for one of the dentists (D4). Across the top is the tooth chart. This shows a square for each of the teeth in the mouth. The chart can be updated through mouse-clicks on the graphics of the teeth, or key-presses from the keyboard to move the selection cursor. In the current interface, the dentist is able to select particular surfaces of the teeth and mark these as having a particular kind of filling. The teeth are represented diagrammatically with a square divided into five areas. Each of these areas represents one of the surfaces of the tooth, as shown in the diagram on the right. Occlusial is the grinding or cutting surface of the tooth, buccal is the side of the tooth closest to the cheek, lingual is the side closest to the tongue, mesial is the side closest to the front of the mouth and distal is the side furthest from the front of the mouth. Teeth can also be marked as missing, and more detailed notes and treatment codes can be selected for each tooth. This information is contained on the bottom part of the screen, which is divided into two parts. On the left side is a treatment plan, which is a textual record of the treatment for a particular patient. On the right side is a list of all the treatment codes. These number in the hundreds and can be selected through mouse clicks as annotations onto the tooth chart or the treatment plan.

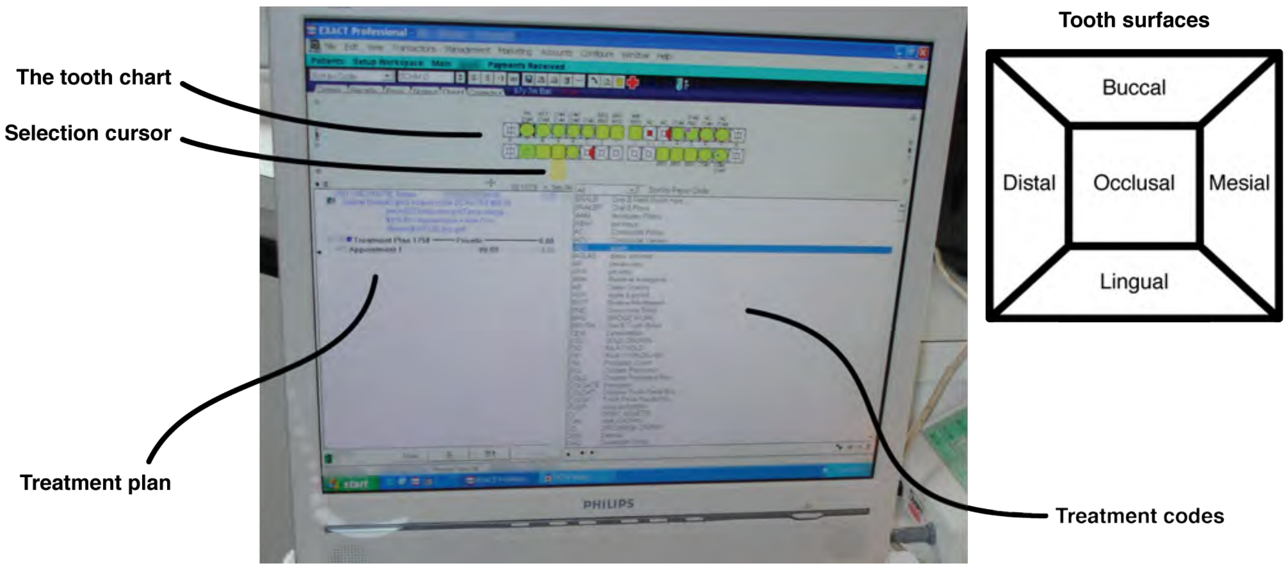


Figure 37: Existing patient record interface.

It was not envisaged that the concept would be able to enter all of the information, as the number of treatment codes runs in to the hundreds and notes can be entered in free text. Rather it was hoped that the device would be able to provide a limited set of useful functions. Using the Tilt-Roll-Wave device, the dentist would be able to:

1. **Tilt** the instrument to move the selection cursor from side to side, thereby selecting a different tooth without losing their place in the mouth.
2. **Roll** the mirror to select a surface on the tooth, whether the inside outside, front, back, or top of the tooth.
3. **Wave** the mirror to make an annotation on the selected tooth in the patient record. As with the original GestureRing prototype, only a limited set of gestures would be defined.

The origin of this concept did not arise from any single insight from the design studies but rather from an accumulation of small observations that together seemed to point to a potentially interesting approach. Having noticed from my field studies that dentists were able to hold their instruments in a number of different ways and fluidly switch between these grips, I wondered if it might be possible to leverage this in a gesture interface design and whether by designing a device that was hold-able rather than wearable, I would open up for a little more variety in the kinds of interactions that would be possible with the device. I had also noticed that dentists have good skill for fine tilting movements of their instruments, and had discovered from my technical explorations that the sensors used in the prototype device were sensitive to this. Therefore, it seemed like an interesting possibility to try to create an input device that would build on the dentist's ability to make these kinds of movements.

The system would require an explicit activation by the dentist to use. Although this would require more effort on the part of the dentist, it would be fitting with other powered instruments that dentists already use that require activation, such as the polishing instruments. Also, it would make the system simpler to implement and give the dentist control over when it should be used. Finally, the concept was not intended as a wholesale replacement for the keyboard and mouse, but a partial one, to be used for situations where the dentist only needs to make some simple annotations and can do that alone. For a more complicated charting, the computer keyboard and possibly the help of the assistant would still be necessary.

To evaluate this design, I organised visits to three dentists in New Zealand (D3, D4, D5) who I had visited earlier, during the technology explorations. Accompanying me on the evaluations were my thesis advisor and the CEO of the dental software company I had previously made contact with, and who once again made the arrangements with the dentists for the visits. We visited these dental clinics over the course of two days, two clinics on the first day and one clinic on the second day. The surgeries were quite different from each other, both in terms of the physical set-up such as spatial arrangement, size and so on, and also in terms of the personalities and approach to dentistry of each of the dentists that we interviewed.

The first clinic we visited was quite large and new. Dentist D3 was the owner and manager of the clinic and he had several other dentists working for him. He seemed to enjoy managing the clinic and because of this he didn't work full time as a dentist any more. This was advantageous for us, because he had quite a lot of time to offer us to discuss our design ideas in one of the surgeries. In total, we stayed for approximately 2 hours. The second surgery was located in an inner-city high-rise building. In this clinic, there was one dentist (D4) who was also the owner. This surgery was smaller. The dentist liked to have his computer and everything within reach and he controlled it himself rather than having an assistant operate it. He liked working alone, although in the past he had had two or three dentists sharing the clinic with him. We visited him during business hours and he was between patients, so we could not spend as long with him as D3, but we were still able to discuss with him for 1 hour. The third surgery belonged to an endodontist (D5). Endodonty is a specialised area of dentistry that deals with the roots of teeth. The kind of work that this dentist did often involved fixing failed root canal procedures that other dentists had attempted. The work involves painstaking and precise work through a microscope using tiny files to clean the root canals and remove any obstructions from previous failed procedures so that they can be filled. He had only recently moved into the surgery. We visited at the end of the day after he had finished with his patients and we were able to 1½ hours.

Whereas previously I had visited these dentists more with the purpose to introduce the general concept of a gesture interface for the dental surgery and brainstorm possible design directions for a gesture-enabled instrument, on this occasion the purpose was targeted to evaluating the Tilt-Roll-Wave concept that I had developed in the intervening time. The objective of the evaluations was to assess with the dentists whether this was a feasible method for changing the selection of the tooth chart and then work on discussing and brainstorming possibilities for what gestures to use to update the patient record. The evaluations were informal and intended to elicit a qualitative assessment by the dentists of the general feasibility of the design concept rather than a formal structured evaluation with pre-specified usability metrics. However, there were some specific questions and points of discussion that I wanted to cover with the dentists, such as:

- What is their preferred posture for holding the device?
- What is their preferred plane of tilt?
- Is the device sensitive enough and is the dentist's control sufficient to the task of moving the cursor?
- Are the dentists able to relate the visual feedback from the computer screen to their manipulations of the device?

- Is it feasible to use gestures for annotating a particular tooth?
- What are some possible candidate gestures?
- How might the device fit with or impact the existing interactions between the dentist, patient and assistant?

4.7.1 Time plan and principles for engagement

The amount of time each dentist had available to discuss the concept with me was different in each case, and was difficult to predict ahead of time. From my previous visits with these same three dentists, I knew that in general one of the dentists was likely to be busy and pressed for time, but it was difficult to predict this with any certainty. Therefore, it didn't make sense to construct a detailed agenda for how to structure the time I had with them. Instead, I prepared a flexible plan for how to use the time and articulated the overall principles by which I would guide my approach to engaging with the dentists to help prioritise which parts of the activity were the most critical and which could be scaled back if necessary. In line with my participatory design approach, my aim was that the dentists should be engaged to participate and contribute their expertise in assessing and suggesting improvements for the device concept. I also held the following three principles to be particularly important on this occasion:

- That the evaluation should if at all possible be carried out in the context of the dental surgery with the dentist sitting in their usual work posture with typical instruments and materials at hand. I knew from previous experience that it is much easier for dentists to relate to their experience of moving and gesturing if they are in their surgery surrounded by the instruments and materials of dentistry.
- To again take simple data visualisations for the device, so that the dentists could get a feel for the sensitivity of it and in particular, what kinds of movements it was responsive to.
- To make the prototype instrument adjustable in terms of the functioning of the software and the placement of the sensors. I knew from previous experience that it is difficult to predict how the dentists would hold the device and that if the device was set up for a different hand posture than the dentist adopted it could derail the evaluation.

My plan for how to use my time with the dentists was to proceed in three parts. First, I would present them the Tilt-Roll-Wave design concept, demonstrate a working prototype of this and ask them for their reactions to the concept and ask them to test it out by interacting with the prototype. The purpose of this first part was to give them a basic understanding of the concept and check for any obvious misunderstandings on my part that could be addressed before we went on.

Once they were familiar with the concept and had time to discuss their initial reactions, I would move on to the second part of the activity, which was to run through a scenario of charting a patient's teeth with the instrumented prototype. In this scenario, I took the role of the patient and the dentist used the instrumented prototype as if it were a real instrument for the examination of my teeth that could also update the electronic patient record. Rather than using their own electronic patient record system, they would use a modified version that we brought with us and which was running on a laptop.

This was the central part of the evaluation activity. The purpose was to move beyond an in-principle agreement that such an instrument would be useful for dentists to attempt to actually use it to control the selection of the cursor on screen while conforming to the necessary posture and positioning imposed by the positioning of the patient in the dental chair. I wanted to see if it was practical, even with such a rough prototype, to use the tilt of the instrument as an input modality for controlling the position of the cursor on the electronic patient record. The terms in which this practicality would be judged included aspects such as whether there is sufficient freedom of movement for the dentist to tilt the instrument to all the required angles, whether the dentist could coordinate the movement of the device with the position of the tooth on the screen, and whether such movements would interfere with the dentist-patient interactions. The other purpose of this part of the evaluation was to fine-tune the sensitivity of the device and to inquire into which mode of operation the dentists preferred (details of the parameters that could be adjusted and the different modes of operation are given below).

For the final part of the examination, I would ask the dentist to propose candidate gestures for use as possible annotations on the teeth in the electronic patient record. This is the 'wave' part of the concept, where dentists would be able to annotate a tooth with commonly used pieces of information. Once the dentist had arrived at a conclusion for what some of these gestures would be, I would ask them to record a set of examples of each such as would be suitable for training a gesture recognition engine. Whether we would be able to carry out this last part of the activity would be dependent on how much time each dentist had to spare. If a dentist was pressed for time, we could drop this part from the evaluation and focus on the second part.

4.7.2 Equipment Set-up

Two prototypes were taken to the evaluation, one a non-functional metal mock-up and the other a functional wooden prototype (Figure 38). The first was a turned aluminium mock-up that had been made by the CEO of the dental software company. This was a non-functional prototype, but it had a more finished feel and had a mirror head attached, so it was easier to communicate the general concept to the dentists and for them to imagine the instrument being integrated into an existing mirror.

Figure 38: Non-functional metal prototype (l) and functional wooden prototype (r).

In addition, a wooden prototype was taken, which had a rougher finish, but which functioned at a basic level. The dentists had seen an earlier version of this prototype on my previous visit to them. In the intervening time, I had refined the form of the prototype slightly (cutting down the tip of the device) and added a switch that would activate the electronics. But still it remained a rather ugly and clunky piece of hardware. Nevertheless, the dentists were able to overlook this and focus on the gestural feel of the interactions. It seems likely that this was because the prototype was also integrated with a version of the dental software that the dentist’s normally used (or had used previously). This meant that the dentists were able to attend to aspects related to device sensitivity, gestural feel, and interface feedback with the functional prototype and questions of appearance, weight and balance with the non-functional metal prototype.

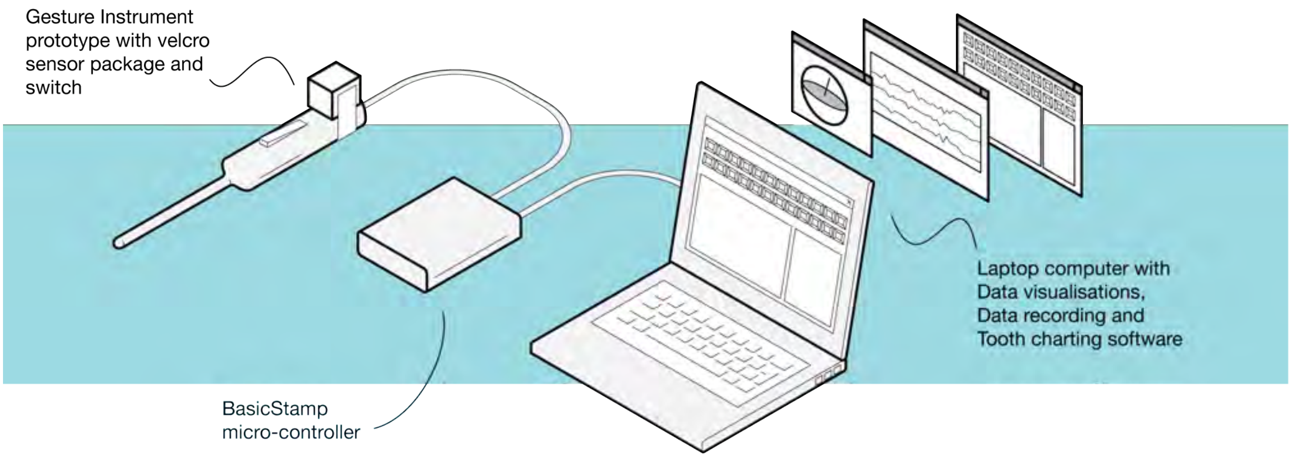


Figure 39: Equipment set-up for evaluation.

The full equipment set up for the use of the functional prototype is shown in Figure 39. This set-up was chosen to allow for flexibility during the evaluations. The wooden prototype of the gesture instrument was fitted with a switch and a Velcro-covered box housing accelerometer sensors. This method of attachment meant that it was possible to explore alternative orientations of the sensor on the fly to try to find which orientation would give the best response depending on the how the instrument was held. The switch on the device was to allow for dentists to activate the device and also for use when recording candidate gestures. The sensor box connected to a BS2 micro-controller, where the signals from the sensors were translated into x,y,z acceleration values and sent to a laptop computer via serial cable. For these tests, a wired version was used, but it was explained to the dentists that a final product would be wireless. Additionally, it was possible to attach a small loudspeaker to the BS2 micro-controller in order to get sound feedback from the sensor box directly. The laptop was used for two purposes in the evaluation. The first was to run the modified version of the tooth charting software that the dentists use in order to investigate the use of the gesture instrument as an input device for this. The second was to record samples of candidate gestures that could be used for making annotations on teeth during an examination.

For the purpose of running and controlling the tooth charting software, two programs were used. The first was a version of the tooth charting software that the dentists normally used, but which had been altered to accept keyboard inputs for changing the location of the selection cursor (these alterations were made by the CEO of the dental technology company, who was familiar with the software). The second program which I named the Tilt-Interpreter, read the acceleration data from the serial port, interpreted each x,y,z triple as an angle and then sent keyboard events to the tooth charting software depending on the angle. The precise details of how the acceleration data from the sensor device should be converted into the movement of the selection cursor on the tooth chart have a direct bearing on several of the questions I was seeking to enquire into in this evaluation. I therefore created the Tilt-Interpreter program such that parameters of its sensitivity and mode of operation could be adjusted at run-time in discussion with dentists.

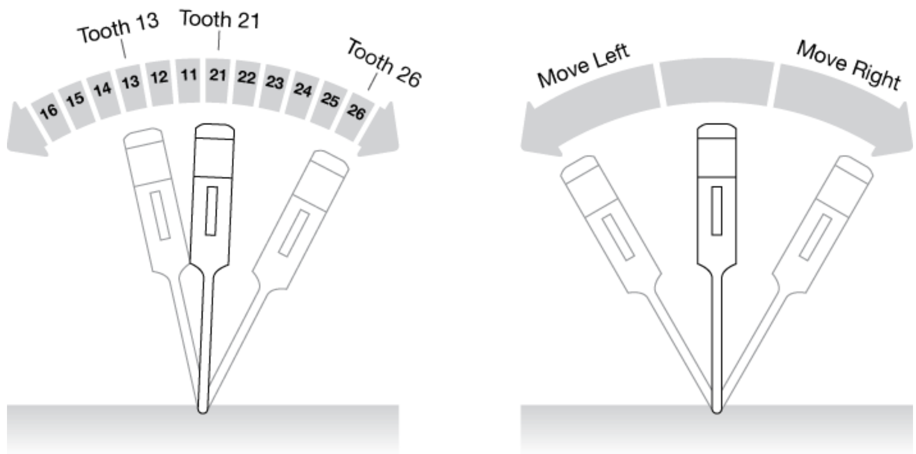


Figure 40: Absolute (left) and relative (right) modes of operation.

The mode of operation for the tilt interpreter could be either relative or absolute, as shown in Figure 40. In absolute mode, the position of each tooth in the mouth was mapped to a particular angle such that when the Gesture Instrument was held at this angle, the corresponding tooth would be selected. The relative mode worked differently; in this mode, the angle of the tilt was translated into a movement of the selection cursor either left or right by an amount relative to the tilt, but the angle of tilt did not map to any particular tooth. One could compare this to the difference between being able to select an item either by a touch screen or a track-pad. With a touch screen, one can select the item directly by pressing on its position on the screen. This is like the absolute mode, where each tooth can be selected directly. The relative mode is more like the way a track-pad works, where one must touch the track-pad and drag in the direction that the cursor should move in order to move the cursor over the item to be selected.

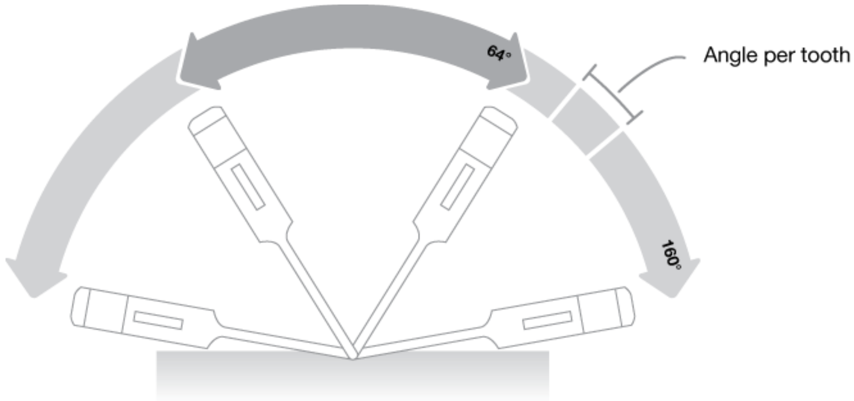


Figure 41: Adjustment of absolute mode parameters.

In addition to providing these two modes of operation, the Tilt-Interpreter software also allowed for the functioning of each mode to be fine-tuned by the adjustment of some key parameters. For the absolute mode of operation, this was simply to specify what the angle for each tooth should be, as shown in Figure 41. Taking just one of the jaws at a time means that 16 tooth positions that need to be specified in this mode. In combination with the limits of the sensitivity of the sensors and the range of movements the dentist can comfortably perform place an upper bound on the angle that can be assigned to each tooth. The smallest angle that the sensors can measure is 2°, which makes a minimum total angle of 32°. From my own experiments, I found that the largest range through which I could physically rotate the device was around 160°, which makes a maximum angle for individual teeth of 10°. This situation presents trade-off between a comfortable range of movement and ease of target acquisition.

Several adjustments could also be made to the Tilt-Interpreter software for the relative mode of operation in order to change the sensitivity of the prototype (Figure 42). This was in terms of several parameters. The buffer angle could be changed, meaning that the dentist would have to tilt the device further before the cursor position would start to move. The buffer angle was necessary, because even when holding the device quite still, there is a jitter in the readings from the sensors and from the movements of the hand, which can cause the cursor to jump about unpredictably.

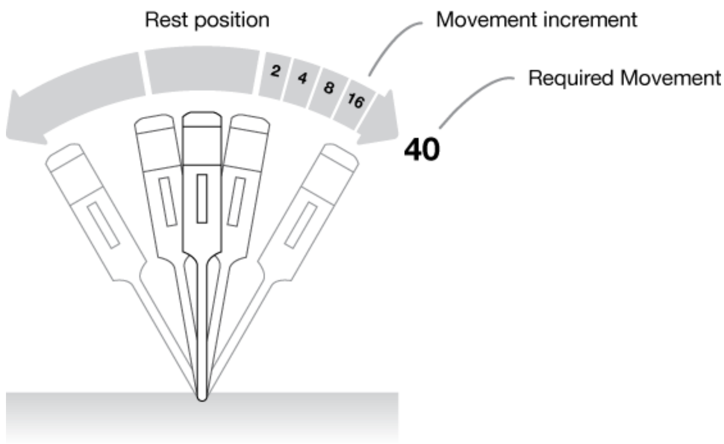


Figure 42: Tilt-Interpreter parameters in relative mode.

Even beyond the buffer angle, the device would not move immediately, but needed to be held for a time until a required movement trigger would move the cursor. Each moment that the user held the device at an angle beyond the buffer, an internal counter would be incremented by an amount that related to the angle at which the device was held. The more the device was tilted, the quicker the cursor position would be changed.

4.7.3 Showing the dentists

When we introduced the concept to the dentists, the first thing we did was show them the metal prototype that the CEO of the dental software company had made (Figure 43). Dentists agreed that of the instruments, the mirror was a good choice to integrate the interaction technology into, because it is used most extensively. The ubiquity of the mirror is tied to its importance as an instrument for the dentist. It is not only used to see into the mouth, but also for retraction (pulling the cheek or tongue away from the teeth) and for reflecting light into the mouth. Therefore it is important that the balance of a final instrument not interfere with these existing functions.

Several suggestions were also made that the interactive part of the gesture device could be packaged separately so that it could be attached to different instruments. One dentist (D4) noted that in a periodontal exam, he would hold the scaler in the right-hand rather than the mirror, so a fixed instrumented mirror would not be much use to him in this case. This also led to the notion that it might be possible to have two gesture-augmented instruments working together in the mouth, say a mirror and a probe. Though we didn't run through the implications that this might have for how the interface would work, it could be an area for further investigation. One question that arose from this is how it would integrate with double-ended instruments, which dentists often use. The opinion from dentist D3 was that it would be a question of whether the utility of the gestural instrument outweighed the convenience of a double-ended instrument. He said that he personally did not mind too much whether he used a single or double-ended instrument.

Figure 43: Dentist D5 tests the balance of the metal prototype.

The notion of separate packaging was also taken up as a possible way to keep delicate electronic parts of the device separate from the parts of an instrument that need to be put into an autoclave. It would be possible to use a disposable plastic sleeve over this removable electronic part such as is currently used with intra-oral cameras. The question of how the instrument would be cleaned was one of the first asked by all three of the dentists. As D4 quipped, ‘if you can’t clean it, they won’t buy it’. Clearly the ability to integrate such an instrument into cleaning procedures is a key criterion for it to be accepted into the dental surgery context. We explained that for the purposes of this evaluation, we were working with the assumption that cleaning the instrument was a solvable problem. All of the dentists were happy to go along with this, and indeed they had several suggestions for how it could be integrated into the cleaning procedures, such as the plastic sleeves mentioned above, or making it out of materials that could withstand existing cleaning procedures.

4.7.4 Trying out tilt as an input method

After the initial introduction of the concept with the non-functional prototype, we switched to the wooden prototype to test out the interactions. The first thing we tried out with this prototype was the use of the tilting movement to control the position of the selection cursor on the tooth chart of the electronic patient record. When first trying out the device, all the dentists' commented on its behaviour in terms of its sensitivity. Prior to going on the trip I had tried the prototype out in my office and set the angle of operation quite high, but still within what felt to me a comfortable range of movement. At the surgery of dentist D3, it was soon clear that this angle was too large for the dentist to use the device comfortably (Figure 44).

He commented on this in terms of the sensitivity of the device, saying, "Not ultra-sensitive is it." By adjusting the position of the sensors and the parameters for the program, we discovered that a more appropriate angle of operation for the dentist was 32 degrees. Which is near the limit of what the device can reliably detect. At the surgery of dentist D4, which was the next one we visited, we first introduced the dentist to the relative mode of operation, which I had adjusted so that it would work over a smaller angle. This time, when the dentist first tried the prototype out in the mouth it moved around too quickly for his liking. Again, he expressed this in terms of its sensitivity, saying, "It's fairly sensitive this thing isn't it? Once it gets moving." For the final surgery, the settings were refined again. This time, the device seemed to work better, however, once again one of the initial reaction of the dentist was to bring up the topic of the sensitivity of the device and highlight it as a quality that would be important to get right, and highlighted a design trade-off between the ability to make movements in the mouth and the limits of sensitivity of the device:

"…so you're going round, … doing an examination type thing. You look at, okay well 1-7 needs an amalgam. You'd be sitting there looking at it and to select, you're probably going to have to take this out and make an action. You're probably not going to be able to do it in the mouth, because it's too subtle. Unless you get really fine movements. And I think if you get really fine movements, you're going to end up getting frustrated with it, because too sensitive." (D5)

Figure 44: Dentist D3 tests the range of tilt.

This focus on sensitivity seems significant, not only because it was a common theme in how the dentists responded to the functioning of the device but also in relation to the qualities of the work of dentistry I had observed previously. Dentistry involves precise movements and fine motor coordination. However, these abilities are not properties of dentists' bodies alone, they are also enabled and scaffolded by the instruments of dentistry. On a previous occasion, one of the dentists (D3) had described the use of the probe as just gliding along the surface of the teeth, feeling for a catch – a sign of decay or a crack. The long thin needle of the probe acts like a spring that magnifies and transmits these tiny catches to the feeling fingers of the dentist's hand.

Clearly, the *sensitivity* of a dental instrument is a key consideration for dentists and there is likely a narrow window between an instrument that is too sensitive and one that is not sensitive enough. The angle of operation is one parameter that would affect the sensitivity of the device. It appeared from the tests that having an angle of operation around 30 degrees was a good target for the device to operate within, but as the response of dentist D5 showed, this was not conclusive. One reason for this might be that other factors, such as sample rate and latency, also have and effect on the perception of sensitivity and these could not be adjusted in the prototype.

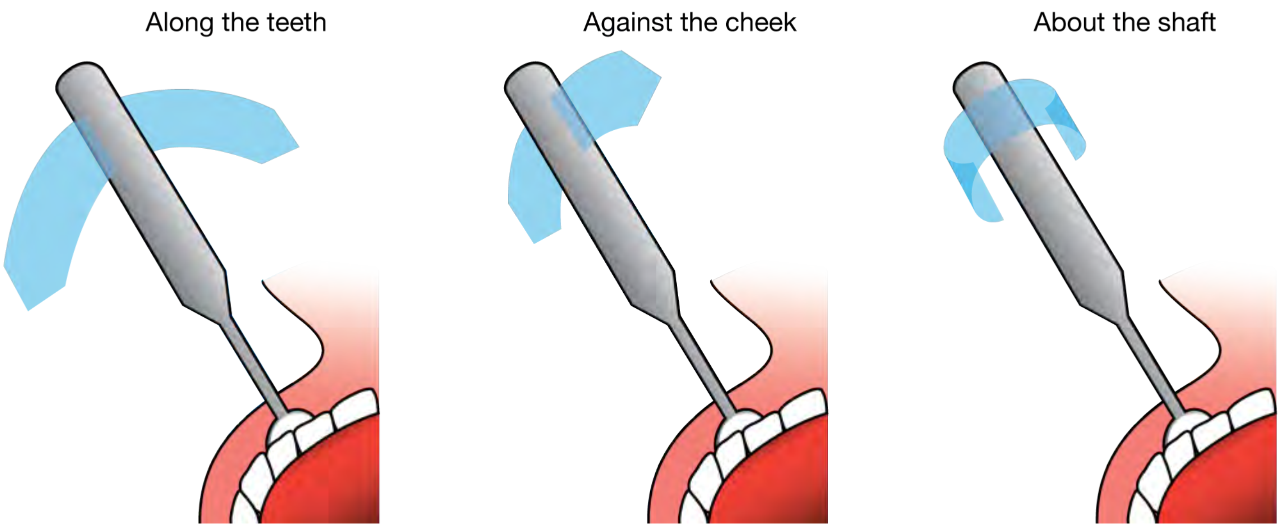


Figure 45: Planes of tilting in relation to the teeth.

A more definitive finding from trialling the tilt method concerned the direction in which the tilt should be performed in the mouth of the patient. As Figure 45 shows, a dental instrument that is sitting against the cheek inside the mouth can be tilted in three separate planes. It can be tilted along the line of the teeth, against the cheek and about the shaft of the instrument. Prior to this visit to the dentist, I had not considered the differences between these different planes of tilting in detail. However, the dentists had a clear preference when working in the mouth for tilting the instrument against the cheek and a clear preference also *not* to rotate about the shaft of the instrument. The reason for this is that when the mirror is used to retract the cheek or tongue, its flat surface rests against this line of the mouth. This in turn supports the dentist to tilt against the line of the teeth and restricts rotations about the shaft.

This presents a challenge for the Tilt-Roll-Wave concept if it is to be used in the mouth, because the concept was to use the roll movement to select a tooth surface. Rather than the roll movement, it is possible that this interaction could be performed with a tilt in the other direction, which while not the preferred plane of tilt was also not rejected by the dentists. In fact one dentist suggested the use of a second tilt at 90 degrees to the first one to chose an item from a menu once the tooth was selected. Another option to explore might be the use of paired gesture sensitive instruments as mentioned earlier.

The final area I wanted to explore with respect to tilting was the appropriateness of the relative and absolute modes of operation. One problem, which quickly became apparent with the relative mode, was moving from the bottom to the top jaw. In the tooth chart, these are two separate lines, one above the other. The problem was that when the selection scrolled all the way one end of the chart, it would jump to the other jaw either immediately above or below. The problem with this was that because the dentist was tilting the instrument towards that end of the jaw, when it jumped to the other jaw, it would immediately jump back again and continue jumping back and forth until the dentist stopped tilting. This was very confusing to the dentists, who described it as "getting stuck".

Unfortunately, we didn't get a chance for a good comparison between the relative and absolute modes with the dentists D3 and D4, because discussion stayed focussed on other issues. However by the time of the meeting with the dentist D5, these issues had been more worked through and we were able to get to a discussion of which of the modes of operation was his preferred one. In this case, we showed the dentist the relative mode of operation first. Although he was able to change the selections with this mode and seemed to accept it as a plausible input modality, there were some problems with how it functioned for him. In particular, he found the activation of the device to move from tooth to tooth a little 'clunky'.

We then introduced the absolute mode and explained how it worked. Once he could see how he needed to tilt the instrument to move the cursor, he immediately said "I like that better", and suggested that one would be able to learn the positions of the different teeth and select them quite quickly, "Like playing the violin". Hearing this from the dentist helped me understand the difference between the two modes in a new way. It seemed to me now, that the relative mode of tilting really didn't offer much advantage over having buttons on the instrument to move the selection forward or back, because the dentist could only go forward or back one tooth at a time. Indeed, dentist D3 had noticed that he could simply lean the instrument to one side and just repeatedly press the button to move from tooth to tooth on the chart. The absolute mode, on the other hand, does offer an advantage over a button because one can immediately pick the tooth that one is interested in. This would allow the dentists to chart the teeth by examining several teeth in a row and then selecting only those that need to be annotated.

4.7.5 Developing candidate gestures

In addition to testing the feasibility of the use of the device tilt as an input modality, another objective of the evaluations was to engage the dentists in a discussion about possible gestures that could be used for annotating a tooth on the electronic patient record and then record samples of these. For this, I used the same equipment set-up as above, but read the input from the device into a gesture-recording program I had developed previously during the project. I set the recording software up so that it would store and graph the data from each gesture on screen as they arrived from the gesture device and only save them to file after confirmation (by pressing the enter key). This meant that it was possible to quickly review each gesture as it was performed and only save those where the data was good.

Reasons for rejecting a sample included factors such as if the switch was not pressed properly, or was released part of the way through the gesture, or if the dentist was still warming-up for the gesture and made a mistake in its execution. Although in a final interface, the data from such mistakes would also be passed through to the recognition software causing problems in the interaction and should therefore be accounted for in a final system, my purpose at this stage was to gather 'ideal' gestures with some variation, that would be suited to training a recognition engine that responded to those gestures specifically. Including mistake gestures would be counter to this purpose, even though it would be necessary to account for and deal with mistakes in a final system. The work of training such as system was beyond the scope of this thesis, but the reason for recording the data was with the possibility taking up the work later, possibly as part of a student project. Recording the data also served a practical purpose in the context of the collaborative design evaluation. It helped to focus discussion on what the specific form of gestures should be. Without this point of focus, it is likely that the discussions would have remained at the general level of the merits of gestural interactions for this application.

Compared to the idea of using tilt to drive the selection cursor, the idea of using gestures to annotate a tooth was less worked out in the Tilt-Roll-Wave concept. Therefore, for the last part of the discussion I asked the dentists to propose gestures for the six most common annotations that they expected they would need to make on the teeth. A challenge for this part of the discussion was to think of how gestures could be distinct and memorable enough as well as subtle enough to be performed repeatedly around the patient's head. Dentist D3 proposed basing his gestures on letters and symbols, an idea that had emerged during the previous occasion we had met him. These were A for amalgam, C for composite, I for inlay and symbols for a cross, a circle and a tick. These were performed as if writing the number or symbol with the head of the instrument.

Dentist D4 was less sure of the idea of using gestures as a way of annotating the teeth. At first, he suggested that you would need gestures for fillings, crowns and missing teeth, but then he grew sceptical of the idea and pointed to the long list of available treatments in his existing software interface, saying that it wouldn't be possible for the full range of possibilities to be accommodated by hand gestures, remarking, "it boggles the mind." There is certainly a possible issue with the device that having only gestures for the six most common annotations would be too limiting and that the need to switch back to a mouse to select annotations that are not covered by gestures would negate any benefit of using the device. This was a point of discussion with all three of the dentists, and a number of suggestions for ways to address it were proposed by them, such as integrating with voice recognition and the use of pop-up menus that could be selected from through another tilting gesture. Another possibility for allowing a greater range of inputs would be to relate gestures to standardized treatment codes currently in use in dentistry.

Dentist D5 had a slightly different need of the device than charting the teeth, because of the specialized nature of his endodonty practice. In his current software system, he needs to use a large number of mouse clicks to work through standard forms as part of the diagnosis process. He proposed that gestures for the device could be made so that he could perform this work using the instrument. He suggested three gestures, for 'tabbing up', 'tabbing down' and 'clicking' his way through these forms. Like dentist D3, these were made as small movements with the head of the instrument. The tabbing gestures were short flicks up and down, and the 'click' gesture was a 'tick' motion. After running through the set of gestures the first time, the dentist commented that they were still too pronounced for his liking, so he performed them again with much subtler movements. He emphasised that it was important that they should be subtle, using mainly the fingers and wrist but not the forearm. Additionally, he noted that they should also be distinctive, saying, "Even in your own mind, you want something that is distinctive."

4.7.6 General discussion of the prototypes

In addition to the specific discussion about the aspects of tilt and candidate gestures presented above, there was also a lot of discussion from all the dentists about general requirements and ideas in relation to the form of the instruments. The topic that drew the most discussion in this respect was the mode of activation of the instrument. The prototype that was presented had a switch embedded in the handle that needed to be pressed down. One issue with this was the position of the switch, which was too far up the handle of the device to be comfortably activated. As the dentist D5 remarked, the button needs to be right where your finger is. All the dentists seemed to go along with the idea that there should be an explicit activation of the device, however there was quite a lot of discussion of possible other methods for activating the device, such as using a foot pedal, or tapping the device against another instrument or the tooth, or having an instrument that you could activate and would then stay on until you de-activated it.

Another issue that received a lot of discussion was what form of feedback the system should give. A problem identified by the dentists with using the interface with current computers is that the computer would need to be close enough to see the tooth chart. This was a problem for two of the dentists, who had already re-configured their way of working to deliberately remove the computer from the vicinity of the chair. Suggestions at how to overcome this again focussed on redesigning the interface, for example by making a larger display of the selected tooth on the existing interface. I also asked dentists for their opinion about sound as a feedback modality. They all said that it's probably something that comes down to personal preference and you would need to be able to turn it off (which is what they would do). The possibility of having small coloured lights on the instrument itself was also suggested by two of the dentists, either simply to indicate that the device was activated, or to convey some extra information. In relation to gestures, dentist D5 also remarked that as he was performing his 'tab-up' gesture he was imagining some kind of screen-based feedback for the gesture where "…you would be seeing it go up. You know, sort of pushing up."

One final area of particular interest of mine going in to the collaborative design evaluations was how the gesture instrument might fit with the interactions between the dentist, assistant and patient. As it turned out, the discussion tended to focus more on the interaction between the dentist and the interface and I didn't get as much chance as I would have liked to enquire into these other aspects. However there was one interesting insight from dentist D3, who talked about the idea that in his practice he makes a point of speaking a lot of information aloud to the assistant, so the patient can hear what is happening and can therefore get a better understanding of the treatment. In relation to this, the gesture instrument might introduce a problem, by no longer requiring the dentist to speak aloud his observations to an assistant who enters them into the computer. However, another possibility is that by being able to specify 'jargon' information with the gesture instrument, the dentist would be freed up to use more everyday explanations to the patient.

4.7.7 Conclusions from the collaborative design evaluation

In a design evaluation such as this, where practitioners are encouraged to evaluate and discuss a design concept based on their professional expertise, gives rise to a good deal of new design information that could be followed up on in subsequent design work. Unlike a more traditional lab-based usability evaluation, one does not arrive at clear quantifiable results. Nevertheless, it is possible to get answers for very specific questions, such as angles and directions of tilt, specific candidate gestures, and so on. For me, the most important outcome of the evaluation for the research, was that it showed a strong potential for aspects of the Tilt-Roll-Wave concept to be carried forward and that the concept was at least a plausible mode of interaction for the dentists. The discussions highlighted though, that in order for such a system to be adopted by dentists, it would need to meet high standards for acceptance. As dentist D5 remarked:

"I suppose to make anything work, it's got to be quite intuitive and it's got to be fast and it's got to be low error rate. It's like anything, you'll put up with it for a little while, but if it is just constantly not giving the right input, you're going to put it on the bench and go back to typing again."

Whereas the dentists evaluate the design concept based on pragmatic considerations for how it might improve their work and judge it against the standards of commercial products, the design project I have described here was of a rather different kind. It was not a commercial product development project, but a research project. I came to the dental surgery as a researcher with an interest in exploring possibilities for gesture in an authentic context of use. For me, introducing my concept to a group of people with such expectations and having them accept the promising potential of such an interface was a good result.

4.8 Chapter Conclusion: Reflecting back on a process of design

This chapter has described key activities from a design process to design a gesture interface for the dental surgery context, leading up to the collaborative design evaluation of a working prototype in three surgeries. Within the setting of a dental surgery, a design problem was identified around accessing and updating the electronic patient record. Current office PC based interfaces present several challenges for dentists to integrate into their work, including that they disrupt the flow of interaction between dentist, assistant and patient and are difficult to keep clean and integrate into infection control procedures.

In order to develop a design response for this problem, I engaged in a participatory design process with dentists to investigate the possibilities of using gesture as an input modality in the context of the dental surgery. Through this process, a great deal was learnt about the work of dentistry and the requirements for a gestural interface for this context. Design methods for engaging with gesture at various stages of the design process were also developed, tested with participants and reported on in this chapter. In line with the objective of *recoverability* articulated in the previous chapter, activities from throughout the process have been reported in detail. I told the 'story' of the design process in six phases:

- **Observational studies:** From video-based studies, preliminary themes of interaction were developed, which captured a range of findings about the nature of gestural interactions, interpersonal relations, and physical interactions at play in the dental surgery.

- **Designerly analysis:** a process of designerly analysis gave a detailed understanding of the spatial relations within the dental clinic through modelling the space of the surgery and tracing the movements of a dental examination.
- **Internal design events:** within a participatory design process, it can be important for designers to engage in explorative design events within the team to develop their understanding of the design space and develop design directions. A key activity in this event was the collaborative analysis of gesture through the video mirror, which highlighted salient influences on gestural interaction including posture, gaze, artefacts, and positioning in relation to others. Initial scenarios of interaction were also developed, which fore-grounded the patient's experience of dentistry and suggested the dental instruments as a promising design direction.
- **Collaborative design enquiry:** a 'meaning in movement' activity was undertaken with dental students. Through this, important qualities and values of dentistry were identified and related to gestural interactions.
- **Engaging technology as a design material:** several steps were taken in order to explore with dentists the possibilities that the technology for detecting gestures afforded. Simple form explorations allowed the investigation of 'gestural affordances', sensor placement and hand-posture. Screen based visualisations gave real-time feedback on sensor response so that participants could relate the functioning of the sensing technology to their movements.
- **Collaborative design evaluation:** a final evaluation of a working prototype was carried out in three separate surgeries. In line with the participatory design approach, these evaluations were designed to engage dentist's expertise in assessing and suggesting improvements for the design concept rather than a formal structured evaluation with pre-specified usability metrics. This process resulted in detailed findings about the dentist's requirements for sensitivity, angles of operation, planes of tilt, modes of operation and candidate gestures for annotation.

The final design concept that resulted from this process was called Tilt-Roll-Wave. It is a gestural instrument that a dentist would be able to use alongside other instruments to interact with the patient record during the examination and charting of the patient's teeth. It is not envisaged that the device would be a complete replacement for the dentist's current system, but rather a small addition to one aspect of it. This gesture interface has some unique characteristics, compared to other gesture interfaces described in the literature survey. Here the focus is on designing something that can be gestured *with* rather than on unobtrusively detecting gestures. By drawing together tilting and rolling movements with a small number of pre-defined gestures (waving) the device avoids limiting itself to one or other kind of interaction. The fine tilting gestures that the device employed are unusual for a gesture interface. However, they are based on movements around which dentists have built an existing skill, they made sense in terms of the interaction and they were a good fit for the technical capabilities of the technology.

This presented me with somewhat of a quandary with respect to the aim of this thesis to enquire into the appropriateness of existing research into human gesture for the design of a gesture interface within an authentic context of use. In carrying out my design project, I was primarily concerned to allow my design decisions to be responsive to what made sense in the design context. Throughout the process, when discussing the design concept with dentists, I discussed it as a *gesture* interface and they were happy to accept it as such. But these would not be considered gestures according to the definition of gestures taken by researchers into human gesture such as McNeill.

I was prompted to look within existing research into human gesture for broader conceptions of gesture, several of which were presented in the literature survey. It seemed to me that in terms of existing theory, what would benefit gesture interface design is not to narrow down to a single definition of gesture, but to open up for a broader range of views on what gesture might be. My experiences of designing for an authentic context of use had given me a view onto the role of gestures in dentistry which was different in some ways from the views of gesture offered by communication-focussed gesture research. However, it was difficult for me to articulate these based on the design process or the final design prototype alone. I therefore undertook to engage in a further round of detailed analysis of the role of gestures in a dental examination based on a video recording taken from early in the observational studies. Results of this analysis are presented in the next chapter.

Chapter 5: The Gestures of Dentistry

Consider the many ways one could frame the work of dentistry for gesture interface design. Focussing on the social interaction between a dentist, assistant and patient, one might highlight its cooperative nature. Looking at the skilful selection and manipulation of instruments and materials, one might cast it as skilled craftwork. There are aspects of information work too, involving as it does the retrieval, editing and up-keep of patient records. And in their interactions with patients, there is also an important educational and public health role for dentists. Gesture plays an important role in all these aspects of the work of dentistry and it would be plausible to take any of these aspects as a focus for the design of a particular gesture interface to support the work of dentistry.

Focussing on one or other of these aspects has implications for the kinds of movements we might take into consideration for gesture interface design. For example, if a gesture interface aimed to support the skilled craftwork aspects of dentistry, then an analytic framing for gesture that excludes the skilled movements of instrument and material manipulation would be of limited benefit.

In this chapter, I step back from the question of gesture interface design as such and explore this notion of the different ways that movement might be framed as gesture through analysis. It is important to reiterate that the analysis presented in this chapter was carried out *after* the design project described in the previous chapter was completed. It was not carried out in order to inform design, but rather was *informed by* the understanding of the work of dentistry and the role of gestures in this setting that I had built through carrying out the design project. In line with the working definition of gesture presented at the introduction of the dissertation and elaborated in the literature survey, I take a broad view of what constitutes a gesture in this analysis. Specifically, I highlight the following two areas in which gesture plays an important role in the work of dentistry:

- **Tooth gesturing:** sequences of gestures the dentist used to explain aspects of the teeth or jaw to the patient. I show how 'tooth gesturing' sequences support *patient education*.
- **Coordinating gestures:** the role that gestures play in the coordination of the work. I show how a range of different kinds of gesture are employed in support of this.

5.1 Analytic approach

In this chapter, I present an analysis of a series of vignettes of interactions between a dentist, assistant and patient during a dental examination. These vignettes are taken from one videotaped dental examination, which is itself one of a number of video recordings of dental work that my colleagues and I made over the course of the research project. On this occasion, three researchers visited the surgery. One was the patient, another videotaped the examination and a third took hand-written notes. Besides the three researchers, a dentist and the assistant were also present. Figure 46 shows the layout of the surgery and the position of these people within it.

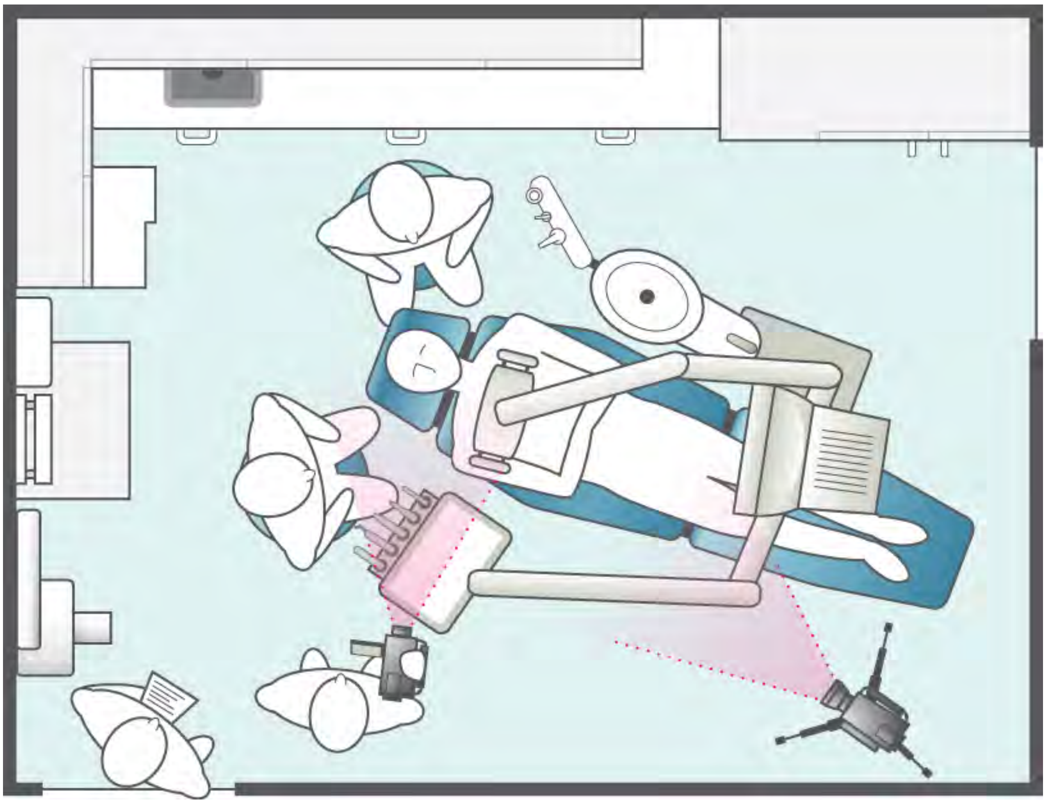


Figure 46: Layout of the surgery and positioning of people and cameras.

I was not present at this examination, however I have visited and observed a number of other dental examinations at the same surgery with the same dentist and assistant. The reason I have taken this particular visit to analyse in detail is because of the set up of video cameras we chose. Whereas previously we had used only hand-held video cameras, on this occasion a tripod-mounted camera with a wide-angle lens was also set up. We decided to use a second camera to record this dental examination because on previous visits we had found it difficult to record all the activity of the dentist and assistant given the limited space of the surgery. We had found that the hand-held camera was best at picking up the detail of up-close interactions, but not so effective for recording the relative positions and postures of people or maintaining a sense of how people move through the space. We hoped that by having a second camera we could address these aspects and also get more of an overview of the activity.

The purpose of the analysis was to develop an account of gestures in relation to the work they to within the dental examination, rather than in relation to pre-existing analytic categories. Video was chosen as the primary source of data for analysis because is allows for repeated viewings of verbal and gestural elements of interaction at a level of detail sufficient to discuss the ways that they are interwoven into interaction (Hindmarsh & Pilnick, 2002). Nevertheless, it is important to recognize that video recordings of work practice only present a particular perspective on the work (Suchman, 1995). Therefore the knowledge of the work of dentistry developed through design project presented in the previous chapter provides a grounding for informing the analysis.

The style of analysis undertaken here is broadly in line with the tradition of workplace studies from CSCW, especially those that pay attention to the detail of interaction in work (Heath & Luff, 1992; Hindmarsh & Pilnick, 2002). My approach has been particularly informed by the approach and assumptions articulated by Jordan and Henderson for Interaction Analysis (Jordan & A. Henderson, 1995).

Within this perspective, knowledge and action are seen as fundamentally social in origin (Jordan & A. Henderson, 1995). This means that expert knowledge is not located in the heads of individual practitioners, but situated within the interactions of members of a community of practice participating in a material world. Methodologically, this implies that studies of practice should be grounded in the observable details of everyday interactions between members of a community of practice. Theories of knowledge and action should also be grounded in verifiable observable empirical evidence. This relates directly to the commitment of Interaction Analysis to the use of video recordings as a primary source of empirical data.

The commitment of Interaction Analysis to verifiable empirical evidence as the basis for analytic knowledge of the world rests on an assumption that the world is not only sensible to practitioners in their everyday interactions, but also to analysts when they observe those interactions on video (Jordan & A. Henderson, 1995). There is a commitment that assertions about what is happening on a video recording should be verifiable by what is recorded on the tape. One important implication of this is that analysts should seek to only talk about mental states and mental events in ways that are grounded in what happens on the tape. Theorizing should be responsive to the phenomenon itself rather than to the characteristics of the representational systems that reconstruct it. This means that methods for transcription should be chosen based on their adequacy for the purposes of the analysis and an attempt to keep the analysis free of pre-determined analytic categories.

Nevertheless, I did come to the analysis with a pre-existing interest in gesture and the possibility of discussing existing theories of gesture in respect to gesture interface design. Therefore, the following vignettes do focus on passages of interaction in which gestures played a significant role. Examples have also been chosen in order to discuss a range of different kinds of gestures within the broad definitional framework presented in the introduction of the dissertation. The ideas about gesture that I came to the analysis with could be thought of as sensitizing concepts (Blumer, 1954), around which potentially different and partial understandings could coalesce (Hoonaard, 1997).

5.1.1 Transcription

As part of my analysis, I made a transcription of the interaction on the video recording. In order to produce this transcription, I used a software program called Transana (available at www.transana.org). This program showed a waveform of the speech along with the video, and allowed precise playback control and synchronising of the video-file and the written transcript. For the purposes of my analysis, I aimed to produce a word accurate transcription of the speech of the dentist, assistant and patient. I also transcribed pertinent aspects of gesturing and other non-verbal interaction, including communicative gestures; object manipulations; instrument use; and shifts in gaze and posture. These are marked in the transcript by being enclosed within circle brackets. To give a better understanding of the form of the gestures described, still frames from the video are included with the transcript. Frames are numbered so they can be referred to from the text.

I did not employ a pre-defined coding scheme for transcribing the gestural interactions. In general, these are transcribed descriptively, with 'RH' and 'LH' used to indicate right and left hands. However, where there seemed a clear instance I did sometimes use words for categories of gesticulation as presented in the literature survey in my descriptions of gestural interactions. One reason for this is that these categories in many cases provided a more succinct way of indicating the kind of gestural interaction ('beat' opposed to 'quick up and down gesture'). Another reason is that I intend to discuss these categories in the next chapter. A particular focus will be the work of McNeill and so I use the terms from his taxonomy of gesticulation (McNeill, 2005). For the reader's convenience, this is summarized again in (Table 9).

Table 9: Summary of McNeill's categories of gesticulation

Category	**Description**
Iconic	Picture the content of speech
Metaphoric	Portray the speaker's ideas, but not directly the speech content
Deictic	Pointing at a thing/area. Space around the body used.
Beat	Marking the rhythm of speech

Dealing with the detail of producing a transcription of the video recording was an essential step in developing the analysis. Trying to transcribe the videotape at a word-accurate level required attentiveness to the recorded interactions and helped me to notice unexpected details of interaction, both in relation to verbal and non-verbal aspects. In attempting to describe textually a gestural interaction, I would often struggle to capture all the detail I wanted. This served to highlight the complexity of movements that might otherwise be glossed as 'the dentist gestured to the patient'.

In these ways, the process of producing a transcript of the video recording was in some ways similar to the activity described in the previous chapter of projecting and tracing the video on the wall. Each of these ways of working with the video recording brought a different kind of awareness of the interactions that were recorded in it. Or, as Jordan and Henderson note, 'any transcription convention embodies a theory of what is relevant in interaction' (Jordan & A. Henderson, 1995 Appendix A). As such, the account presented in this chapter should be seen as an additional complementary view on the interactions of a dental examination to the picture built through the previous chapter.

5.2 The Setting

The picture below shows a view of the surgery from the beginning of the check-up. Three people are visible in the picture. On the left is the dentist, in the middle is the patient, and in the background is the assistant. Two researchers (Campbell and Cederman-Haysom) are out of shot standing behind the dentist.

Figure 47: View of the surgery from the start of the examination.

The room is quite small. On the back wall is a row of cabinets with a bench below. There is a basin built into the bench and cupboards beneath. The surfaces of the benches are cluttered with items and materials and the cupboards have sheets of paper and a clipboard hanging from them. The cabinets and bench extend a little way onto the adjacent wall and are adjoined by a light-box and an x-ray tube mounted on an extending arm.

A dental chair, in which the patient is sitting, occupies the middle of the room. Attached to the dental chair is a rinsing basin and a bracket with instruments for the assistant. The dental chair also has two poles attached to its middle. The dentist can adjust these by moving them back and forth. One extends out at waist height and holds the bracket table, which is where the dentist places his instruments. The other reaches out above the chair and holds a light that the dentist uses to illuminate the mouth. In addition to these poles, there is a short movable bracket with a computer monitor attached to it. The computer monitor is positioned above the legs of the patient and angled so it is visible to the dentist, assistant and patient. To interact with the computer, the dentist and assistant use a wireless keyboard and mouse, which are stored above the cupboard.

There are two doors into the surgery, but neither is visible in the picture. One, positioned out of shot to the right of the picture, leads to a small laboratory where instruments are sterilised and materials stored. The other, out of shot to the left of the picture, opens on to a hall that leads to the reception area. The dental clinic also has a second surgery, an office, a reception area, a bathroom, and a staff lunchroom, as described in the previous chapter's section on scale modelling of the space (section 4.3.1).

5.2.1 Overview of the activities comprising the examination

Agreeing on what to do	Taking the x-rays	'A little look'	Discussing the initial observations	Comprehensive check	Cold pellet test	Scale and Polish	Finishing up

Figure 48: Overview of activities in the examination.

The video from which this account is drawn covers approximately 40 minutes of a dental examination. It starts from when the patient, dentist and assistant had entered the surgery through to the end of the examination when the patient stood up from the dental chair and the dentist and assistant begin cleaning up the workspace. Within this, several phases of activity are apparent, as summarised in Figure 48 and described below.

The dentist and patient started by **agreeing what to do.** This involved discussing and agreeing on what was to be done in the examination. The dentist checked with the patient that her reason for coming to the check-up was because of some sensitivity she had been experiencing on a tooth. She confirmed this, and also requested a scale and polish, which the dentist agreed to.

During the exchange above, the assistant began preparing the surgery to get ready for **taking the x-rays** of the patient's teeth. She laid a lead apron over the patient's torso, gave the patient some glasses to wear and handed an x-ray film to the dentist. Next, the dentist showed the patient how to position her head and bite down on the x-ray film holder while the x-ray was being taken. The assistant moved into the laboratory and the dentist went out into the hall while the x-ray was taken. This procedure was then repeated for the other side of the mouth.

Once the x-ray films were exposed, the assistant re-entered the room, collected the films and went back to the laboratory to develop them. The dentist sat down behind the patient, took his probe and mirror from the bracket table and told the patient that he would take **'a little look'** at the patient's teeth. During this initial examination of the teeth, the dentist identified a series of vertical cracks on one of the patient's molars and a gap in her bite.

The dentist then spent some time **discussing the initial observations** with the patient. This involved describing these observations to her and discussing what the possible causes for the vertical cracks and the gap on the molars might be. During this discussion, the assistant brought the developed x-rays back and clipped them up on the light-box. She then prepared for the next part of the examination by getting the keyboard and mouse from the bench and sitting down next to the dentist and patient. The assistant sat with the keyboard on her lap as the dentist and patient continued discussing the observations, now referring to the x-rays that the assistant had clipped up.

After several minutes of discussion, the dentist announced that he would begin a **comprehensive check** of the patient's teeth. He moved his chair back behind the patient's head and adjusted the light so it was shining on her mouth. He first checked the patient's jaw joint, noted some clicking, and explained to the patient what caused this. He then moved back behind the patient and examined the glands beneath her jaw before taking a mirror and probe and examining her teeth in detail. In addition to looking directly at the teeth in the mouth, the dentist also looked at the x-ray on the light-box. As the dentist progressed through the comprehensive check, he dictated his observations to the assistant who entered the information into the patient record. The dentist paused after each set of observations was entered into the computer, moved around to the side of the patient and explained what they meant.

After the comprehensive check, the dentist and assistant carried out a **cold pellet test** to see if the tooth with the filled root was getting any sensitivity. This test hadn't been planned ahead of time for this visit, but rather was called for in response to the findings of the examination and the discussion with the patient. In this test, the dentist placed a cold swab on the patient's tooth to see if she had any feeling in it.

In the final part of the examination, the dentist and assistant worked together in the mouth of the patient, performing a **scale and polish** of the teeth. The assistant held a suction instrument and an air instrument for both parts of this activity. The dentist held the mirror, along with first an ultrasonic scaler and then a polishing instrument. The dentist and assistant worked around the mouth, first scaling and then polishing. They paused at regular intervals to give the patient 'a little rest' where she could pause and relax her jaw.

When the scale and polish was complete it was time for **finishing up** the examination. The dentist took off his gloves and spoke with the patient while the assistant started clearing away the instruments and materials from the examination. The two cameras were stopped at this point.

5.2.2 Further qualities of the work

The preceding presentation of the sequence of activities of the dental examination gives an overview of the order of events and how different parts of the examination feed in to each other. However, it fails to capture some important qualities of the work that are worth highlighting further.

A dental examination is not a pre-defined sequence of actions that can be run through by rote. The details of the work to be undertaken in the examination are somewhat open to negotiation (e.g. the request for a scale and polish) and must be adapted to the particulars of the patient's situation (e.g. the inclusion of cold pellet test). The physical enactment of this series of events is tangled up with the context of a particular examination. An overview of the activities of the dental examination can give only a vague impression of this relation of actions to the context. We can see from the description above that explaining to the patient is an important aspect of the ‘comprehensive check’ part of the examination, but are yet to get to the detail of how this explaining is done. This is of particular relevance for this study, given the focus on gestures. In the next section, I will focus in on the role that ‘tooth gesturing’ plays in supporting the explanations of the dentist.

The work also has a highly cooperative nature in regards to the actions of the dentist, assistant and patient. Whereas the overview above focuses on the activities of the dentist and patient, if the focus was instead on the activities of the assistant, we would see a slightly different sequence. Looking at how these sequences fit together starts to give a better impression of the cooperative nature of the work. For instance, that the assistant’s preparation of the space and materials anticipated and fitted subsequent activities of the dentist, or that the dentist used the time where the assistant was developing the x-rays to begin a preliminary examination of the teeth and how when she brought the developed x-rays in, he immediately moved to include them in his examination and discussion with the patient. The work of the dental examination is more a cooperative weaving of strands of activity than a linear sequence of actions. This weaving is also apparent in the moment-to-moment actions and interactions of the dentist, patient and assistant as they respond to the unfolding situation. The role of gesture in the coordination of these different activities is examined in the section following the next.

5.3 Tooth gesturing

Dentistry involves the integration of a range of partial, sometimes partially overlapping stories, indications and views of the teeth of the patient. To build a picture of a tooth, the dentist examines its visible surface, inspects x-rays of the inner structure, *feels* it with the tip of the probe, consults its history as recorded in the patient record and listens to descriptions of the patient’s experiences. The building of this picture is a gathering of various partial lines of indication that sometimes contradict or pull in different directions rather than a straightforward extraction of information. The pictures that the dentist builds and the lines that he or she follows are built in the service of the larger work of the examination. They open up for treatments to be justifiably pursued or deferred.

A significant part of the process of building of these pictures is for the dentist to make them visible and understandable to the patient. Gestures are one important part of how dentists do this and this 'tooth gesturing' forms one of the most striking uses of gesture in the dental examination. This section details the use that the dentist made of gestures when describing aspects of the teeth and mouth for the patient. The dentist from this surgery was especially adept at this and watching him gesture in this way was one of the distinctive qualities, which led me to see dentistry as an interesting context in which to pursue my research project.

The initial reason these gestures appealed to me was because I had an existing interest in the possibilities of developing a gesture interface to support the work of dentistry and here were clear instances of gesturing about teeth and other parts of the mouth. They also stood out for their dynamic qualities and their scale. They had a clear and practiced quality, which I will argue derives from being part of a *repertoire* of gestures and movements about the teeth and mouth from which the dentist can draw.

As I spent more time observing, discussing and designing for the work of dentistry, I also came to see these gestures as part of the larger task of *patient education*, an aspect of dentistry which all the dentists I spoke to talked about as a key part of their work. The idea of patient education relates both to the longer-term public health functions of informing patients about how to take care of their teeth, and to shorter-term need for shared understanding, cooperative work and decision making within the course of a dental examination. Thus, the notion of educating the patient can be as much about helping him or her to understand why a particular course of treatment is justified as about imparting more general knowledge about the functioning of the teeth.

In the examples that follow, I will try to give a sense for the roles that these gestures play, their forms and the variety of gestures that comprise them. I wish to show how these gestures help the dentist make hidden structures of the tooth and jaw visible, relate them to the experience of the patient, other information resources in the dental surgery and draw motivation for the ongoing work of the examination.

5.3.1 A Molar tooth has three roots

In one case, the dentist demonstrated the shape of a molar tooth and explained how this, combined with the angle that the x-ray was taken from, corresponded to the image of the tooth recorded on the x-ray film. This explanation was prompted by a question from the patient over whether the tooth would not be getting sensitivity because the root of the tooth had been filled in an earlier dental procedure.

Excerpt 2: The dentist described the shape of a molar tooth.

Frame 2.1 	D: No root, yeah - as far as I can tell. The uh, a molar tooth has actually got three roots (turns back to patient and holds LH up with the fingers pointing down to imitate a tooth and makes a beat on 'roots').
Frame 2.2 	D: You've got two that are superimposed over each other if you're looking at it from the side (RH indicates a viewing plane), which we do (RH points to x-ray) on the x-ray.
Frame 2.3 	D: The large back root (RH points to 'back root'), towards the back of the mouth (RH points to own mouth).

Frame 2.4 	D: Um, (turns to x-ray) so on there (LH points to x-ray)…
Frame 2.5 	D: …we can only really see the (turns back to patient and clasps hands in front) two (makes circular shape with both hands) root canal (beat) fillings (beat), um, but (back and forth gesture) but we should (LH partially makes tooth shape) actually see three. But we can't (makes back and forth gesture with both hands) tell if (LH flat and starts 'counting off' with RH) they've missed one, or that they're just superimposed (back and forth gesture) over each other (turns to the x-rays).
Frame 2.6 	D: (turns back to the patient) We, then, what we would do is take an x-ray (RH indicates plane of x-ray) from a slightly (beat) different (beat) angle.
Frame 2.7 	D: We, we're (looks at x-rays then back to patient) deliberately doing it from (LH tooth, RH indicates angle) square on…

Frame 2.8 	D: (looks back to x-ray & points with LH) …so that we can see the contact.
Frame 2.9 	D: (Looks back to patient.) So that there are no overlapping teeth (makes 'tooth' gesture), there.

In this sequence, the dentist used his left hand to stand for a single molar tooth while talking about it and gesturing to it with his right hand. He held down his thumb, index finger and middle finger of the left hand to show the positions of the roots of the tooth (Frame 2.1). Then he used his right hand to indicate how these relate to the angle that the x-ray was taken from. He indicated the angle of the x-ray with his right hand by holding it flat pointing into the tooth from the side (Frame 2.2). He next pointed to the thumb of his left hand, which represented the third root of the molar tooth and showed that this is oriented towards the back of the mouth, emphasising this by pointing to the side of his own mouth (Frame 2.3).

Next he released his left hand from the shape of the molar tooth and turned to the x-ray, referring to it both verbally and with a pointing gesture (Frame 2.4). He turned back to the patient with his two hands clasped in front of him. At this point, his gestures took on a different dynamic quality, with a more rapid succession of gestures, as he explained to the patient that one of the roots was hidden from the angle that the x-ray was taken. Some of the gestures in this part (e.g. the 'back and forth' gesture) are difficult to interpret but seem to correspond to the idea that there is ambiguity in how the x-ray could be interpreted (Frame 2.5). He explained that to get an image of the back root on the x-ray they could take the x-ray from a slightly different angle and made a deictic gesture directly at the patient's face showing the angle (Frame 2.6). He then held his left hand representing the line of the teeth in the jaw and his right hand indicating the x-ray angle and explained that they deliberately take the x-ray from square on with his right hand indicating the angle (Frame 2.7) before pointing back to the x-ray picture (Frame 2.8) and finally making a gesture to show the teeth overlapping (Frame 2.9).

This sequence of gestures began with the dentist introducing the iconic gesture of the shape of the tooth, which he then performed a number of deictic gestures around with his other hand to introduce the different parts of the tooth and relate to the x-ray (Frames 2.1 – 2.3). This initial iconic gesture stood out from the other gestures that the dentist made in several respects. Firstly, it was maintained it for 12 seconds, which was a long time compared to the other gestures that the dentist performed. Secondly, the dentist changed his position and posture to make the gesture and held it up high almost at the level of his face, where the patient could see it (compare the angle of the dentist's left arm in Frame 2.3 where his elbow is held up at shoulder height with the angle of his arm in Frame 2.5 where his elbows are at his sides). The scale of the gesture was also large in comparison to what the dentist was describing (a single tooth)

The dentist's explanation of the shape of the tooth did not rely on the gestures alone. He also referred back to the x-ray film, to the angle that the x-ray was taken from and to his own and the patient's mouth. The role of the initial iconic gesture of the molar tooth in relation to these other resources seems to be that it provided a central image around which these items of information could be related and made coherent.

The dentist was talking about this tooth in particular, because there had emerged a discrepancy between the patient's experience of pain and the indication that the tooth had lost its nerve. By showing the structure of the molar tooth and explaining how one root can be hidden from the x-ray, the dentist was able to accommodate the experience of the patient with the divergent indications of the tooth and x-ray, because as he explained, there is the possibility that the back root was missed in the root-canal (Frame 2.5). The gesture also formed the basis for further actions and possibilities, such as when the dentist explained that they could take the x-ray from a slightly different angle (Frame 2.6). Later in the examination, the dentist and assistant used a cold-pellet test to allow the patient to experience herself that the tooth had no feeling and in fact had lost its nerve (section 5.4.3).

5.3.2 Clicking of the Jaw

In a second example of tooth gesturing, the dentist explained to the patient what caused the clicking of her jaw. In this sequence, the dentist used his two hands and arms to represent the jaw joint. One hand represented the ball of the jaw and the other represented the socket that the jaw sits into. He then described a cartilaginous disc that sits between the ball and socket. Next, he showed how the jaw joint moves when the mouth is opened and pointed out that it not only rotates, but also translates. As he talked about the movement, he made gestures that illustrated what he was saying by first changing the angle of his forearm and then moving the position of his arm.

Excerpt 3: The dentist explained the cause of the clicking.

Frame 3.1 	D: The reason why you get clicking is you've got the, (holds up RH in fist) the, the um, jaw, comes up (RH beat) into a ball, essentially.
Frame 3.2 	D: Which sits (cups LH over fist) into a socket (LH beat).

Frame 3.3 	D: Um, in between that ball and socket (RH thumb & forefinger indicate thin surface between ball and socket) there's a disc (RH repeats), (lowers hands) a cartilaginous disc. (**Note:** In the image, the dentist is holding his forefinger and thumb in a pinch posture to show the position of the cartilaginous disc).
Frame 3.4 	D: (Brings hands back up into ball and socket.) Now when you open your jaw, it doesn't just rotate (RH rotates down then back)…
Frame 3.5 	D: …it rotates (RH rotates down) and then translates (moves RH fist), then moves (repeats movement) down this slope (repeats movement).
Frame 3.6 	D: (Brings hands back into clasp). Um, you've got a, (RH claw shape) a ligament, which pulls (RH pulling) that jaw forward (repeats) and also (RH beat) pulls this disc forward.

Frame 3.7 	D: And, because you're getting a click on opening (points to his own mouth), um, it, the, the disc is not moving at the same rate as the, the jaw, ah jaw. P: Oh, okay
Frame 3.8 	D: So it actually runs over the edge of that disc and just causes a little click (makes repeated gesture showing jaw running over edge) as it um hits that edge there. You're not getting any pain (beat), so there's no inflammation (beat), nothing to really worry about at the moment (sits back on his chair).

In this example, the dentist's gestures established a set of spatially related images within which to explain the movements and relations of the various parts of the jaw. As with the 'molar tooth' sequence of gestures, the scale and positioning of the gestures in this sequence stood out from other gestures that the dentist made. Once again, he changed his position and posture and held his hands up high so they would be visible to the patient. The scale of the gestures was again large in comparison to what they represented (a jaw joint).

The dentist began the sequence of gestures by introducing and relating the two main parts of the jaw that his explanation was built around: the ball (Frame 3.1) and socket (Frame 3.2) of the jaw joint. Similar to the molar tooth example, he maintained his right hand in the position of the ball of the jaw for 10 seconds when first introducing it. Once he had established this, he went on to describe other more complex or subtle spatial relations. He established continuity with these gestures that subsequent gestures built upon. For example, when he introduced the cartilaginous disc into the picture (Frame 3.3), he used his right arm, which had been acting as the jaw. He kept his left hand in place acting as the socket and traced the position of the disc between this and the ball. Similarly, when he described how the ligament pulls the jaw forward (Frame 3.6), he made a gesture for the ligament that corresponded to where the position of the jaw joint had been and maintained the orientation of the previous gestures. By positioning new gestures relative to the positions of previous gestures, the viewer is able to relate the new gesture to the now remembered position of the previous gestures.

In contrast to the 'molar tooth' example, the dentist did not use gestures to draw other information resources such as the x-rays into the explanation, but he did once again gesture to his own mouth. Having established this picture of the mouth in the air, the dentist then gestured to his own jaw when he talked about the patient's mouth. The dentist said "…you're getting a click on opening…" and held his hands to either side of his own mouth (Frame 3.7). This indication to the mouth had the quality of a kind of punctuation in the description and served to relate the gestural image of a jaw back to an actual jaw.

We can also see from the excerpt that the explanation is delivered with a diagnostic purpose. The dentist ended his explanation by telling the patient that because there was no inflammation or pain, there was 'nothing really to worry about at the moment' (Frame 3.8). This is not a bare explanation of the cause of clicking, told in relations and movements of the parts of the jaw, but one delivered with a particular purpose within the context of this examination.

This highlights a danger that in presenting and analysing this sequence of interaction as a vignette, it will be seen in isolation from the other events of the examination. This sequence of gesturing is situated within the 'comprehensive check' part of the examination and was immediately preceded by the dentist's placing his hands on either side of the patient's jaw and asking her to open and close her mouth, an action by which both the dentist and the patient were able to feel the clicking of the jaw. This seems significant, given that the dentist had actually already noted that the patient was getting a click on her jaw joint earlier in the examination when he was placing the x-ray film in to her mouth, yet he did not stop and explain the clicking at that point. Due to the regularity of the actions comprising a dental examination, an explanation of the clicking of the jaw *has a place* in the overall structure of an examination, because there is a standard sequence of checks that the dentist makes during the comprehensive check, starting with the jaw joint, then the glands, gums and then on to the teeth. This is an example where the work of educating the patient does double-duty. It both informs the patient of the underlying longer-term reasons for the clicking of the jaw and relates back to questions that had arisen within the short-term context of the examination.

5.3.3 Pro-gnathic retro-cline pattern

Shortly after, during the 'comprehensive check' part of the examination, the dentist and assistant made a note in the patient record that the patient's teeth had a 'Pro-gnathic retro-cline pattern with class 1 anterior occlusion.' Immediately following this entry into the computer, the dentist turned to the patient and explained that this means that the patient's teeth are sitting slightly back in the mouth, but that she is still getting a good bite. In this case, rather than representing a single tooth with his gestures, he used his whole hand to represent the plane and angle of the teeth.

Excerpt 4: The dentist explained the meaning of pro-gnathic retro-cline pattern.

Frame 4.1 	D: (Looking at computer.) Okay, um (glances at assistant), pro gnathic, that's g-n-a-t-h, pro-gnathic pattern with retro-cline lower anteriors giving class 1 anterior occlusion. (Continues looking at computer screen).
Frame 4.2 	D: (Turns to patient.) Okay, what that's saying is that your lower jaw (RH c-shape around own chin) has a tendency (brings RH back to chin and nods head forward) of being a little further forward than the (removes RH from chin and holds it flat pointing down) classic, um, convex (RH beat) profile (moves RH closer to his face).

Frame 4.3 	D: So the (RH grips chin again), your teeth then are compensating for that by (RH flat in front of him and brings LH up near it) instead of the lower teeth sitting slightly forward…
Frame 4.4 	D: …they're sitting slightly back (angles RH back)…
Frame 4.5 	D: …and allowing (brings LH flat to meet RH) a good bite (moves hands back and forth over each other). So that means you've got, (moves hands back to either side of his jaw) P: […] (overlapping speech)
Frame 4.6 	D: …but you've got a good (points index fingers while keeping hands beside face) um, bite on the molars, and so that's giving a very good (LH retraction) ah, overall (RH beat) bite there. (RH indicates how the teeth are angled back.)

In this example, the dentist used his gestures to represent planes of teeth, rather than an individual tooth or part of the jaw as he did in the first two examples. He did this by using his two hands, held flat with the fingers together to show the angle of the teeth. Then by angling his hands forward and back, and changing the curve of his fingers, he showed how these planes related to the mouth of the patient and compared to a more classic profile (Frame 4.2). For example, where he said, "a little further forward than the classic … convex profile", he held his hand up with the fingers slightly cupped describing the shape of the classic profile. Continuing on, when he talked about the patient getting a good bite, he first held his right hand angled forward as he said 'slightly forward' (Frame 4.3), then when he said 'slightly back' he angled his hand back (Frame 4.4) and finally brought his other hand up over the top and said 'allowing a good bite' as he moved the fingers of his hands back and forth over each other (Frame 4.5). As with the previous two examples, he again gestured to parts of his own mouth corresponding to parts of mouth that he was talking about. For example when he said, "what that's saying is that your lower jaw", he touched to his lower jaw (Frame 4.2). The synchrony between the words of the dentist and the shifts in the shape and position of his hands is striking. The dentist coordinated the positioning of his hands to show the various planes and angles of the teeth with the accompanying speech so that each reinforced the other.

As with the 'clicking of the jaw' example, the dentist ended his explanation by telling the patient that although the angle of her teeth is slightly different to the 'classic convex profile', they are still '…allowing a good bite.' Once again, the sequence of gesturing does work in the examination by supporting an explanation and interpretation. The dentist is furnishing the patient with a description of some aspect of her teeth along with a judgement of whether further treatment is warranted. A difference between this example and those discussed so far is that here, the explanation was made in order to translate the technical language of dentistry into terms understandable by the patient. This is in contrast to the previous two examples, where the explanation served to give visible gestural form to otherwise hidden aspects of the teeth or jaw. There are therefore different reasons for making explanatory gestures, sometimes they serve to make visible hidden structures of the teeth and sometimes they serve to translate the opaque terminology of dentistry.

5.3.4 Demineralisation

The dentist also used gestures to help explain internal structural aspects of the teeth. In the following excerpt, he explained the process of demineralisation to the patient and explained how this would result in the tooth developing cracks along its side. This example differs from the other ones presented in that it does not begin with a clear central iconic gesture that is elaborated with other gestures, but instead a more rapid succession of gestures of a less iconic nature (though still with some iconic elements).

Excerpt 5: The dentist discussed the effects of demineralisation.

Frame 5.1 	D: Now the cracking (RH indicates left side of patient's mouth) on that left hand side… (RH retraction)
Frame 5.2 	D: …is (counting gesture), partly, is partly to do with the forces of course (hands in C shape moving in and out), partly to do with the fact that (counting beat) it's got a fairly large filling,
Frame 5.3 	D: …but mostly (counting beat), um (hands back into opposing C's) that in conjunction with that fact that…
Frame 5.4 	D: …the tooth (counting beat) has lost its nerve.

Frame 5.5 	D: Um, and so the organic (hands in C's) component of the tooth, (counting gesture) the tooth is made up of collagen (C's beat) with a (RH makes circles around stationary LH) mineral matrix (both hands in C's) around it.
Frame 5.6 	D: Um, and so the collagen (counting beat) component without the blood supply (RH dips down and up) to keep that (beat) um, healthy, um (hands in C's) deteriorates…
Frame 5.7 	D: …and the tooth becomes more, a hard (beat), um (counting gesture) brittle (beat) mineralised (C's) structure (fingers and thumbs of hands come together) there.
Frame 5.8 	D: So (beat) any forces (C's) then not being (beat) absorbed (beat) by that suppleness…

Frame 5.9 	D: …and (RH chopping) tend, you tend to get little cracks within the tooth structure.
Frame 5.10 	D: Um, (counting gesture) pretty straightforward, as we discussed last time, the way to do that, the way to treat that one, eventually is to put a crown over it (hands showing the crown surrounding the tooth) and in fact (counting beat) what we would do, since you've had a root filling…
Frame 5.11 	D: …is to put a core (hands in cylinder) inside that tooth. Um, that core (beat) is a solid metal core with (RH finger points downwards) posts going down into the root, into the root canals. And we would probably put (pointing beat) posts down all the canals if we could. And then ah, and then put a crown (beat) over the top there.
Frame 5.12 	D: But that's, ah, something that we don't have to deal (counting beat) with now. Things are (points to the x-rays) otherwise looking really really good.

In this excerpt, the dentist began by pointing to the cracked tooth on the side of the patient's mouth and saying "Now the cracking on that left hand side" (Frame 5.1). As he continued talking, his gestures alternated between a 'counting' gesture where he held first two fingers of his right hand in the palm of his left hand as he listed a series of steps that could be taken in relation to the tooth (Frame 5.2, 5.4, 5.10, 5.12), a 'facing c shapes' gesture where he held the thumbs and fingers of his two hands together so that together his hands made a circular shape (Frame 5.3, 5.5, 5.8), and several beat gestures, superimposed over both the counting gestures and the 'facing c shapes' gestures.

An interesting aspect of this vignette is that the kind of gesturing that the dentist engages in is less iconic than the other tooth gesturing sequences discussed so far. The facing c shapes gesture seems to mainly be a metaphoric gesture at the outset of the excerpt, perhaps embodying the concept of solidity or a structure, which is what the dentist is talking about. However, in the later parts of the excerpt, the dentist seemed to begin to employ the facing c shapes gesture in a more iconic way, as standing for a tooth. For instance, in Frame 5.6 he maintained his left hand in a c-shape and then rapidly gestured down and up with his right hand in time with his mention of the blood supply to the tooth. Similarly, he made a chopping gesture with his right hand while holding his left hand in the c-shape when mentioning the development of cracks in the tooth structure (Frame 5.9). When he described the procedure of inserting a core into the tooth, he pointed down with the index finger of his right-hand into the middle of the c shape of his left hand (Frame 5.11).

The gesturing in this case seems closer to the kind of 'spontaneous idiosyncratic communicative movements accompanying speech' described by McNeill than the more 'rehearsed' gestures presented so far. A salient point in this respect is perhaps that in this example the dentist describes an internal, structural characteristic of the tooth, whereas in the preceding examples the gesturing was about aspects of the teeth that had a more obvious iconic referent. One can imagine that it is easier to make an iconic gesture about the physical shape of a molar tooth than an internal chemical process such as demineralisation.

5.3.5 Gesturing to explain, explaining to educate

In this section, I have presented four excerpts where the dentist used gestures to help explain aspects of the teeth or jaw to the patient. The gestures comprising these sequences are recognisably gestures in the everyday sense of the word as well as the sense taken by gesture researchers such as McNeill. The gesturing was communicative in purpose, it was integrated with the accompanying speech and it included instances of gesture from all the categories in McNeill's taxonomy (iconic, metaphoric, deictic and beat) (McNeill, 2005). Elements of the gestures that were important for the meaning such as the posture of the hands, rhythmic qualities of the gesture and indexing of gesture to elements of the material setting are also familiar from other studies of conversational gesture. Yet they also have some distinctive characteristics, which led me to distinguish them as 'tooth gesturing'. To conclude this part, I present my reasoning making this distinction.

One distinctive characteristic of examples of tooth gesturing was their scale and positioning. They were quite large, both in comparison to what the dentist was describing and also the other gestures he made when talking to the patient. In three of the cases, they began with clear iconic gestures of parts of the teeth or jaw, which were maintained in position and elaborated with other gestures or deictic references to the environment. Also, the gestures had a practiced quality, especially the sequences of gestures about the shape of a molar tooth and the movements of bone, ligament and cartilage that cause the clicking of the jaw. It is reasonable to assume that the dentist would be called upon to give explanations about features such as these on a regular basis and thereby develop a repertoire of gesture elements to support him in this. These are significant findings of the analysis and are discussed in greater detail in the next chapter.

Sequences of tooth gesturing were also positioned within, related to, and supported by the temporal arrangement of activities of the examination in distinctive ways. The way that the dentist, in shifting from examining teeth to explaining concepts, moved to the side of the patient and changed his posture both served the practical purpose of making the gestures more visible and also helped make sequences of tooth gesturing recognisable as such because of the contrast between this posture and the other postures of the examination. Tooth gesturing also related to the preceding and subsequent events of the examination in particular ways. A good example of this was how the dentist's explanation of the shape of a molar tooth accommodated the preceding report by the patient of her experience pain with the divergent indications of the teeth and the x-rays and justified for the subsequent cold-pellet test. This sequence of gesturing sits within a stream of activity with the preceding events of the patient relating her experience of pain, the dentist's taking of the x-rays of the teeth and his examination of the teeth and the subsequent activities of the cold test and the dentist and patient's discussion of that.

Tooth gesturing also supports an important aspect of the work of dentistry, which dentists I spoke to referred to as 'patient education'. Dentists explained that beyond treating the teeth of the patient, it was also necessary to help patients understand the concepts of dentistry and what was happening with their teeth. The examples above provide further evidence for this, since they demonstrate the time and care the dentist took to explain the meaning of difficult terminology and describe hidden structures of the teeth and jaw. I have also discussed how these explanations served to open up for subsequent investigations or presented justifications for not pursuing treatment. Patient education is done for the purpose of making the patient more knowledgeable about their teeth, so the patient can be in control of their teeth, can take better care of their teeth, and also so the patient can understand why a particular treatment might be necessary or not. This also has a direct relation to the business of dentistry, because if a patient does not understand the necessity of a potentially expensive treatment, they may be more inclined to defer treatment and vice-a-versa if they do not understand why a symptom of the teeth does *not* require treatment, they may leave the examination with a worry that a problem with the tooth has been left untreated.

5.4 Coordinating gestures

The previous section dealt with the gestures that the dentist makes when explaining aspects of the teeth and jaw to the patient. In addition to this mostly individual work, there is a lot of work in the dental examination that requires a high degree of cooperation. The examination under consideration involved the actions of three active participants: a patient, a dentist and an assistant. This was typical of other surgeries that I visited, though there was some variation. In one surgery, the dentist often carried out examinations unassisted, whereas in another two assistants would sometimes be involved. As a minimum, the dental examination always involves the cooperation of at least two people, a patient and a dentist and in this sense a dental examination is inherently inter-personal. It is work *on* a person, the patient, who is also an active participant *in* the work.

Gesture plays an important role in the moment-to-moment coordination of the work of the dental examination. From the excerpts and overview already presented, one may already glean an impression of how the work of the examination is divided between people. For instance, that the assistant left the room to develop the x-rays while the dentist carried out an initial examination with the patient, or that the dentist and assistant worked together in the patient's mouth when performing the scale and polish. However, we are yet to examine the detail of how these streams of individual activity are woven into a coherent collaborative performance.

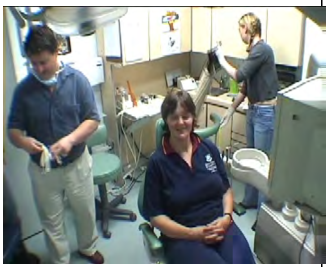
In my examination of the following excerpts from the dental examination, I work from the assumption that gestures are only one of a range of resources that people have available for coordinating their work and that the production and interpretation of gestures is bound up with all the other resources and actions available in the setting. I therefore do not restrict myself to only looking at gestures, but also to other aspects of the work that seem salient for the analysis such as speech, instrument use, sounds from the environment, gaze and posture. In line with the broad working definition framework, I will also take an inclusive view of what constitutes a gesture, including manipulative gestures as well as communicative ones.

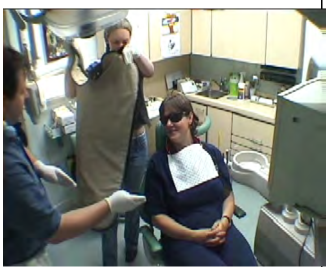
5.4.1 Some glasses for you

If one reflects on the helpless feeling of sitting in a dentist's chair, it may seem surprising to see the patient as an active participant in the work of the dental examination. Yet all the dentists I spoke to emphasised the importance of involving the patient in this way if the work was to be a success. This creates a challenge for the coordination of the work, because although the dentist and assistant might both be familiar with how each other work and the sequence of activities, the patient is a newcomer and needs to be guided through the process.

Neither the dentist nor the assistant was solely responsible for guiding the patient through the process of the examination, though they did assume different roles in relation to this aspect of the work. The dentist mostly took the role of communicating with the patient, whereas the assistant mostly did the work of preparing the surgery for upcoming procedures. The following excerpt shows how the dentist and assistant coordinated these different kinds of actions to get the patient ready to take an x-ray.

Excerpt 6: Preparing the patient for the examination.

Frame 6.1 	D: (Goes to back wall and pulls some surgical gloves from a dispenser) A: (Holding a lead apron, moves her chair a bit and drapes the apron over it.)
Frame 6.2 	A: (Picks up a bib from the bench and moves over to the patient.) D: (Moves back to the left side of the patient while beginning to put the gloves on.) Okay [patient], so you've had this raging toothache. A: (Puts bib around patient's neck.)
Frame 6.3 	P: Not particularly, but I do feel that it's a bit sensitive and I can't remember if I had x-rays before because I was pregnant? I think I didn't, or I wasn't sure if I had low, (right hand waves) low um radiation. But I didn't have any last time did I? D: No, you didn't have any last time [here]. A: (During this exchange, returned to the bench and picked up a pair of glasses and opened them as she turned back to the patient.)
Frame 6.4 	D: Okay, so we're just… A: (Extends her arm out to the patient's chest with the glasses) D: …going to be doing a check-up today. In particular (RH beat) having a look… look at that ah tooth on the left. Um, and just making sure that everything is okay. P: (Looking at D:) Yeah.
Frame 6.5 	D: Just got some glasses for you. (Points to the glasses that A: is holding) A: (Moves glasses forward a little more.) P: (Looks down at glasses and takes them) Oh, thank you.

Frame 6.6 	A: (Gets the lead apron from the chair.) P: (Looks back to the dentist.) If possible, I'd also like a scale and polish too. It's been a while since I had one. (Puts on glasses.) D: Okay, righto…
Frame 6.7 	A: (Still holding the apron, picks up x-ray film from the bench.) D: We've got about [40] minutes, so… A: (Hands x-ray film to the dentist.) P: All right, okay.
Frame 6.8 	D: Okay, so we're going to put a lead apron on here… (Two handed deictic to the apron and then to the patient).
Frame 6.9 	A: (Lays the apron down on the patient's chest.) D: ...and we'll start by taking (beat) some x-rays. A: (leaves the room by the right door)

The excerpt begins with the patient and dentist discussing the reasons for this visit (a toothache) and what had happened on a previous visit. Meanwhile, the assistant began assembling items to be used in the examination. After bringing in a lead apron and draping it over the back of a chair (Frame 6.1) and putting a bib on the patient (Frame 6.2), the assistant took some glasses from the bench, opened them and turned back to the patient (Frame 6.3). At this point, the dentist and patient were discussing whether the patient had received radiation on her last visit and the patient's gaze was directed toward the dentist.

The assistant waited with the glasses held in front of her until the dentist moved to the next part of the introduction. With his words, 'Okay, so we're just', the assistant moved the glasses forward toward the patient. However, the patient's gaze was still directed towards the dentist and she did not notice the assistant holding the glasses out (Frame 6.4). The dentist continued, saying that they would be doing a check-up and would pay particular attention to a tooth on the left. The patient responded 'Yeah' and the assistant continued standing with the glasses held before her. Next, the dentist made an explicit reference to the glasses, saying "Just got some glasses for you" and pointed with his right hand toward the assistant. Simultaneously, the assistant moved the glasses forward a second time, slightly closer to the patient. The patient looked from the dentist down to the glasses, said "Oh, thank you" (Frame 6.5) and took them.

Immediately upon passing the glasses to the patient, the assistant turned away to get the lead apron from the chair and the patient looked back to the dentist and requested if she could also have a scale and polish (Frame 6.6). The assistant then picked up the x-ray film from the bench and passed it to the dentist as he told the patient that there was about 40 minutes in the examination, which the patient acknowledged (Frame 6.7). Finally, the dentist said that they were going to "put a lead apron on here" and made a two-handed deictic gesture towards the patient (Frame 6.8). The assistant laid the lead apron down over the patient's torso and left for the door as the dentist began explaining what would happen in the next part of the examination (Frame 6.9).

During this exchange, the dentist and assistant carried out different tasks. The dentist talked to the patient about what was to happen in the examination and the assistant assembled the items that were required for the first part of the examination (the lead apron, the bib, the glasses and the x-ray films). As the example shows, these streams of activity were not independent, but interwoven and mutually supporting. The assembly of items was coordinated to fit with the explanation of the procedure, which in turn made recourse to the assembled items for support.

One of the ways that the dentist and assistant coordinated their work here was to produce their speech, actions and gestures so they fitted together as a unified gestural performance. Consider how the assistant timed the presentation of the glasses to the patient so it coincided with the dentist verbally referring to them and making his own deictic gesture directing the patient's gaze to them (Frame 6.5). The words and gestures of the dentist *together with* the putting forward of the glasses by the assistant made clear that the patient should look down, take them and put them on. The fact that the assistant maintained her posture and position holding the glasses in front of her for some seconds before this presentation (Frame 6.4) is worth noting, because at this point the dentist had not made any mention of the glasses. The assistant's maintained posture evidences anticipation on her part that the glasses would become relevant to the conversation.

Another example of this unity of gesture, speech and actions between the dentist and assistant comes from where the assistant placed the lead-apron on the patient's torso in time with the dentist's verbal and gestural introduction (Frame 6.8). Though the coupling in this example of the actions of the assistant and dentist was not as tight as the previous example, there is still a clear coordination between their speech, actions and gestures. The most visible aspect of this was that at the point where the dentist said "okay we're going to put a lead apron here", the assistant was already standing behind the patient holding the lead apron. Then as the dentist finished his statement and made a two-handed deictic gesture to the torso of the patient, the assistant moved forward and laid the apron down over the patient (Frame 6.8). Consider also how the assistant ordered her presentation of the items for the patient to wear. Although she brought out the lead apron before the bib or the glasses, she kept it aside (Frame 6.1) and did not give it to the patient until the bib and glasses had been put on and the dentist was ready to introduce it.

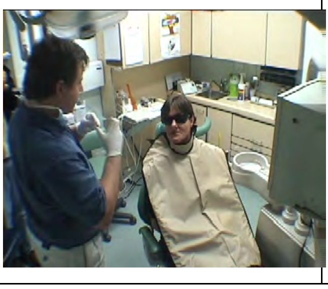
Interestingly, this level of coordination did not seem necessary for when the assistant put a bib around the patient's neck (Frame 6.2). In this case, the conversation between the patient and dentist carried on independently of the actions of the assistant with the dentist making no verbal or gestural reference to the bib. A likely reason for this is that the lead apron is more physically obtrusive and therefore warrants a more explicit signalling from the dentist to the patient, whereas the bib can be slipped on without disturbing the ongoing interactions between the dentist and patient.

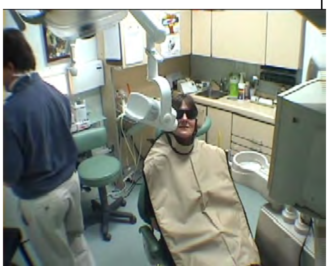
The fine coordination between the speech, actions and gestures of the dentist and assistant is even more startling if we recognise that they did not speak directly to each other *at all* during the excerpt. The dentist only spoke to the patient and the assistant did not speak at all. It seems reasonable to propose that the dentist and assistant are able to coordinate their actions in such a unified way because of a shared familiarity with the work of the dental examination. This highlights an important aspect about the gestures we find in dentistry that distinguishes them from the gestures of everyday conversation. The regularity of dental procedures and dental practitioners' familiarity with the work provides a shared frame around which they can organise their gestures and anticipate one another's actions more than might be possible for people engaged in everyday conversation. Speech and gesture play an important role in cueing these coordinated actions, but these cues are *anticipated*, which is a key difference from interactions around more spontaneous conversational gesticulations.

5.4.2 Just get you to bite down

The next excerpt shows the part of the examination where the dentist explained to the patient how the x-ray would be taken and showed her how to hold the x-ray film in her mouth. It continues from immediately after the events discussed in the previous example. This excerpt shows how the dentist made use of the physical affordances of the x-ray film to explain to the patient what her actions should be. It also shows how the dentist oriented his gesturing so that it corresponded to the patient's orientation when biting down on the x-ray film.

Excerpt 7: The dentist positioned the x-ray.

Frame 7.1 	D: We'll take (beat) diagnostic (beat) x-rays of the left (deictic) and the right (deictic) um, to see (two handed iconic of teeth?) in particular what's going on underneath (slicing gesture) any fillings if there are any and (iconic) in-between (beat) the teeth. P: Yeah.

Frame 7.2 	D: (Takes the x-ray film which he has been holding in his LH and rotates it using both hands while looking down at it). When I take the x-ray (transfers x-ray film to RH and extends it towards the patient.) I'll just pop (RH holding film, left hand iconic of teeth biting) that in… P: Okay. D: ...and just get you to bite down (repeats iconic) on that little… P: Uh-hum. D: ...cardboard tag there.
Frame 7.3 	P: (Opens her mouth). D: (Positions the x-ray film in between her teeth). And then that sits right in there, wonderful.
Frame 7.4 	D: (Turns to the wall and pulls the x-ray arm towards him. He leans over and positions the x-ray tube next to the patient's mouth.) I'll just angle this. Just keep your head still there, just wherever it's comfortable. (Adjusts the position a little, then stands back leaving the x-ray tube next to the patient's mouth.)
Frame 7.5 	D: Great, we're just going to run away. (Leaves the room by the door to the left). (There is a beeping sound).

The excerpt begins with the patient seated upright in the dental chair wearing the lead apron. The dentist stood on her left side facing perpendicular to the chair and described what kind of x-rays they would take, how these would relate to the patient's teeth and what he expected to see with them (Frame 7.1). The dentist made several gestures accompanying this speech. He made beats accompanying the words 'take' 'diagnostic' and 'between' and deictic gestures accompanying the words 'left' and 'right'.

Next, the dentist showed the patient how she should bite down on the x-ray film and how it would be placed in her mouth. The dentist was careful in his explanation of this to perform his gestures around the x-ray film in an orientation that would align with the patient's jaw. Before making the iconic gesture showing how the patient should bite down with her teeth, the dentist paused and looked down at his hands, where he had been holding the x-ray film in his left hand. He rotated this with both hands and then switched it to his right hand. He moved closer to the patient and extended his right arm holding the x-ray film so it was in front of the patient. In his hand, he held the x-ray film in the same orientation as if it were in her mouth. Once the x-ray film was in the right orientation, he indicated how the patient should bite down on the cardboard tag of the film by bringing the index and fore fingers of his left together like teeth. Again – in order to perform this gesture, he rotated his left hand so that his fingers were 'opening' in the same orientation as the patient's jaw (Frame 7.2).

The patient then nodded, said 'Okay' and opened her mouth. The dentist moved closer and guided the film, which he was still holding in his right hand, into the mouth. When the film was in place, the dentist said "…that sits right in there. Wonderful" and moved his hands away (Frame 7.3). Finally, the dentist positioned the x-ray tube next to the cheek of the patient and then left the room for the x-ray to be taken (Frame 7.4, 7.5).

In contrast to the previous excerpt where the dentist and assistant coordinated their actions in a highly fluid way without speaking directly to each other, the dentist here made more explicit use of speech and gestures to explain to the patient what she needed to do. A salient point of difference between the examples is that whereas the dentist and assistant are working daily with each other in the dental surgery, the patient only visits occasionally. These varying levels of familiarity with the work mean that it takes a different kind of interaction for the dentist to coordinate with the patient as a participant in the examination.

Though the gestures described here clearly serve a communicative purpose and are similar to the kinds of communicative gestures studied by gesture researchers, they also have some distinctive characteristics that are worth highlighting. The really interesting point about this sequence of gestures is that it shows how the communicative gestures of the dentist are organized around physical affordances of the artefact of the x-ray film and the practical action of the patient biting down with her teeth. The artefact of the x-ray film served to scaffold both the gestures of the dentist and the physical actions of the patient and thereby provided a bridge between the dentist's gestural explanation and the actions that the patient needed to make. This had an important implication for how the dentist organized his gestures, because he needed to bring them physically into an alignment that related to the body and physical actions of the patient. When the dentist showed the x-ray film to the patient, he positioned the film directly in front of her mouth and in the same orientation as it was to be placed in the mouth. This served to establish a spatial correspondence between the position of his gestures mimicking the teeth, the teeth themselves and the action that the patient would need to perform with them.

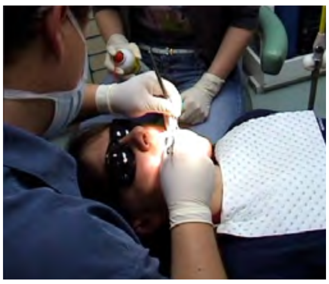
Another example of the relation between the positioning of artefacts, gestures and actions from this excerpt is where the dentist positioned the x-ray tube next to the cheek of the patient. Here the patient must remain still while the x-ray is taken (Frame 7.5). In this respect, the dentist's positioning the x-ray tube at a comfortable angle for the patient gives her a bodily reference for the position she needs to maintain (Frame 7.4).

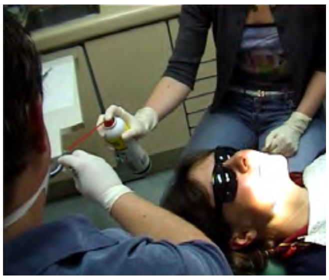
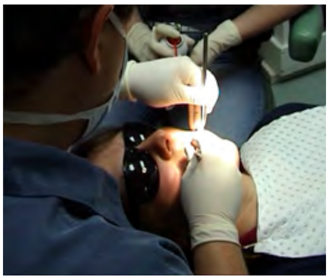
5.4.3 Cold-pellet test

During the examination, a discrepancy emerged between the patient's experiences of pain on a particular tooth, what the x-rays revealed about the inner structure of the tooth and the dentist's observations of it. The patient had reported pain on one of her molar teeth, yet the x-ray showed that this tooth appeared to have had its nerve filled in. Also, the examination showed that there was a gap in the patient's bite on that side of the mouth, so the dentist said that he would expect the other side of the mouth to be having problems. The dentist decided to perform a cold pellet test to verify that the tooth had no nerve left.

This procedure is not part of a routine examination. It was included in the examination in response to specific observations and discrepancies that became apparent within the examination. Yet a cold pellet test is not an unusual or rare procedure either. When the dentist requested the test, the materials for it were close-at-hand on the bench behind the assistant and the dentist and assistant were able to quickly prepare and perform the test. The following extract describes how this test was carried out.

Excerpt 8: The dentist and assistant performed a cold pellet test.

Frame 8.1 	D: (Looks at the assistant) [Assistant], could I please have the cold pellet test. (Gets something from the bracket table and waits as the assistant prepares the cold test). A: (Turns to the bench and gets some items). D: (Holds out LH, palm up).
Frame 8.2 	D: We're going to use some circuit freeze. A: (Places something in dentist's upturned hand).
Frame 8.3 	A: (Shakes aerosol can). D: (Picks up the item that the assistant put in his hand with tweezers). D: (Holds out RH with tweezers). A: (Sprays tweezers). D: Thank you.
Frame 8.4 	A: (Takes away the aerosol can) D: (Goes to the patient with the mirror in LH and tweezers in RH.) Now I'm going to pop this on the tooth in front of that one at first. That should give you an idea of what you should be feeling. (Places instruments in patient's mouth). And as soon as you feel the cold. P: Mmm-hmm.

Frame 8.5 	D: Yep, good. (Removes the cold-test from the patient's mouth and holds it up for the assistant to spray it). A: (Sprays the pellet).
Frame 8.6 	D: (Goes back to the patient's and puts the pellet into the mouth). D: (Still holding the pellet in place, changes his head position to look at the patient). Nothing? P: Uh-uh. D: Fantastic. (Removes the cold pellet).
Frame 8.7 	D: Okay (removes the instruments from the patient's mouth) great. (Looks at the assistant) that's fine. A: (Puts aerosol can back on bench). D: Okay, well (reaches over to the bench and drops the pellet from the tweezers) no response to the cold, (reaches to the bracket table and puts the tweezers down) cold test there, so… P: Okay, that's good.
Frame 8.8 	D: ...you, the, it's either been filled, the nerve has been taken out and it's not been filled, or the nerve is totally dead and it... P: Okay. D: ...[inaudible] under there. (Puts mirror down).

On the surface, the interaction of the preceding excerpt may seem rather mundane. The dentist held something out for the assistant to spray, placed it against one of the patient's teeth and then repeated the same action for the tooth beside. Yet if one takes a little time to look at the detail of the coordination of the movements of the dentist and assistant, one can see that there is actually an astounding depth and intricacy in these interactions. To illustrate, the next paragraph describes in detail the interactions between the dentist and assistant for approximately the first 30 seconds of the above excerpt (Frames 8.1 – 8.3). In this part, the assistant gave the cold pellet to the dentist, which he then held out as the assistant sprayed it.

The dentist began by turning his head to the assistant and asking, "…could I please have the cold pellet test." At this point, he was sitting with both arms low and relaxed. He held the mirror in his left hand and his right hand was free. The assistant left the computer mouse on the bench and then turned to the wall behind her where she began gathering items for the test. Meanwhile, the dentist looked over to the bracket table and took a pair of tweezers from it with his right hand. He then looked back to the assistant as she continued getting items from the bench. Now the dentist held his left arm in the same position as before, but his right arm was bent at the elbow with the hand up and holding the tweezers. After a few seconds, the assistant turned and rolled her chair to the bench behind the patient. As she did this, the dentist lifted his left arm slightly and turned the hand palm up with the probe tucked behind his index finger (Frame 8.1). The assistant reached to a tray at the back of the bench with a pair of tweezers. She took a pellet from the tray and shook it with the tweezers over the tray then brought her hands back to the front of the bench. As the assistant drew her hands back, the dentist further lifted his upturned left hand so it was level with the edge of the bench. The assistant made an adjustment to the pellet with her left hand and then transferred it to the dentist's upturned left hand with the tweezers of her right hand (Frame 8.2). The dentist took the pellet from his left hand with the tweezers of his right hand. At the same time, the assistant put the tweezers from her right hand down on the bench, took the aerosol can she had placed there earlier and began shaking it. The dentist reached across his body with his right hand holding the pellet in the tweezers and dropped his left hand down. The assistant reached forward so the nozzle of the aerosol can was pointing at the pellet and sprayed it. The dentist held the tweezers still and the assistant sprayed them for a second or two until the dentist said "Thank you" (Frame 8.3). The assistant withdrew the aerosol can and the dentist turned to the patient to apply the cold pellet test.

This description highlights the way that our everyday uses of language to describe gestural interactions (e.g. 'the assistant gave the cold pellet to the dentist, which he then held out as the assistant sprayed it') elides much of the detail of the dentist and assistant's coordination of their actions. The action of spraying the cold pellet test was initiated verbally by the dentist explicitly asking the assistant for the "cold pellet test" and ended when he said "thank you", so the speech of the dentist plays an important role in the coordination of the activity here. What about the gestures of the dentist and assistant?

By examining this detail of the action, we can see that it isn't the case that the dentist asked for the cold pellet test and then waited motionless while the assistant gathered the materials. Rather, he progressively adjusted his posture and the position of his arms through a series of stages (Frames 8.1, 8.2) until he was at the position to receive the pellet when the assistant was ready to give it. The dentist's gradual adjustments of the position of his hand worked to establish a posture for the assistant to perform her actions in relation to and were simultaneously cued by the actions of the assistant. The gestures of the dentist and assistant were gradually brought together to establish a shared place within which cooperative actions could occur.

This anticipation and reciprocity of action is apparent again later in the excerpt where the dentist removed the pellet from the patient's mouth, reached back to the assistant and held it out so she could spray it again with the aerosol (Frame 8.5). Again, this was not a linear sequence of actions where the dentist first held the pellet out *and then* the assistant moved her hand forward to spray it. Rather, the assistant began moving her hand to the place where the pellet was to be sprayed as soon as the dentist removed the pellet from the mouth and started moving his hand back. The hands of the assistant and the dentist moved *together* to the place where the pellet was sprayed. There was a gradual convergence of postures, positions and movements that allowed for the preparation of the pellet for the test.

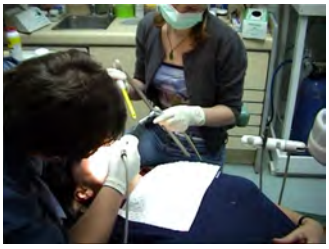
It should be clear that I am taking a broader view of gestures with the analysis of this excerpt. These are gestures that *request*: closely linked to the physical actions of passing and receiving objects. To take a more familiar example as a point of comparison, we could think of the kinds of gestures one finds around a dinner table. Consider the case where a dinner guest asks for an item and simultaneously reaches out their hand a little way towards the person that they have made the request of. There is then a gradual reaching together and adjustment of the posture of the hand as the item is picked up, brought forward and exchanged. In the sense that one can extend a hand that requests politely, or one that demands aggressively, these movements can be seen to have a gestural quality in addition to the practical action they perform of transferring an item. In the case of the dentist and assistant, the dentist extended his hand *upturned* and *relaxed* and brought it *gradually* to the position where a shared action could be performed. There is a feeling in this of showing a kind of patient, attentive, anticipation of the actions of the assistant, which is fitting with the cooperative atmosphere of the work.

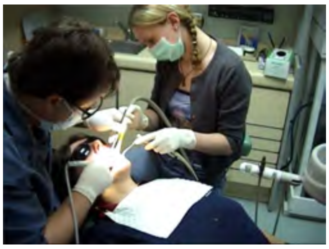
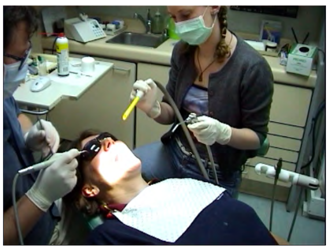
5.4.4 Four-handed dentistry

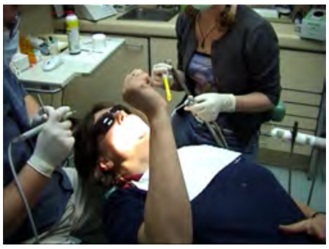
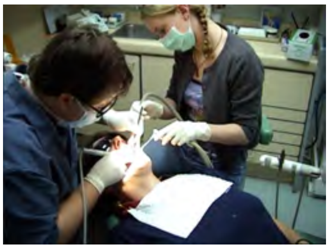
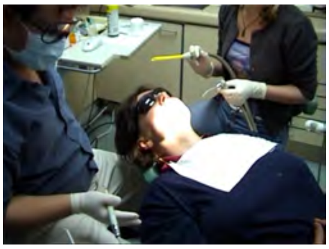
The cooperative nature of the dental examination and the deep role that the gestures of participants play within this is reflected in the terminology dentists use to describe the organization of the work. Dentistry involving one dentist and one assistant (such as in the videotape under discussion) is referred to as 'four handed dentistry' because it involves two hands from the dentist and two from the assistant. Similarly, if two assistants are involved with the dentist, it is referred to as 'six handed dentistry'.

This is a fitting way to describe the work of dentistry. It calls attention to the way that the movements of the different people must come together and work in unison in order to get the work done. A good example comes from the part of the examination where the dentist and assistant worked together to scale and polish the patient's teeth. In this part of the examination, the dentist and assistant sat on either side of the patient, with their gaze directed at the patient's mouth. Each held two instruments, which they had inside the patient's mouth. The dentist held an ultrasonic scaler and a mirror, and the assistant held suction and air instruments. The sound of the powered instruments in this excerpt makes it difficult to make out everything that was said. Inaudible speech is marked in the transcript with square brackets.

Excerpt 9: The dentist and assistant cleaned the teeth.

Frame 9.1 	D: (Goes back to the patient's mouth, first looking with the mirror then positioning the ultrasonic scaler.)

Frame 9.2 	D: (Withdraws the scaler slightly). A: (Places the suction and the air instruments in the mouth).
Frame 9.3 	D: (Puts the scaler back into position). D/A: (Work together in the mouth).
Frame 9.4 	A: (Removes suction and air instruments from the mouth). D: (Seems to be looking at the teeth on the side). [Inaudible]
Frame 9.5 	A: (Brings suction and air instruments back up to the mouth). D/A: (Work together in the mouth).
Frame 9.6 	P: [Inaudible]. D/A: (Remove instruments from the patient's mouth). P: (Closes and opens mouth).

Frame 9.7 	D: [Inaudible] bit of a catch 22 that one but... P: (RH gestures to her mouth). D: Yeah. (Throws his head back sharply). P: [Inaudible]. D: No, they've [inaudible] but [inaudible].
Frame 9.8 	D/A: (Go back to the mouth). D: (Still working in the mouth) Bit of a, a vicious cycle that's down there because the scale causes inflammation, which also causes recession, and exposes the root surface which allows scale to build up. D: Which causes more... P: Aha.
Frame 9.9 	D/A: (Remove instruments). D: ...and makes it very [difficult] to remove [there]. [That's fine]. (Extends RH fingers and makes as if to touch the patient on the shoulder). P: (Closes mouth).

A feature of the work of scaling and polishing is that the dentist and assistant gave the patient regular breaks so she could rest her mouth. The excerpt begins with the dentist re-positioning his instruments after one such break. He first looked with the mirror and then positioned the ultrasonic scaler in the mouth (Frame 9.1). Next, the dentist withdrew the scaler slightly but kept the mirror in position and the assistant placed her instruments into the mouth (Frame 9.2: this is difficult to see in the frame, but is clear in the video). Then the dentist replaced the ultrasonic scaler and the dentist and assistant began working in the mouth (Frames 9.3-9.5).

In the next frame, the patient made a noise and the assistant quickly removed their instruments from her mouth (Frame 9.6). It seems that the ultra-sonic scaler caused some pain for the patient and this is what the dentist and assistant were responding to. The patient then made a quick upward gesture with her right hand, which the dentist echoed by throwing his head back sharply (Frame 9.7). The dentist said that it is "…a bit of a catch 22…" and then returning to the mouth continued "…because the scale causes inflammation, which causes recession, and exposes the root surface, which allows scale to build up" (Frame 9.8). Finally, the dentist and assistant removed their instruments. The dentist indicated to the patient that they were finished with the scaling verbally and with a gesture towards her shoulder and the patient closed her mouth (Frame 9.9).

The scaling and polishing of the patient's teeth took up approximately the last 10 minutes of the examination. The dentist and assistant did not hold their instruments inside the patient's mouth for this whole time. Rather, they periodically removed their instruments so that the patient could "have a little rest", as the dentist put it. These pauses established a regularity that helped to mark out a rhythm for the interaction. There was also a rhythm at the finer level of interwoven movements of the four hands of the dentist and assistant and the postures of their bodies as they leaned forward and back, shifted their gaze and from the variations in sound as instruments were activated, engaged with the teeth, angled and withdrawn.

There was a rhythm in who moved first and who then responded and in how one response led to another. This is apparent when the dentist and assistant brought their instruments back to the patient's mouth after each rest. Each time the dentist and assistant went back to the mouth, they went back to a different spot in the mouth, because they were working their way around the mouth. There was an intricate coordination of positioning and then making space so that the other person could bring their instruments into the mouth. Consider how the dentist first used the mirror to find a position for the ultrasonic scaler and then withdrew the scaler slightly so the assistant could bring her instruments into the mouth. Once again the conception of gesture here is broader than the kind of gestures usually studied by researchers into conversational gestures. We are dealing with the gestures of accommodating and inviting the actions of another, intimately tied to a particular practical activity.

5.5 Chapter Conclusion: The role of gestures in dentistry

In this chapter, I have presented a number of excerpts of interaction from the work of a dental examination that show some of the range of roles that gestures play in this setting. I concentrated on two broad categories in this chapter; tooth gesturing and coordinating gestures. For each of these categories, I presented four excerpts and described some of the key concepts in the terms of the content of those excerpts. Before ending this chapter, I will re-state these points in summary form.

Tooth gesturing refers to sequences of gestures where the dentist explains aspects of the teeth or jaw to the patient. Key concepts in the descriptions of tooth gesturing were:

- **Distinctive character of tooth gestures:** Tooth gestures appear to often consist of a central iconic gesture, which was introduced at the start of the sequence, maintained and elaborated with other gestures. Examples presented were a gesture showing the shape of a molar tooth, a gesture showing the movement of the jaw joint and a gesture showing the planes of the teeth. A contrasting example was also presented and it was hypothesised that the aspect of the tooth being explained (whether easily representable or not) may have a bearing on whether a central iconic gesture is produced.
- **Gesture repertoires:** There seems to be an element of practiced performance to some of the dentist's tooth gesturing. Because the dentist is repeatedly called upon to explain concepts about the teeth such as the clicking of the jaw or shapes of teeth, it is possible to build and refine a repertoire of gestures that can be called upon for these explanations.
- **Patient Education:** Tooth gesturing forms part of the way that the dentists explain concepts to the patient and as such supports the work of patient education. Patient education is an important part of dentistry with the aim of making the patient more knowledgeable about their teeth, able to care for them and able to accurately assess the necessity of treatment. The last point highlights the importance of patient education for the business of dentistry, since patients who understand the need for treatment are more likely to accept the need for necessary but expensive treatment.

The gestures of tooth gesturing are communicative movements accompanying speech and are therefore largely compatible with the definition of gestures (gesticulation) used by communication-focussed researchers such as McNeill. In contrast, my presentation of Coordinating Gestures involved a broader view of what might constitute a gesture. This was in line with the broader conceptions of gesture explored in the literature review. This set of excerpts contains instances where familiar communicative gestures were used, but also ones where the gestures were tied to the manipulation of instruments and artefacts. The common link between the excerpts is that in some way the gestures of people play a role in how they coordinate their work. Important concepts from this group of excerpts were:

- **Unified gestural performances:** A startling observation from the excerpts was the extent to which the dentist and the assistant were able to coordinate their actions, gestures and speech to such an extent that they could produce a combined production of gesture. Similar to the concept of gesture repertoires, this concept draws from the idea that the dentist and assistant's familiarity with the setting and work of the dental surgery supports them in producing these unified performances. A point of contrast with this was the way the dentist employed more explicit gestures and verbal explanations when explaining to the patient what she needed to do. It was reasoned that this was likely because the relative lack of familiarity of the patient with the procedures of the examination.
- **Artefacts and instruments support gesturing:** Because the artefacts and instruments of dentistry are meaningful in terms of the actions of dentistry, they can be used as 'hooks' around which to gesture. One example was the way the x-ray film allowed the dentist to demonstrate with his fingers how the patient should bite on the film. Another example was the way the use of the instruments and materials in the preparation of the cold pellet test served to structure the gestures of reaching and passing back and forth that were made around them.
- **Placing gestures:** Gestures in the dental surgery are embedded in the spatial and temporal structures of context. The spaces of surgeries are arranged with care to support the actions and gestures that go on with in them. Gestures also imbue space with meaning by establishing frames and places around which other people can orient their gestures. An example from the excerpts was the preparation of the cold test, where the movements and gestures of both the assistant and dentist established the point where they could both spray the pellet. Likewise, the gestures establish temporal rhythms that help render the various phases of the work recognisable, such as the rhythm of rests during the scale and polish, and the rhythms involved in patterns of positioning as the dentist and assistant brought their instruments into the mouth.

This chapter has discussed several aspects of the role that gesture play in the accomplishment of a dental examination. I have tried to give a sense for the richness and complexity of gestural interactions that occur in a dental examination. In the next section, I will discuss these results with respect to the research on human gesture presented earlier in the literature review and the results of the design project presented in the previous chapter. I argue for the importance of adopting a broader conception of gestures and discuss what this might mean for gesture interface design.

Chapter 6: Discussion

In this research project, I set out to investigate the appropriateness of existing research into human gesture for the design of gesture interfaces. The overall theme of this chapter is the relationship between general and specific views of gesture and how these relate to gesture interface design. A point of departure for the thesis is the need for gesture interface research to move beyond a technical focus and investigate how to design for authentic contexts of use and characteristics of gesture that are specific to those contexts. In engaging with specific contexts, general views from existing research can still be useful. This discussion is taken up in this chapter in relation to my experiences of engaging in a project to design a gesture interface to support the work of the dental examination presented in chapter 4 and the results of the analysis of the gestures of dentistry presented in chapter 5.

On the side of existing research, I take the work of McNeill (McNeill, 1992, 2005) as the starting point and focus for the discussion, before bringing in some of the broader conceptions of gesture introduced in the literature survey. I start with and focus on McNeill's work for the following four reasons. First, given its prominence, it is likely to be many gesture interface researchers' initial contact with research into human gesture. Second, there is a well-known existing example of the use of this framework in the gesture interface literature in the work of Cassell (Cassell, 1998). Third, McNeill has himself collaborated with computer scientists and given commentary on gesture interface research (Quek et al., 2002). Fourth, while recognizing the diversity of approaches and research traditions within human gesture research, McNeill's work can be seen as representative of communication-focussed gesture research, especially in regard to his taxonomy of gestures, which is in broad agreement with the taxonomies of other communication-focussed gesture researchers (Kendon, 2004, chap. 6).

McNeill's framework is intended to capture general characteristics of one kind of gestural activity. It will be argued that gesture interface designers can benefit from use of McNeill's framework both for analysing specific instances of gestural activity and for focussing design questions. However, it will also be argued that in important respects, the perspective on gestures that this gives is somewhat limited for the needs of gesture interface design. Consequently, gesture interface design can benefit from a broader range of existing research into human gesture. This opens up a potentially vast range of diverse research for gesture interface designers to draw upon and here the importance of engaging with a specific context of use again comes into play. The final argument of the chapter is that existing research and theory should be treated as a *contingent* resource for design. This captures the idea that in navigating and drawing on existing research, gesture interface designers should be guided by the particular needs of their design project rather than pre-existing theoretical commitments.

As a frame for the discussion of this chapter, I begin in the next section by setting out some criteria for assessing the appropriateness of existing theory for design based on discussions from within HCI of the relation between theory and HCI practice.

Following this, I discuss existing research into human gesturing in relation to the findings of the thesis. I first re-examine the examples of 'tooth gesturing' presented in the previous chapter from the point of view of McNeill's taxonomy of different kinds of gesticulation. I discuss one of the design concepts developed early in my design process in relation to this to show some ways in which analysing gestures through this taxonomy could be useful for design.

I then move to a discussion of how some of the broader conceptions of gesture introduced in the literature survey might benefit gesture interface research. As demonstrated in the literature review, communication-focussed research into human gesture exemplified by McNeill, has a narrower conception of gestures than the range of movements that have been employed by gesture interface research. This was also true of the final Tilt-Roll-Wave prototype that resulted from my design project. I finish the section with a discussion of the ways that we might understand the Tilt-Roll-Wave concept against a broader conception of gestures.

The chapter concludes with summary of the findings about the gestures of dentistry that resulted from my own design project and the analysis of the previous chapter. I also return to and elaborate on the idea of seeing theory as a contingent resource for design and the implications of this for the development of gesture interface research.

6.1 Relating to theory in HCI

As a field, HCI has drawn on research and theory from a number of different disciplines and this has lead to focussed discussions over what can be expected from research and theories from other fields when we bring these into HCI. One way to think of theory is as a pair of spectacles that frames some parts of the world and obscures other parts. The pragmatic goals of HCI have a direct bearing on the way that theory is engaged with and what we expect from theory in the field (Halverson, 2002). In this sense, when discussing different theories it is important to assess their strengths and weaknesses (the parts of the world that they frame or obscure) relative to the practical objectives of HCI – or more specifically, for the purposes of gesture interface design.

Theory can help in understanding and explaining a phenomenon of interest, such as characterising salient aspects of user experience (Rogers & Muller, 2006). In helping to describe current practice, theories can be useful for making sense of data and eliciting new design concerns (Rogers, 2004). The value of a theory may be judged not only on whether it provides an objective representation of reality, but also on how well it helps shape an object of study in relation to a particular design or research agenda (Barthelmess & K. Anderson, 2002, p. 14).

By shaping an object of study and helping to understand initial experiences, theories and frameworks can inspire subsequent design work (Benford et al., 2005). Theory can also have a more direct relation to design activities throughout the design process. At the early stages of design, theory can be useful for mapping a theoretical space in terms of a design space and providing useful concepts for design (Rogers, 2004). This can be both through the transfer of research findings from one discipline into another (e.g. applying findings from research into human gesture in gesture interface research) and through the provision of theoretical concepts that are useful for design (e.g. the concept of affordances originally from ecological psychology). Theories may help to compare different design approaches and give insight into the tradeoffs involved, within a given design situation (Reeves, Benford, O'Malley, & Fraser, 2005). It is thought that appropriate theory can allow the "…researcher to select, articulate and validate particular forms of external representation in terms of how they support the activity to be performed" (Rogers, 2004, p. 113). Theories and frameworks may also be employed as analytic tools for improving an interface once the functionality has been decided, by questioning assumptions about user actions (Benford et al., 2005).

6.1.1 Criteria for discussing appropriateness of theory

So far, I have talked about the different roles that theory and existing research can play in relation to HCI practice, but what about more direct criteria for discussing the appropriateness of existing research? Rogers suggests two important areas to consider when using theory: *adequacy* concerns whether the theory gives a satisfactory account of the phenomenon of interest; and *transferability* concerns whether ideas from the theory can be usefully applied for design (Rogers, 2004). Halverson offers a slightly more detailed view, and proposes four important attributes for theories, which are: descriptive power, rhetorical power, inferential power, and application power (Halverson, 2002). Of these, the first two (descriptive power and rhetorical power) can be seen as relating to Roger's notion of adequacy, whereas the final two (inferential power and application power) relate to the notion of transferability.

Descriptive power means that the theory should provide a conceptual framework that helps make sense of and describe the world (Halverson, 2002). For design, this can include describing a phenomenon or setting of interest, as well as helping with a critical assessment of technology in that setting. Such a framework may take the form of named concepts linked through a relatively simple syntax that allow observational data to be matched and modelled (Rogers, 2004). An alternative (and less 'definitive') approach is to think of theory as providing a set of 'sensitizing concepts', which give researchers "…a general sense of guidance and reference when approaching empirical instances" (Blumer, 1954, p. 7).

Rhetorical power means that the theory should provide a language for discussion by naming relevant concepts in the phenomenon or setting. In terms of rhetoric, the theory should allow findings to be conveyed clearly and succinctly and help convince others of the correctness of interpretations (Halverson, 2002). This is not simply a matter of having a vocabulary to talk about a phenomenon of interest (though that is certainly important), but also entails the idea that *by naming* aspects of the world in design-relevant ways, problems and opportunities worth pursuing can be systematically identified. As Rogers notes, "…the mere act of naming gives credence to the analysis" (Rogers, 2004, p. 129).

Inferential power means that the theory should guide the process of enquiring into and understanding phenomena, assist in the drawing of conclusions, and lead to insights for design. This might also be described as the idea that theories should provide 'analytical leverage' (Fitzpatrick, 1998, p. 234). A theory also has useful inferential power if it is able to help us reason about likely outcomes of following a particular design decision, such as making an informed assessment of what the likely effects of introducing a given technology into a setting might be (Halverson, 2002).

Application power refers to the idea that theories should have applicability in the real world for pragmatic reasons of design, such as informing and guiding design decisions. Theories can operate at a range of different granularities, and it is important that analysis should be at an appropriate level of detail for moving from description into design (Halverson, 2002). Rogers identifies *formative, generative,* and *prescriptive* roles for theory in relation to this idea of application power. The formative role captures the idea that a theory should provide a set of easy to use concepts to inform design. The generative role captures the idea that a theory should provide design dimensions and concepts to inform design. The prescriptive role captures the idea that a theory should provide advice on how to design or evaluate (Rogers, 2004).

Obviously, the relevance of each of these criteria for discussing a theory depends on the particular qualities of that theory and the uses to which it is put. Where theory has been developed outside of design (e.g. for understanding processes of gesticulation), it may be more appropriate to judge it based on the extent to which it helps to understand and explain existing practice (its descriptive and rhetorical power) than the extent to which it is useful for design (its inferential and application power). Nevertheless, whether an existing theory can usefully contribute to design is a legitimate concern, so we should not restrict ourselves from considering the contributions that a theory may make in this respect, even if it was originally developed for more explanatory purposes.

6.1.2 Discussing a variety of existing research

An argument that has been made throughout this dissertation is that gesture interface research would benefit from drawing on a wider variety of existing research into human gesture than it has so far. At the start of the thesis, a working definition of gesture was proposed that incorporated a range of different kinds of gestures, from communicative gestures, to gestures performed for exploring meaning about the world, to gestures performed to effect a material change in the world (Figure 2). In the literature review, several strands of research into human gesture were drawn in and related to the different aspects of this broad working definition. This liberal approach to existing research is in line with the way that the wider field of HCI has related to research from other fields. HCI draws on research and theory from a diverse range of disciplines and employs research of other disciplines in many ways (Rogers, Bannon, & Button, 1994). This diversity is a result of the growth of the HCI and widening of topics with which it is concerned. As Rogers notes, "…theory can and should be used eclectically in HCI" (Rogers, 2004, p. 132).

An eclectic approach to theory does however also raise some issues, which are important to be aware of (Halverson, 2002). One problem is that terminology and concepts from different strands of research can be confusing and difficult to relate (Rogers, 2004). As was shown in the literature review, even a term such as 'gesture' is used in a wide variety of different ways by different researchers. For McNeill, gesture refers to gesticulation only, whereas for Ingold, it refers to any skilful embodied movement. It is still possible to survey and highlight the strengths of different approaches, but this requires that we are careful to set out the potential confusions that arise (Rogers, 2004).

A pertinent lesson that has been learned in HCI is that theories cannot be simply lifted out of an established field (such as human gesture research) and applied to a different but seemingly related domain (such as interacting with computers via gestures). This lesson was learned early by researchers in HCI through the difficulty of applying findings from cognitive science (Landauer, 1995), but similar observations have been made of more recent attempts to draw on theories from the social sciences (Sharrock & Randall, 2004). As Sharrock & Randall observe, "much of the interest in candidate sociological and psychological theorising seems to us to be based on the naive supposition that generalisations look much the same regardless of the disciplines that deploy them" (Sharrock & Randall, 2004, p. 193). A similar issue has been discussed already in the literature survey with respect to the differences in orientation and framing between human gesture research and gesture interface research and it will be returned to again later in this chapter.

One problem, when drawing together a diversity of research is that they may have widely differing, or even contradictory epistemological assumptions. A salient example in this respect for the discussion I undertake in this chapter is that some of the literature I want to discuss comes from a tradition of *ethnomethodology*. This is an approach to the study of interaction, which aims to give an account of how particular forms of social order *get done* (Sharrock & Randall, 2004). Thus, ethnomethodologists seek to produce rigorous descriptions of situated actions and practices and show how through the *doing* of these practices the activities of a setting are 'produced and reproduced' by members (Crabtree, Nichols, O'Brien, Rouncefield, & Twidale, 2000). The important and distinctive characteristic of the ethnomethodological approach with respect to the current discussion concerns its relation to theory. Ethnomethodology avoids the use of theory and pre-existing categorisations either as an aid to or product of analysis. As Crabtree et al. state:

> "Ethnomethodology refuses to theorize practice in that, and precisely because, members' real-world practices are only discoverable. … Ethnomethodology offers no theories then, it does not build theories and does not build them because it has no work for them to do" (Crabtree et al., 2000, p. 670).

The question therefore arises as to how we might discuss ethnomethodological research alongside more theoretical approaches. Although *theory* is be eschewed by ethnomethodology, *generalization* of findings from ethnomethodological research is possible, but the form that such generalizations can take is different than what is offered by explanatory theory (Sharrock & Randall, 2004). Rather than abstract explanatory generalizations, ethnomethodology is able to provide generalizations about regularities in the way practice is done (Sharrock & Randall, 2004). An approach that several researchers have taken for making these kinds of generalities available for design is to codify them as patterns, after the architectural tradition (e.g. Crabtree et al., 2002). Keeping in mind that the criteria presented in the previous section have been established for the purpose of discussing the value of *theory* for HCI it is reasonable that we could also discuss ethnomethodological research in those terms (especially the notions of descriptive power and application power). This is the approach that I take in this discussion.

A trend in HCI which would seem to support the bringing together of a diversity of existing research, has been towards frameworks rather than fully-fledged theories in the traditional scientific sense. The distinction is that frameworks provide a set of related constructs for understanding a domain rather than producing testable hypotheses (Rogers, 2004, p. 128). Forlizzi and Battarbee advocate for such a 'framework approach' when they write that:

> What is needed is a framework that articulates experience in a way that does not rely on the point of view of any single discipline, but provides a common design oriented frame of reference for all the relevant actors involved in design (Forlizzi & Battarbee, 2004, p. 261).

In this sense, the definitional framework presented in the introduction of the dissertation and elaborated in the literature survey could provide the beginnings of such a framework, but it should not be construed as aiming for any stronger theoretical status. This is both due to pragmatic reasons (the heterogeneous body of research that I seek to discuss and the initial exploratory nature of this research project) as well as a hesitation about what the worth of any 'grander' theory of gestures would be in isolation of knowing *how* it would be applied and for what purpose. As Rogers notes, "…it seems that only the researchers who have developed the grand theories are able to use them" (Rogers, 2004, p. 121). The aim here is rather more modest – to put concepts from a range of existing research into relation with one another so the differences and similarities can be made clearer and discussed with respect to the needs of gesture interface research and design.

6.2 Describing tooth gestures with McNeill's taxonomy

As demonstrated in the literature survey, McNeill presents a clear taxonomy of the different kinds of gestures that accompany speech, which is in broad agreement with the taxonomies of other communication-focussed gesture researchers. In this section, I re-examine the gestures in one of the instances of 'tooth gesturing' presented in the previous chapter from the perspective of McNeill's taxonomy. I concentrate here on the contribution the taxonomy might make to the task of *describing* such gestures (its descriptive power). In the next section, I will turn to a discussion of how one might go about *applying* insights thus gained to developing an early design concept from my design project (its application power).

The particular kinds of gestures that McNeill focuses on are *gesticulations* (in the terms of Kendon's continuum), which he defines as *spontaneous idiosyncratic communicative movements accompanying speech* (McNeill, 1992). Within his definition of gesture, McNeill also proposes a taxonomy consisting of four categories: *iconic, metaphoric, deictic* and *beat.* As introduced in the previous chapter, tooth gestures were sequences of gestures made by the dentist that illustrated aspects of the structure, shape and functioning of the teeth and jaw. The gestures that comprised these sequences are at once familiar according to McNeill's definition and include recognisable examples of all the *general* kinds of gesture from his taxonomy, but also have characteristics *specific* to their production within the context of a dental examination. Of particular note here is the proposal made in the previous chapter that sequences of tooth gesturing draw on a *repertoire* of gestures developed through repeated performance. The notion of a repertoire of gestures presents an important point of difference to the emphasis in McNeill's definition on *spontaneous* gestures (a point of difference which I return to later in the chapter). However, for the purposes of the analysis and discussion of this section, such gestures are *close enough* in quality to the spontaneous communicative gestures that McNeill takes as his focus for a legitimate application of his taxonomy.

Consider the first example given in the previous chapter, where the dentist described the structure of a molar tooth and explained how it corresponds to the image recorded by the x-ray. Other than the question of whether some of the dentist's gestures are drawn from a repertoire, this sequence of interaction between the dentist and patient clearly comprises the kind of gesturing that McNeill takes as his focus. The sequence of speech and gestures that the dentist produced was prompted by a question from the patient about the x-ray image and was plainly communicative in effect. Within this sequence of speech and gesture, we can see examples of all four of the kinds of gesticulations that McNeill identifies in his taxonomy.

Iconic gestures present images of concrete objects or actions that are also mentioned in the associated speech. In the sequence of gestures under consideration, a clear example of what McNeill would describe in this way is the gesture of the molar tooth that the dentist formed by holding his left hand out in front of him with the thumb, index and middle fingers pointing down in the shape of the roots of a molar tooth, while simultaneously describing the shape of a molar tooth in his speech (Figure 49).

Figure 49: An iconic gesture representing the shape of a molar tooth.

This gesture provided a central image around which other gestures and speech could be organised. This was also the case for other examples of ‘tooth gesturing’ presented in the previous chapter, with the notable exception of the ‘demineralisation’ example. In that instance, the gesture made by the dentist had a mixture of iconic and metaphoric characteristics. It was suggested that this reflected that the topic of the explanation concerned an internal, structural property of the tooth without a clear iconic referent.

Metaphoric gestures are similar to iconic gestures in that they picture the content of speech, however they correspond to parts of the speech that do not have a concrete representation. In contrast to the central iconic gesture of the molar tooth discussed above, metaphoric gestures don’t ‘stand out’ as much in the sequence of tooth gesturing describing the molar tooth. One example is from where the dentist turned back to the patient after having looked to the x-ray and said, “…we can only really see the two root canal fillings, um, but, but we should actually see three.” When he mentioned the ‘two root canal fillings’, he extended his hands slightly and formed them into opposing C-shapes, which together made a circle (Figure 50).

Figure 50: A metaphoric gesture made when describing internal aspects of the tooth.

Although the gesture here was made to accompany the speech describing the root canal fillings that were visible on the x-ray, the gesture does not directly represent the two root canals in an iconic way. Rather, it seems to present the notion of a solid mass of material, the idea of something that can be grasped by the hands, or something contained (perhaps because the root-canal fillings are contained within the tooth). This is similar to the form of 'conduit metaphor' gestures identified by McNeill, where the gesture represents some content of the discussion as a metaphoric substance held between the hands and presented to the listener (McNeill, 1992, p. 149). In this case, the dentist elaborated the gesture by moving his hands back and forth relative to one another when he explained that the x-ray does not show whether the third hidden root has been filled or not. Metaphorically, the moving back and forth of the hands seems to reflect this ambiguity in how the x-ray can be interpreted.

Deictic gestures locate a position in space. Typically, this involves pointing at a location with an extended index finger and other fingers curled in. Deictic gestures can also be made with other hand postures and can also employ a wide variety of body parts, such as elbows, feet, and even the lips. The thing pointed at can be either physically present or an abstract concept given a metaphoric position by the act of pointing. In the sequence of gestures under discussion, the dentist made extensive use of deictic gestures in his explanation of the shape of the molar tooth and how it related to the image of the x-ray.

Figure 51: Deictic gesture indicating the 'back root' of the iconic gesture.

For instance, while holding his left hand in the shape of a molar tooth, he pointed to it with his right hand to indicate parts corresponding to the two roots at the front of the mouth and the large root at the back of the mouth (Figure 51). He also held his full hand in a plane pointing along the angles that the x-ray was or could be taken from (Figure 52). These planes were indicated both in relation to the mouth of the patient, and in relation to the iconic gesture of the molar tooth made with the other hand. The dentist also pointed to objects in the surgery that related to his unfolding description of the tooth. For example, he pointed several times to an x-ray of the tooth that was clipped up on the light box located on the wall behind him, sometimes with a shift in posture and gaze and sometimes without. He also pointed to his own jaw to show the position of the molar relative to the mouth.

The last of McNeill's categories of gesticulation is beats. These are simple in form, typically consisting of rapid up and down movements of the arms or hands. According to McNeill, these movements are timed to coincide with and thereby give emphasis to associated speech content. Although the form of beat gestures is simple, McNeill regards them as important in revealing the process of language production because they tend to mark discourse shifts and the introduction of new concepts.

Figure 52: A beat gesture made when showing the angle of the x-ray.

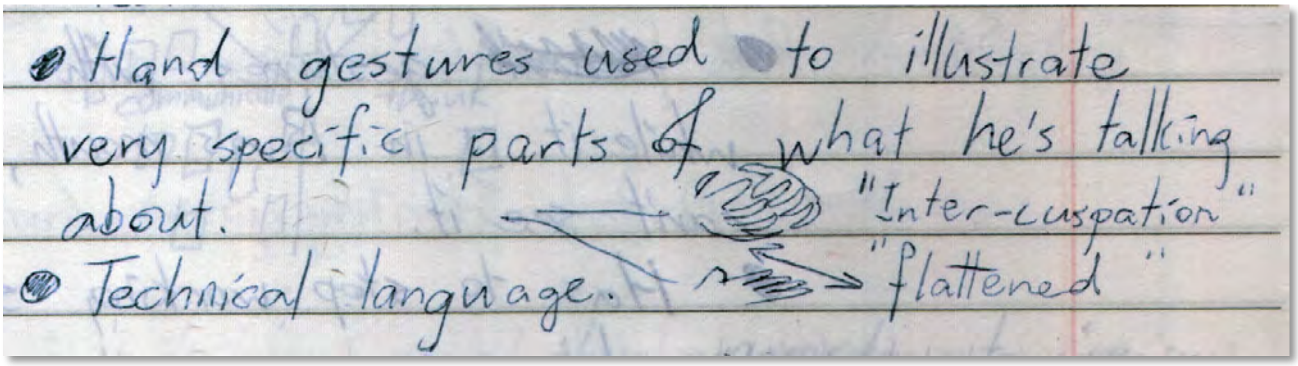
Such gestures are readily observable in the sequence under consideration. When the dentist first made the iconic gesture representing the shape of a molar tooth with his left hand while saying "…a molar tooth has actually got three roots" he produced a beat on the word 'roots' by moving the whole left hand rapidly down and up. Another instance was when the dentist explained to the patient about the "…root canal fillings…" he made separate beats on the words 'canal' and 'fillings', this time with both his left and right hands, which were held in facing C shapes as discussed above. Later, when the dentist showed how he would take an x-ray "from a slightly different angle", he made beats on the words 'slightly' and 'different' with his right hand while it was held pointing at the patient's jaw indicating the angle of an x-ray (Figure 52).

An interesting characteristic of these three examples, which aligns with McNeill's own observations, is that the beat gesture co-occurred with another gesture. In the first case, the beat was with the iconic gesture showing the shape of a molar tooth, in the second case the beat was with the metaphoric gesture of two hands making facing C shapes, while in the third case the beat was made along with the deictic gesture showing the angle of an x-ray. In these cases, the beat gesture was made by rapidly moving the same hand that formed the other gesture (iconic, metaphoric, or deictic) up and down while maintaining hand shape.

These co-occurrences highlight a significant point, which is that the distinctions in McNeill's taxonomy should be regarded *dimensionally* rather than categorically. Often, gestures cannot be strictly separated into a single category. They can at one moment combine elements of different categories – either through layering of gestures as above, or through combining qualities of different kinds of gestures, such as the somewhat iconic and metaphoric gesture about the demineralisation of the teeth (Figure 50). As McNeill points out, "…the essential clue that these semiotic properties are dimensional and not categorical is that we often find iconicity, deixis, and other features mixing in the same gesture" (McNeill, 2005, p. 41).

It is therefore difficult to make a perfect mapping between gestures produced in a sequence of interaction and the pre-defined categories of McNeill's taxonomy. Nevertheless, looking at gestures from a taxonomic perspective does prompt us to notice that there are different *kinds* of gestures, which play different *roles* in the dentist's overall explanation of the shape of the tooth. This point may appear tautological, but consider the following initial notes I made when watching a segment of video from a dental examination (research journal 2002:1 p.67). The video showed a sequence of 'tooth gesturing' much like the ones I have been discussing so far (Figure 53).

These notes were not intended as more than a preliminary log of the action in the video recording to support later analysis. Yet in comparison to what I have shown of the richness and variety of tooth gestures above, one can see how the phrase 'hand gestures' glosses a range of interrelated and intertwining kinds of gesture. This reflects Cassell's point that we are not usually conscious of the detail of gestural interactions we encounter or produce (Cassell, 1998, p. 195). Looking at instances of 'tooth gesturing' through a taxonomic frame such as McNeill's prompts one to attend to and explicate the different kinds of gestures they involve.



- Hand gestures used to illustrate very specific parts of what he's talking about. "Inter-cuspation"
- Technical language. "flattened"

Figure 53: Initial note on a sequence of 'tooth gesturing' from research journal.

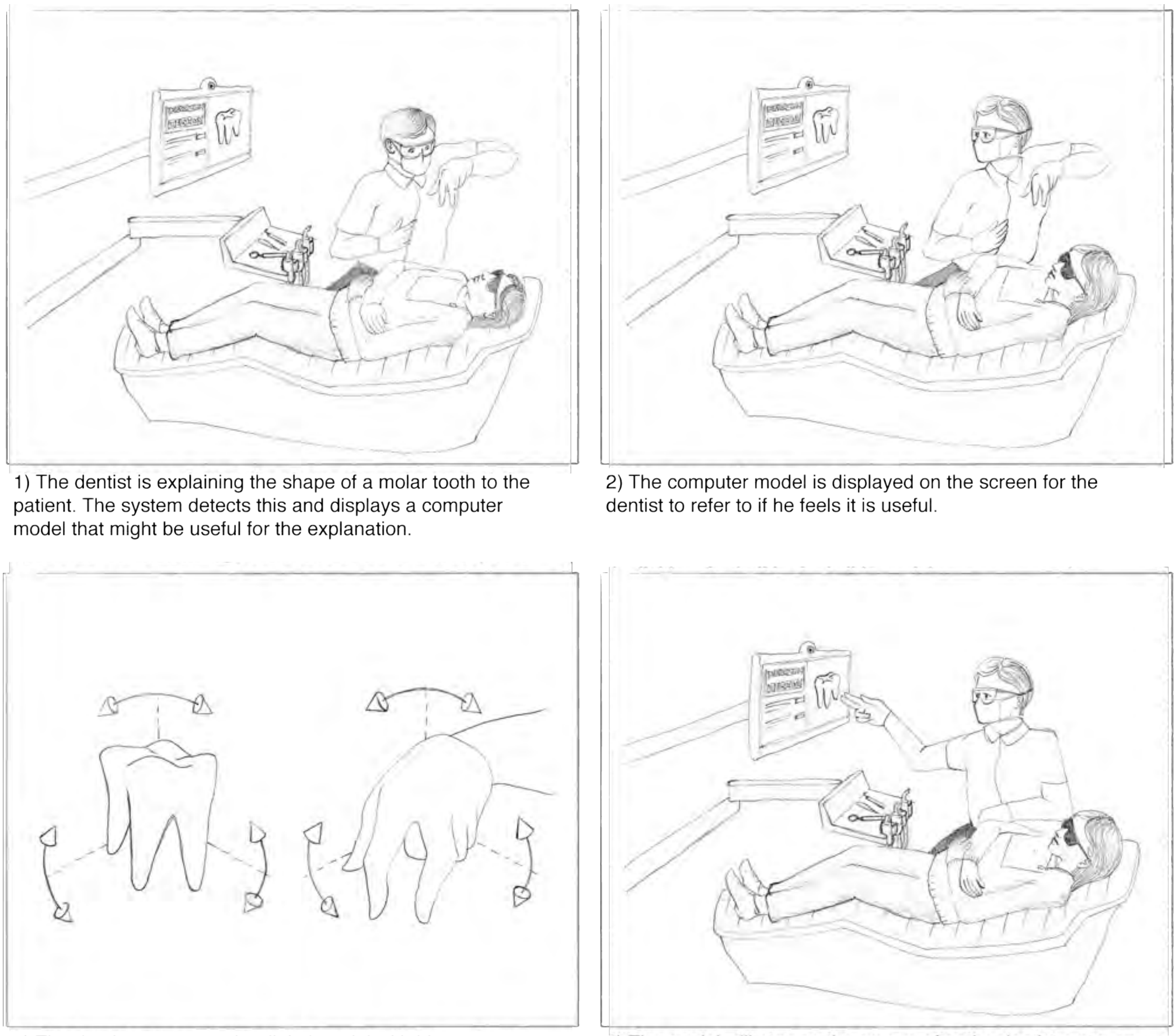
In terms of the criteria for discussing theory presented at the start of the chapter, this highlights that McNeill's taxonomy provides *descriptive power*, at least for describing instances that are close to the kinds of gestures that he takes as his focus. My main experience of this from the research project was in the choice to use the categories from McNeill's taxonomy in the transcription of excerpts from the dental examination presented in the previous chapter. I did not employ the taxonomy as a coding scheme where every instance of a gesture was identified and classified in according to it, but rather as a succinct way to describe particular gestures within the transcript. This meant that rather than writing something like, 'quick up and down gesture with the hand', I could write 'RH beat'. This obviously makes the transcript easier to read and also gives a precision to the description of the action, which is desirable.

Another consequence of employing the taxonomy (even in a loose way) is that it prompts further questions about gestures. If a gesture is identified as metaphoric or iconic, we can ask: of what? If one is identified as a deictic, we can ask: to what does the gesture point? If we see a beat, then we can ask: what does it serve to emphasise? Asking such questions can help us deepen the analysis and identify commonalities across instances of gestural interactions. For example, all the examples of 'tooth gesturing' presented in the previous chapter were characterized by a central *iconic* gesture, which was noticeable and memorable and represented the part of the mouth under discussion. An interesting exception to this was the 'demineralisation' example (Excerpt 5). I speculated that this was because an internal chemical process was being discussed (demineralisation) which lacked a clear iconic referent. From the analysis, we can also see how *deictic* gestures serve to relate the ongoing explanation to parts of the iconic gesture of the tooth itself and other information resources in the surgery, such as the x-rays. We also see how *beat* gestures are sometimes overlaid on the iconic gesture, thereby giving emphasis to aspects of the gestural performance. By drawing out these aspects of the gestures involved in tooth gesturing, it is possible to give a more detailed account of what makes an instance of tooth gesturing recognisable as such.

6.3 Application to a design concept

Beyond helping to describe aspects of gestural interaction, it is also reasonable to ask whether McNeill's taxonomy of different kinds of gesticulation can be useful in guiding design decisions for a gesture interface. In this section I revisit an early design concept developed in the internal design workshop (section 4.4.2) to consider how McNeill's work could support developing the concept further. I have selected this particular early concept because it is possible to make a link between the kind of gestures it responds to and the kinds of gestures that McNeill takes as his focus, which is not the case for the final Tilt-Roll-Wave prototype. I will return to the final design concept in the next section, where I discuss the ways in which a broader range of human gesture research might benefit gesture interface design.

The original concept developed in the design workshop was called the 'tooth stone'. The idea was that the dentist would be provided with a three-dimensional graphical computer visualisation of a tooth whose orientation could be changed by manipulating an accompanying tangible 'tooth stone' (Figure 26, left). The intention was that dentist could use the computer visualisation as an additional resource for explaining aspects of the teeth and the tooth stone would provide an easy way to orient the visualisation on screen. Revisiting the 'tooth stone' concept in the light of the observations about tooth gestures, the question arises whether it would be possible to use tooth *gestures* to select and control such visualisations during an examination. Ideally, this would require less work to bring relevant visualisations into the explanation and eliminate the need to interact with a computer peripheral to adjust their orientation. A brief scenario of use illustrating the concept is presented in Figure 54.



1) The dentist is explaining the shape of a molar tooth to the patient. The system detects this and displays a computer model that might be useful for the explanation.

2) The computer model is displayed on the screen for the dentist to refer to if he feels it is useful.

3) The dentist can rotate the digital model with his gesture

4) The model will stay on the screen after the dentist removes his hand so he can still point to it.

Figure 54: Augmenting 'tooth gesturing' with computer visualisation.

In the concept, a computer vision system is used to track the gestures of the dentist. When a sequence of 'tooth gesturing' is recognized, an appropriate computer model of the teeth is displayed on the computer screen alongside the electronic patient record. Whereas a visualisation of a molar tooth is shown in the scenario above, for an explanation about the clicking of the jaw, a model of the bones and ligaments of the jaw joint would be shown instead. The computer vision system would also track the orientation of the dentist's gestures and match the orientation of the model to this, thus making it possible for the dentist to adjust the view of the model of the teeth to better support his explanation (e.g. by rotating to a side-view of the teeth as seen by the x-ray) without the need to interrupt his gesturing to pick up and operate a computer mouse.

An important aspect of this concept is that it does not try to replace the current gestural explanations of the dentist. They work fine as they are. Rather, the intention is that *additional* resources would be made available to the dentist to draw into his explanations for aspects of the teeth that are difficult to describe through gesture and speech alone. In fact, something like this already happens during instances of tooth gesturing such as the sequence examined in the previous section, where the dentist turned and pointed back to the x-rays pinned up on the light box behind him at one part of the explanation.

In fact, a feature for providing three-dimensional computer graphic models of teeth is already available in some dentistry software products. Several of the dentists I spoke to who had this feature, but they tended not to use it. The general impression I got from the dentists was that they regarded it as a slightly gimmicky feature and it required a lot of work to switch to the special three-dimensional view of the teeth and manipulate the mouse to rotate and orient the model. A notable exception was the endodontist who I interviewed in the final stages of the design project (dentist D5). He demonstrated a program he had installed on a second computer in his surgery. The program contained a library of detailed models of teeth, including internal features such as veins and nerves. The endodontist described how sometimes when explaining aspects of a procedure to a patient, he would browse through this library to find a tooth with similar features to the patient's and display it on the screen to support his explanation. However, this was done before a procedure began at the bench on the side of the surgery where the use of a mouse is less problematic.

I want to emphasise at this point that this wasn't a design concept that I took further than the early concept of the 'tooth stone' and the reason was because I thought that there were more promising alternative directions to take. Thus, the concept should be read as an example that supports a discussion of McNeill's taxonomy and theory in relation to design, rather than a fully realised design response itself. Importantly, one of the things that McNeill's theory can help with in this case is highlight some of the likely *problems* that the concept would encounter and why it may *not* be worth pursuing further.

6.3.1 Recognizing sequences of tooth gesturing

The system outlined above would certainly be technically challenging, but in terms of technical ambition, it is not outside the realms of what some gesture interface researchers hope that gesture interfaces will become capable of. I am thinking in particular here of approaches to interaction such as context aware computing (Dey, Abowd, & Salber, 2001) and perceptual user interfaces (Pentland, 2000a), which seek to detect, model and make inferences about the context and actions of the user in order to provide computational support for their activities. Unobtrusive recognition of user activities, including gestures is often an aim of these systems and it would also be the biggest technical impediment to the implementation of our system. Analysing the gestures of a sequence of tooth gesturing through McNeill's taxonomy can help shed some light on the challenges that would need to be overcome for such recognition to be feasible.

The first challenge would be to detect when sequences of tooth gesturing begin and end. The central iconic gesture is the most recognizable feature of sequences of tooth gesturing, both for a human observer and likely also for a computer gesture recognition system. However, analysing sequences of tooth gesturing through McNeill's taxonomy highlights that though they typically consist of a clear central iconic gesture they are not restricted to this. They also involve other gestures and can continue on after the central iconic gesture has ended. The question arises as to how our system would determine that a sequence of tooth gesturing has ended and that the three-dimensional model of the tooth should be withdrawn.

On this, McNeill's notion of gesture *catchments* would seem relevant. In McNeill's theory, a catchment is a segment of gestural discourse built around a shared image (McNeill, 2005, p. 164). In McNeill's theory, catchments are larger discourse units and are used as analytic tool to support McNeill's claim of 'growth points' – units of mental imagery underlying speech and gesture production. According to McNeill, catchments can be recognised when gesture features recur over multiple gestures, for example the features of the roots of the molar tooth, which recurs through the sequence of tooth gesturing we have been examining. Identification of catchments also relies on detailed transcription of accompanying speech, analysis of speech tone and knowledge of the stimulus that gesturers are responding to. Automatic recognition of catchments has also been attempted in the gesture recognition literature, based on simple physical features of gesture such as and movement symmetry and patterns of hand oscillation with promising results (Quek et al., 2002; Xiong & Quek, 2006). However, it would remain to be seen whether such an approach would work within the dental surgery or even whether the granularity at which catchments unfold within gestural activity aligns sequences of tooth gesturing. A simpler method may be to show a visualisation whenever a candidate tooth gesture is detected and fade it out after some duration.

The co-occurrence of different kinds of gestures with the central iconic gesture of the tooth means that the gesture recognition system must be tolerant to these other gestures as they move around the central iconic gesture, sometimes occluding it, sometimes joining physically to it, sometimes changing its position. A related problem is that through the course of a single sequence of tooth gesturing, the central iconic may be performed, withdrawn, performed again, and so on. Further, once the meaning of the central iconic has been established, repeated performances of the iconic may be abbreviations or variations. Therefore, even though the notion of a repertoire of tooth gestures would suggest some stability in performance of tooth gestures from examination to examination, *within a single sequence of tooth gesturing* it is evident that the form of tooth gestures is likely to vary. The system would therefore need to be able to accommodate a greater range of variation in the form of the gestures it responds to.

The final problem, concerns the difference between the clearly iconic gestures of the 'molar tooth', 'clicking of the jaw' and 'pro-gnathic' sequences and the more metaphoric example of 'demineralisation'. As discussed previously, a plausible explanation for the different quality of gesturing made in relation to this example is that the topic of the explanation (demineralisation) is an internal structural quality of the tooth rather than a part of the tooth with a clear iconic representation. If internal features of the teeth such as demineralisation are more difficult for the dentist to enact in an iconic gestural form, then dentists may find additional resources for the explanation especially useful in these situations. However, from the perspective of gesture recognition, sequences made around metaphoric gestures would likely be more difficult to detect than clear iconic gestures. Our system might face the bind where the cases in which it has the most potential to support the dentist, are also the ones that are the hardest to detect and respond to.

6.3.2 Suggesting Alternative Design Approaches

Given the complications for the design concept raised in the previous section, we might reconsider the feasibility of the concept altogether. Clearly, it is valuable to be able to expose limitations in a design concept through an analysis such as this, but it would also be useful for gesture interface design if McNeill's taxonomy could help suggest possibilities for *alternative* design approaches.

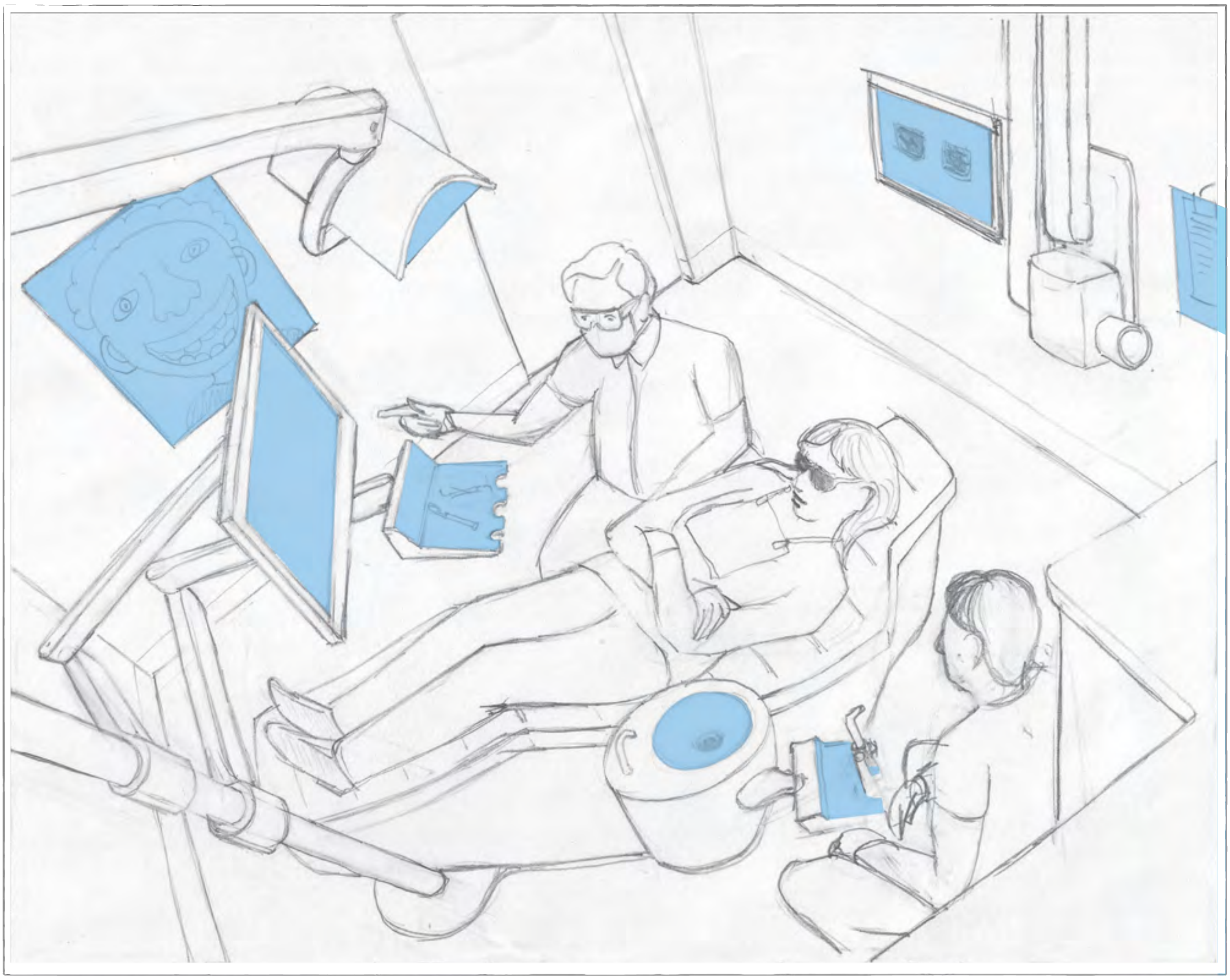


Figure 55: Thinking about the dental surgery as a space where pointing is done.

For example, consider how we might proceed with the development of our system if instead of trying to respond to the iconic gestures of teeth, we tried to support the *deictic* gestures that the dentist uses to relate to other information in the surgery during sequences of tooth gesturing, perhaps by highlighting relevant information resources when they are pointed to. This would suggest that we look at the space of the surgery as a space for pointing is done and think about the different kinds of information resources that the dentist has available within it (Figure 55).

In this respect, it would still be useful to have an understanding of the character of whole sequences of tooth gesturing and the different gestures (including deictic gestures) that comprise them. It would be worth attending to the way that the dentist weaves these many gestures into a coherent explanation within the space of the surgery. In this respect, the focus that the central iconic gesture of the tooth provides is significant. Once the central gesture has been made, a space is established within which other gestures of deixis, metaphor, and beat can be positioned. The performance of gesturing that the dentist makes is then oriented within this space for the benefit of the patient. The analysis of the space of the dental surgery presented in the design chapter is relevant here, particularly the scale-modelling and video-tracing activities described in the section on designerly analysis (section 4.3). These activities provide viable approaches for trying to understand relations between gestures and the space of the dental surgery.

A potential problem with trying to respond to deictic gestures arises from the fact that, as McNeill points out, deictic gestures may or may not point to something that is physically present. For example, a deictic gesture might be made to the x-ray displayed on the light-box or it might be made, metaphorically, to the occasion of the previous dental examination. It would bear further investigation to determine whether non-concrete deictic gestures are prevalent enough to disrupt the functioning of the system.

6.3.3 How gestures change when we use them as input for a computer system

As was demonstrated in the literature review, the kinds of gestures that gesture interface researchers have tended to employ in their interfaces are quite different from the kinds of gestures (gesticulations) that McNeill takes as his focus. I have therefore been careful, in the design examples here to use gestures that already occur in sequences of tooth gesturing and are recognisably gestures of the kind that McNeill takes as his focus. However, the question arises as to whether in taking such gestures (however unobtrusively) as inputs for a computer system, some of their characteristics are changed. I think that this is the case and it is a critical issue for gesture interface researchers to be aware of when seeking to apply theories from human gesture interface research.

Returning to the first design concept, where central iconic gestures were unobtrusively recognized as a way of providing additional visual resources for the dentist to draw in to the explanation of the teeth – part of the rationale for detecting these gestures is that because they are drawn from a repertoire of gestures, there are likely to be recurring gesture forms (e.g. the iconic gesture of the molar tooth) that would make gesture recognition feasible. Presumably, implementing such a system would involve assembling a corpus of tooth gestures and training the system to recognize these. Leaving aside the fact that repertoires of gestures are likely to vary from dentist to dentist and that as pointed out above, the forms of iconic tooth gestures are actually more variable than they first appear, the likely effect of such a system is that when dentists *want* additional resources to be displayed, they will *tailor* their gestures to what the computer system can recognize. In the terms of Kendon's continuum, this would mean that the gestures would start to become more language-like and emblematic. In fact, this is precisely the observation that Cassell makes of the gestures employed in many gesture interfaces (Cassell, 1998).

Consider also, the idea in the first concept of tying the orientation of the computer visualisation of the tooth to the orientation of the dentist's iconic gesture. Assuming that gesture recognition has been successfully performed, this would provide a logical and elegant solution for the otherwise fiddly task of adjusting the orientation of a visualisation on the screen. But as soon as the dentist starts to twist his or her gesture around in the air to control something on the screen, he or she is no longer *gesticulating* in the sense that McNeill takes as his focus.

A likely response to the issues raised here is that computers need to respond to a greater range of the aspects of human interaction, notably speech. A system could, also perform recognition on the spoken utterances of the dentist during sequences of tooth gesturing and use this as further information to disambiguate gestural input (Oviatt, 1999). This does not affect the point at issue however, which is that as long as people adapt *their* gestural performance for the benefit of better recognition, the kind of gestures that gesture interfaces employ is likely to be different to 'natural' gesticulation. Continuing to improve unobtrusive gesture recognition is a worthwhile undertaking for gesture interface research, but it is also worthwhile considering a broader range of views of gesture for the kinds of gesture interfaces that we can make today. I turn to this in the next section.

6.4 We need a broader conception of gesture

Gesture classification of the kind undertaken in the previous section could be useful for gesture interface design. It is also an important part of the research of McNeill. However, it is important to realise that for *neither* side is classification of gestures an end in itself. For gesture interface design, the final objective is to produce interactive systems that can respond to gesture in useful ways. For McNeill's research, the objective is to shed light on the cognitive mechanisms underlying speech and gesture production. Note the difference between these ends – the production of interactive systems in support of particular modes of interaction on one hand and the production of analytic accounts in support of particular research objectives on the other.

In the literature review, a gap was identified between conceptions of gesture in the traditions of gesture interface research and research into human gesture exemplified by McNeill. A response to this gap proposed by several gesture interface researchers, is that the conventional meaning of gesture has been distorted within gesture interface research and it would be better to concentrate on the communicative gestures accompanying speech that are studied by communication-focussed gesture researchers such as McNeill (Cassell, 1998; Quek et al., 2002).

This thesis proposes a different response. The point of departure is to suggest that gesture interface designers should first focus on designing gesture interface systems that are useful for people within authentic contexts of use. This was the approach I took in designing a gestural interface for the dental surgery context. I engaged in a participatory design process where I studied dentistry work, developed design concepts with dentists and evaluated a working prototype in three separate dental surgeries. From such an approach, it is more important that the overall interface is a good fit for the context than that a particular gestural interaction adheres to a pre-existing definition of gesture. Rather, the notion of 'gesture' becomes part of the *language game* by which design is carried out (Ehn, 1988) – a kind of sensitizing concept around that allows an understanding of gesture to emerge through the design process, that makes sense in relation to an evolving design concept and the context of their work.

In the case of the Tilt-Roll-Wave concept, the gestural interactions combine continuous tilting gestures and a limited set of pre-defined 'hand-waving' gestures. These are similar to gestures employed in many other gesture interfaces, where 'manipulative' and 'semaphoric' gestures have been commonly used (Quek et al., 2002) and the evaluations carried out with the dentists showed that this was a promising approach to the interaction with the patient record in the context of the dental surgery. However, the gestures employed by the Tilt-Roll-Wave concept are clearly different than the kinds of gestures that McNeill takes as his focus.

The argument from Cassell and others that gesture interface research should pay more attention to the kinds of communicative gestures that are studied by researchers such as McNeill is therefore highly pertinent. In this section, I address this gap in conceptions of 'gesture' from a different perspective. I suggest that it is perhaps not a problem that needs to be resolved, but a natural result of the different research objectives of these two fields. In my design project, I relied on a participatory design process rather than existing research into human gesture to inform the development of the design. From this perspective, one might argue that gesture interface design can get along perfectly well without theory. I don't go quite this far. I think that existing research into human gesture can be useful for gesture interface design, but rather than narrowing on a single conception of gesture, it would be of more benefit for gesture interface research to take into consideration a *broader* range of approaches to human gesture research.

The main problem to address is that there are characteristics of gestures specific to their context of production where gesture designers could profitably respond to them, but which are systematically excluded from the communication-focussed gesture research exemplified by McNeill. I first consider some of the other kinds of communicative gestures that have been studied within research into human gesture and where 'tooth gesturing' might fit in relation to these. Next, I move on to a discussion of a continuum gestures from communicative to manipulative kinds, based on the observations from the last chapter about the roles that gesture plays in relation to the coordination of work in the dental examination. The aim is to flesh out the broad working definition of gestures that was presented in the introduction of the thesis by bringing in a range of viewpoints on gesture and discuss how these can be brought to bear on the understandings of the work of dentistry. Following this, I return to a discussion of my design concept in the light of this broader conception, before concluding the chapter.

6.4.1 Repertoires and Kendon's continuum

McNeill's focus on communicative gestures is a common distinction made by many researchers into human gesture, but not all researchers focus so exclusively on *gesticulation*. As was presented in the literature survey, the different kinds of communicative gestures have been studied by researchers into human gesture can be arranged on a continuum, which is known as Kendon's continuum. In this continuum, different kinds of communicative gestures are arranged based on their relationship to speech. Gesticulation, the kind of gesturing that McNeill takes as his focus, is positioned at one end of the continuum and as one moves away from this, gestures become progressively more conventionalised, independent of speech and language-like.

As the analysis of the preceding sections and the previous chapter shows, the communicative purpose of gestures was certainly important in the way that gestures were employed in the dental examination. The dentist was adept at translating the terminology and concepts of dentistry to be understandable by the patient. Sequences of 'tooth gesturing' play a central role in this. I have already noted that these sequences of gestures have a practiced quality. I speculated that the dentist would repeatedly encounter the need to explain concepts such as these and could thereby build a *repertoire* of gestures to support him in this. This idea of a repertoire of practiced gestures presents us with something of a distinction from McNeill's focus on *spontaneous* communicative gestures, which is worth exploring further.

In order to clarify how *repertoires* might relate to other kinds of communicative gestures, we can try to place them on Kendon's continuum. As I have already argued, repertoires of tooth gestures are close to the form of gesticulations that McNeill takes as his focus. They are plainly not speech-linked gestures, pantomimes, emblematic gestures or signs from conventionalised sign languages. Yet the notion of a gesture that draws from a repertoire of previous experience would also seem at odds with the definition of gesticulation as *spontaneous idiosyncratic communicative movements accompanying speech*. I have therefore placed a grouping of repertoires between the categories of gesticulation and speech-linked gestures on the continuum. In order to reflect the tentative nature of this placement and categorisation, I have kept the grouping off the 'main line' of the continuum (Figure 56).

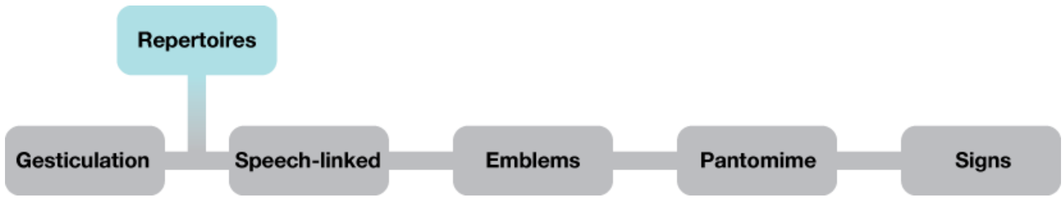


Figure 56: 'Repertoires' placed on Kendon's continuum.

Some support for this positioning can be drawn from existing studies of home-signing, which is the spontaneous emergence of sign-systems among deaf children growing up without exposure to formal sign-languages (Goldin-Meadow, 1995). Studies have shown how the signs of these children can emerge from more spontaneous gestures. The example already mentioned in the literature survey was of a boy who initially performed an elaborate sequence of gestures showing the mounting and starting of a motorcycle, which on subsequent performances became stylized to a simpler 'revving' hand gesture (Scroggs, 1981, as reported in Kendon 1995).

These observations show how initially spontaneous gestures can evolve into more standardized forms within a stable interactional setting. In this sense, a salient point of difference with the dental surgery is that sequences of tooth gesturing are performed for a new patient each time. Repertoires are not fully spontaneous gesticulations, because the dentist is well practiced at giving these kinds of explanations, but neither can they evolve into more 'language-like' forms, because the patient lacks the same familiarity with them.

Other researchers into human gesture have also suggested the existence of gesture repertoires. For instance, Kendon has focussed many of his studies of the use of gestures in informal face-to-face conversation within a southern Italian context. Within this particular cultural setting, the use of conventionalized emblematic gestures is common and much of Kendon's work has been concerned with the way that speakers from this part of Italy incorporate these kinds of gestures into their interaction (Kendon, 2004). Results of these studies suggest the existence of a common set of hand shapes and movement patters that form what Kendon calls "…a repertoire of representation techniques" (Kendon, 2004, p. 318). The notion of a repertoire of gestural forms has also been proposed within a study of gestural activity at a car mechanic (Streeck, 2002). This study proposed a relation between the practical activities that these people carry out in the course of their work and the gestures that they make – an observation which is discussed in further detail in the next section.

By contrast, most of the studies carried out by McNeill use a standard experimental set-up where a person is shown an animated cartoon and is then asked to recount the action in the cartoon to a second person that has not seen it. The person recounting the cartoon is not told that the purpose of the study is to analyse gesticulation, just that the study is about communication. Within such an experimental set-up it is unlikely that people would possess any pre-existing repertoire of gestures for describing cartoons and it's not surprising that the gestures produced would be spontaneous. The point here is not to challenge the validity of studying gesture within such a setting; but simply that *it is a setting*, just as are the settings of southern Italians, home-signers, mechanics, and dentists.

This raises an important issue, which is that in relation to the work of a dental examination, what makes sequences of tooth gesturing interesting is not that they suggest the existence of an abstract category of *repertoires* of gestures, but that they do a particular kind of work within the unfolding examination. Tooth gestures are important because they help with the job of patient education. We have already seen how a detailed analysis of the different kinds of gestures comprising sequences of tooth gesturing can be useful for understanding the ways that these sequences of gesturing work. It is also worth understanding how they are *situated* within the unfolding sequence of activities of the dental examination (Figure 57).

Discussing the toothache — Taking the x-ray — Describing tooth shape — Cold-pellet test

Figure 57: Investigating the toothache.

In the previous chapter, I showed how the sequence of gesturing about the shape of a molar tooth could be seen as a response to a disparity between the patient's reported experience of pain and the indications from the x-ray and visual inspection of the tooth that pain would be unlikely. In this sense, the 'molar tooth' gestures could be seen both as an explanation of the shape of a molar tooth and also as a way of accommodating these disparities and providing a motivation for subsequent work such as the cold pellet test that was carried out later. In serving as one of the means by which the dentist explains concepts of the teeth and jaw to the patient, tooth gestures support the work of patient education. But also, beyond the immediate explanatory purpose (and by virtue of it), tooth gesturing also serves to make the patient more knowledgeable, allows the patient to be in control of their teeth and understand why a particular treatment might be necessary. On this point, gesture interface researchers should be mindful of the ways in which gestures are *situated* within a particular context (Suchman, 1987), not least when we seek to bring existing categorical schemes to bear in helping us tease apart the details of how those gestures are performed.

6.4.2 Coordinating gestures: from communication to manipulation

In this section I want to move on from communicative gestures, to consider a wider range of purposes that gestures might serve in the dental surgery. Although the *communication-focussed* group of researchers into human gesture are the most well known within the gesture interface research community, there are other strands of research into human gesture which take a broader view of gesture and that gesture interface research could benefit from drawing on these. What I want to do in this section is work with extending our conception of gesture from communicative gestures through to manipulative gestures. An area from the previous chapter where this played out in an interesting way was in the analysis of the way that gestures (broadly conceived) support the cooperative aspects of the work of the dental examination by allowing the dentist, assistant and patient to coordinate their activities.

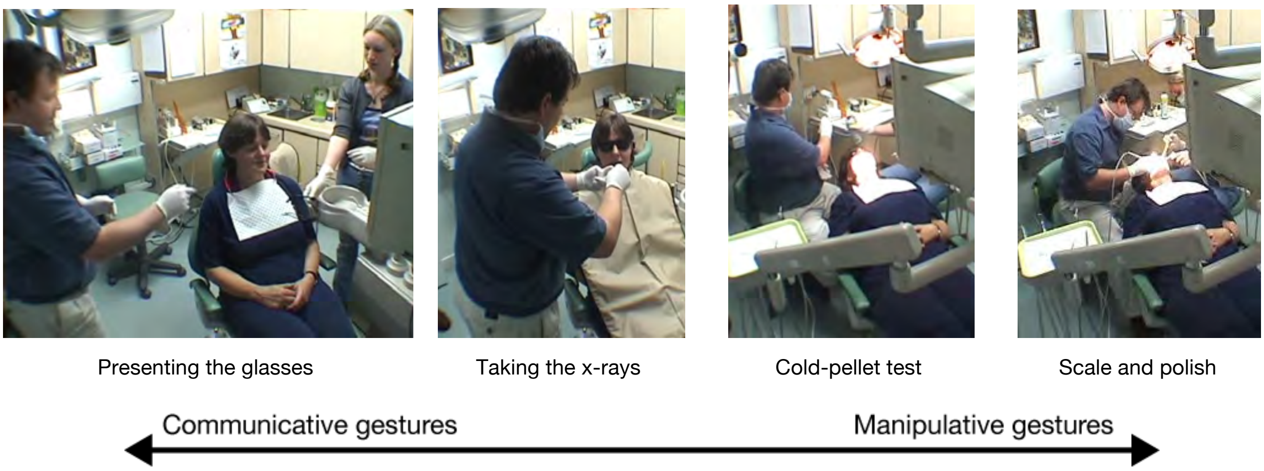


Figure 58: A continuum from communicative to manipulative gestures.

As I showed in previous chapter (section 5.4), the dentist, assistant and patient all need to coordinate their actions to get the work of the examination done and gestures play an important role in this coordination. For the purposes of the present discussion, the examples I presented can be arranged on a continuum from more communicative to more manipulative in quality (Figure 58). These examples have already been discussed in detail in the previous chapter, so the point here is not go into a lot of new analysis of them. Rather, it is to suggest some additional literature that might give additional insights into these gestures and help to 'flesh out' a broader understanding of gestures.

At the left-most end of the continuum is the example where the dentist and assistant presented glasses to the patient. In this example the dentist used only speech and gesticulation to talk to the patient and direct her attention to the assistant. The assistant passed the glasses to the patient but she did it in a rather gesture-like way, similar to a beat gesture, by timing the presentation of the glasses so it coincided with the dentist's speech and his own deictic gesture. I argued that the way the assistant waited with the glasses held ready for the patient to take them but slightly back from the patient's main line of view *until the dentist mentioned them* evidenced an anticipation on her part that they would become relevant to the interaction.

In relation to this example, some work from the tradition of ethnomethodological workplace studies in CSCW seems particularly relevant. Hindmarsh and Pilnick have studied the work of administering anaesthesia and the way that anaesthetists and anaesthetic assistants coordinate their activities around a patient during this process

(Hindmarsh & Pilnick, 2002). In their analysis, they adapted the concepts of 'front-stage' and 'back-stage' from Goffman's regions metaphor for social performance (Goffman, 1959). These concepts were used to help explain the ways that the anaesthetists and assistants organize their interaction around the patient and differentiate between those parts of work that are available to the patient (front-stage) and those that take place outside of the patient's awareness (back-stage). In many work settings, there is a physical separation between front and back-stage areas of work, such the walls in a store that separate the customer-facing counter from the staff-only storage areas. Anaesthesia is different, in that the perceptual field of the patient, which is limited by the patient's recumbent position in a hospital gurney and varies as he or she progresses from wakefulness to sleep, is what separates front-stage from back-stage activities (Hindmarsh & Pilnick, 2002).

Hindmarsh and Pilnick convincingly demonstrate that anaesthetists and assistants orient to this limited and varying perceptual field as they work. The anaesthesiologist tends to work front-stage, dealing with the patient and explaining the procedure, while the assistant works back-stage, regulating the operation of the anaesthesia equipment. Further, they show how a back-stage for collaboration between anaesthetist and assistant can be established fleetingly through interaction, within otherwise front-stage work by subtle glances, gestures, and careful design and timing of utterances. In one example, it was observed that during an anaesthetist's explanation to the patient of what the effects of the gas would be, the assistant reached out to and touched the gas dial while looking at the anaesthetist – ready to begin increasing the flow of gas at a time appropriate to the explanation. This reaching out and turning was not only performed as an instrumental action, but was carefully designed to *show* an awareness of the anaesthetist's explanation to the patient and to *provide* the anaesthetist an awareness of the assistant's readiness with the gas.

A remarkably similar dynamic seems to be at play in the cooperative work of the dental examination. Looking at the example of presenting the glasses in these terms, we can say that the dentist was dealing with the front-stage activities of greeting the patient, discussing what was to be done in the examination, and getting the patient seated in the chair. Meanwhile, the assistant was occupied with the back-stage activities of bringing materials into the dental surgery for use in the examination (the bib, x-ray film, lead apron and glasses). The dentist stood to the left of camera in front of the patient, whose attention was directed to him as they talked. Meanwhile, the assistant moved around behind the patient and in the right side of the room leading to the internal laboratory.

Importantly, these front-stage and back-stage activities were not entirely separate strands of activity, because some of the materials that the assistant brought in needed to be placed *on the body* of the patient. These materials therefore needed to be moved from back-stage to front-stage at opportune moments. The picture above shows the moment where the assistant 'reached in' to the front-stage area of the dentist and patient's conversation to present the glasses for the patient to wear (Figure 58, left). Recall how, in the example the assistant stood for some time just to the side of the patient waiting for the moment to present the glasses coincident with the dentist's speech and gesture. To carry the stage metaphor a little further, this is like 'waiting in the wings' for the right moment to make an entrance on to stage. In the analysis of the previous chapter, I described the presentation of the glasses in this case as a *unified gestural performance* from the dentist and assistant. To explicate this idea a little in the light of the front-stage/back-stage idea, what I meant by this is that the assistant moved the glasses forward (from back-stage) *at the same moment* as the dentist referred to them verbally and with a pointing gesture (from front-stage). The dentist did not 'direct' the assistant with his gesture, nor did the assistant 'prompt' the dentist with her presentation of the glasses. Rather, it was the simultaneous production of gestures from *both* the dentist and assistant that cued the *patient* (the audience) to the required action.

Hindmarsh and Pilnick suggest that being able to read the 'interaction trajectories' of the embodied conduct of colleagues is part of the *professional vision* (Goodwin, 1994) of expert practitioners, which allows collaborative work such as anaesthesia to unfold without explicit cues and directions to action between participants. In this reading of the conduct of colleagues, gestures and practical actions are intimately entwined. As they write:

> "The bodily movements are intelligible, at least in part, with regard to the objects and artifacts being manipulated and over and around which gestures are formed and designed" (Hindmarsh & Pilnick, 2002, p. 160).

The close relation between gestures and physical objects and artefacts is also a feature of the next example on the continuum, which was where the dentist instructed the patient how to bite down on the x-ray film. In this example, the dentist's gestures were closely related to the physical artefact of the x-ray film, how this would be put into the patient's mouth and how the patient should bite down on it.

On this point, the studies of the gestures of a motor mechanic carried out by Streeck are instructive (Streeck, 2002). He showed how a car mechanic employed communicative gestural forms, which were directly tied to the physical manipulative gestures of repair and interaction with the mechanical components of the engine. In several examples, a mechanic employed a 'cranking' gesture, based on the physical action of turning a key in the ignition of a car, and a 'flipping' gesture connected to the physical actions of removing and rotating a part of the carburettor.

This focus on the connection between communicative and manipulative gestural activity resonates with the observation that the physical artefact of the x-ray film serves as a kind of 'bridge' between the communicative gestural activity of the dentist and the physical actions of placing the film into the mouth and biting down on it. It highlights that gestural explanations about activities in the surgery are not disembodied exchanges of representational forms, but enacted embodied movements directly linked to the manipulative activities to which they refer. As Streeck argues, the link between communicative and manipulative gestural activity is insufficiently acknowledged in studies of gesture. As he writes of the field:

> "Gesture is theorized in line with a philosophical tradition that disembodies the mind and communication. But gesture, far more than other modalities of communication, highlights the bodily foundations of conceptual systems" (Streeck, 2002, pp. 19-20).

From this perspective, studies of gestural activities in practical domains such as the car mechanic's (and the dental surgery) offer the advantage of better seeing the connection of communicative gestural activity and lived bodily cognition. This is certainly supported by the findings of my studies of the gestures involved in the cooperative work of the dental surgery.

The third example in the continuum above is the one where the dentist and assistant together prepared a cold-pellet test. The gestures and movements in this example were less directly communicative or tied to speech. However, the way the dentist and assistant moved during the preparation of the cold pellet test served not only to effect that preparation, but also to coordinate their movements and communicate to one another how to move. I suggested that the gesture of the dentist as he progressively brought his upturned hand into a position where it could receive the cold-pellet test from the assistant as a kind of 'gesture of request', not unlike the gestures that dinner guests might make in requesting and passing items along a table.

The area of gesture studies in which these kinds of gestures have been most closely studied is in developmental psychology, where studies of the gestural behaviour of infants are used as a way to understand and track social development (e.g. Messinger & Fogel, 1998) or in the study of non-human primates, where gestures are studied as a way of assessing cognitive abilities of great apes (e.g. Tomasello, 2007). This research points to a central developmental role for such gestures in the acquisition of social and cognitive skills. For example, Messinger and Fogel studied the occurrence of what they call 'proto-imperative' gestures between infants of 9-15 months of age and their mothers (Messinger & Fogel, 1998). These included gestures used to request, where the arm was held out toward an object, and gestures used to offer, where an object was held out to an interaction partner. Such gestures can have both an instrumental function (of gaining possession of a desired object) and an expressive function (of using an object to make social contact with a partner). Studies of the development of home-signing in deaf children have also shown how children make gestures by reaching out towards objects. These studies have shown how even such relatively simple gestures can lead to the emergence of more structured language-like gesture forms (Goldin-Meadow, 1995).

Surprisingly, given the important role that such gestures have been shown to play in infant development, this kind of gestural interaction appears to have been little studied in adults. Whereas studies of request gestures in infants tend to concentrate on *enumerating* the occurrence of such gestures and their relation to other communicative forms (e.g. vocalisations). It would also be valuable to have studies of these kinds of gestures in adults, which paid attention to the specific expressive *forms* that they take (e.g. whether conciliatory, relaxed, demanding and so on) and the pragmatic functions this plays in interaction. It would also be very interesting to see the role that such gestures play in more complex cooperative activities, such as the cold pellet test, which is not only the request and passing of an object from one person to another, but also involves the collaborative manipulation and preparation of the object during the process of exchange.

At the right-most end of the continuum is the ‘four-handed dentistry’ example. In this example, the dentist and assistant worked together in the mouth of the patient during the scale and polish of her teeth. The movements of the dentist and assistant were more continuously focussed on the task of scaling the teeth of the patient, with short breaks to allow the patient to rest her jaw and, in the excerpt presented in the previous chapter, in response to an explicit gesture of discomfort from the patient.

Compared to the other examples presented, this is the one that involved the most directly ‘manipulative’ gestures. As such, we will have to look elsewhere than the communication-focussed gesture research such as McNeill’s, for insight into these gestures. This is for the simple fact that this area of research defines gestures as communicative movements, so would not consider manipulative movements gesture at all. However, as pointed out in the literature survey, an area of research in which such movements *are* considered as gestures is in the emerging field of the anthropology of movement. Notably, the anthropologist Ingold presents a view of gesture as *skilled movement*.

In one paper, Ingold uses a description of the process of sawing a plank of wood as an illustration of some themes in relation to a process of skilled action (Ingold, 2006b). Ingold begins by pointing out that even a simple task, such as sawing, is not a discrete step in an operational sequence (of for instance assembling a bookshelf); but instead has a *processional* quality, meaning that it is made up of a number of smaller steps, where each is itself also not discrete but “…is a development of the one before and a preparation of the one following” (Ingold, 2006b, p. 67). Such activity has a journey-like quality and as with a journey, recognizable phases are recognizable within it. Ingold identifies these as: getting ready, setting out, carrying on, and finishing off. We can use them to help analyse the rhythms of activity within the process of cleaning the teeth of the patient.

The first of these phases, ‘getting ready’, describes the process of assembling the materials required for the activity and forming an initial conception of the work to be done. With the example of sawing the plank of wood, Ingold describes this as involving the bringing together of the plank, the trestles and saw, the marking of a line for the cut with a pencil across the width of the plank, and resting his knee and palm down to bring his weight down on to the plank. Getting ready then, is not a pure, detached and 'in-the-head' process of planning, but one in which a thinking agent is thoroughly engaged with the material world. In the case of the 'four-handed dentistry', this involved the dentist and assistant selecting the required instruments and plugging them in to the hoses, which provide their power, suction, air and water, looping their hands underneath these hoses so that they fell down over the back of the hand and moving closer to the mouth of the patient. In the case of dentistry, which is work *on* the body of another person, getting ready also involves getting the patient ready. Thus, as the dentist was bringing the ultrasonic-scaler instrument up to the mouth of the patient, he gave a little demonstration of its functioning by holding it out in front of her and pressing the button to show how the water came out.

'Setting out' describes the moment in the process where attention shifts from the process of rehearsal and preparation to beginning the performance itself. To illustrate this, Ingold describes the first few tentative back-stokes of the saw made to mark the beginnings of a cut from which to proceed. In the example of the 'four-handed dentistry', we see this where the dentist and assistant brought their instruments into the mouth of the patient to begin the process of cleaning the teeth. As was pointed out in the example, there was a subtle back and forth between the actions of the dentist and assistant at this point. The dentist first brought his mirror into the mouth and then positioned the ultrasonic-scaler, before retracting it slightly to make space for the assistant. At this point, the assistant brought the suction instrument into the mouth, then the air instrument, adjusted the angle of these in the mouth before the dentist brought the ultrasonic-scaler back into position. Ingold describes how the initial backward cuts of the saw serve to establish a guide along which subsequent cuts can follow. In the same way, the initial positioning and angling of the dentist and assistant's instruments established a configuration of instruments and hands within which the process of working around the next segment of the mouth could proceed.

'Carrying on' is what we might think of as the 'main part' of an activity. In the example of sawing a plank of wood, this is where the sawer switches from the initial establishing strokes into the steady rhythm of the cut. In the case of the example of the 'four-handed dentistry' this was where once the dentist and assistant had their instruments in place and began cleaning the teeth. In this phase of the activity, the dentist bent his head slightly forward as he gradually engaged the ultrasonic-scaler with the teeth. The dentist held the instrument in a pen-like grip as his hand moved in slow rotations from the wrist. He held the mirror delicately, maintaining and adjusting its position relative to the progressing ultrasonic-scaler. The movements of the assistant with her instruments had a steady quality. She held the suction instrument in a stable position and made small dabbing movements from time to time. She kept the air instrument at a consistent angle, which she gradually adjusted as the other instruments moved around the mouth. Whereas Ingold's example of sawing a plank of wood highlights the tuning of the rhythm of the saw to the line of the cut, here we see how the rhythms of the movements of the dentist and assistant were tuned to the progression of cleaning across the teeth in the mouth as well as to the rhythms of each other's movements.

Ingold describes how in proceeding from 'carrying on' to 'finishing off', attention shifts to the final part of the activity. In the case of the saw, as the cut nears the edge of the plank, the sound of each successive stroke drops in pitch. The sawer moves one hand under the free end of the plank to gradually take the weight and prevent the plank from splintering at the end when the waste wood comes free. In the case of the 'four-handed dentistry' example, there comes a point within the rhythm of the work where the patient needs to be given a rest. The dentist and assistant coordinated the removal of their instruments at this point, like they did when bringing the instruments into the mouth. The dentist removed his instruments and leant back from the mouth, but the assistant leant forward and used the extra space made available to make some quick dabs with the suction instrument to remove the saliva and water, which had built up in the patient's mouth. Once she had done this, she also removed her instruments leant back. The patient closed her jaw while the dentist and assistant waited with their instruments held up, ready to lean forward for the next section of cleaning.

The significance of this for gestures is that for Ingold, gestures are the ways in which the 'stories' of tools are 'told' through use. The function of a tool is not inherent in the tool itself, but only exists in relation to the capacities for that tool to be *brought into use* by skilled practitioners. Skilled manual gestures are in this sense what *make* a tool. They are the means by which the function of a tool is realized. Concomitantly, a practitioner's capacities for skilled gesture are also what *make* a hand more than merely a complex arrangement of muscles and tendons. As Ingold writes:

> "But the hands I use in sawing are more than that. They are skilled. Concentrated in them are capacities of movement and feeling that have been developed through a life-history of past practice. What is a hand if not a compendium of such capacities, particular to the manifold tasks in which it is brought into use, and the gestures they entail? Thus while hands make gestures, gestures also make hands. And of course, they make tools too. It follows that gesture is foundational to both tool-making and tool use. The point would be obvious were it not for a certain conceptual blindness that causes us to see both bodies and tools out of context, as things in themselves" (Ingold, 2006b, p. 73).

Contrast this with the following view expressed by researchers from within gesture interface research (writing in collaboration with McNeill):

> Gesture and manipulation are clearly different entities sharing between them possibly only the feature that both may utilize the same body parts. (Quek et al., 2002, p. 173).

The examples in this section are intended to challenge the idea that so categorical a boundary can be drawn around where one kind of gesture stops and another begins. What they show, rather is that gestural activity of different kinds are intricately linked to one another and the context in which they are situated.

6.4.3 Gestures should be seen as situated activity

The notion of context is important here, and allows us to make a link to broad debates within HCI over the notion of context and how this relates to the kinds of computational support we might provide for work. Broadly, this debate can be seen as centring on two different views, in the fields of context-aware and ubiquitous computing on the one hand, and CSCW on the other (Chalmers, 2004). On one side, there has been a strong tendency in context-aware and ubiquitous computing to see context as an underlying structure of information that can be described and extracted from a work setting (e.g. Kirsh, 2001) or easily objective features that can be recorded from physical sensors in the environment, such as location, identity, and status (Dey et al., 2001). In contrast, views within CSCW have tended to focus on intersubjective aspects of context (Chalmers, 2004) and the notion of context as a dynamic construct of ongoing situated action (Greenberg, 2001). The view of context taken here can be seen as firmly within the second of these two traditions. It also resonates with more recent attempts to provide a common foundation for conceptualizing context based on an embodied interaction approach (Dourish, 2001). What studies such as mine can offer in relation to understandings of context is a view on the fine-grained moment-to-moment interrelations between context and particular practices of embodied gestural conduct.

It is particularly important that the understanding of gestures that we develop for gesture interface design retains a link to the context of their production, and this has been a point of emphasis throughout my analysis and discussion of the gestures of dentistry. This is a choice in favour of widening the frame of what we consider a gesture, rather than narrowing it down. In the next section (the final of this chapter) I take up a discussion of the Tilt-Roll-Wave concept in light of the ideas discussed so far, and consider what implications they might have for the further development of the design and for the relation between theory and the design process.

6.5 Returning to design

The discussion of this chapter has so far been focussed on existing research into human gesture and how this might relate to the ways that we understand the gestures of the dental examination. I have discussed in detail the taxonomy of gesticulation offered by McNeill, as well as a range of other strands of gesture research that offer a broader view of gestures. It is now time to return to the research question that this dissertation seeks to address, which is to reflect on the appropriateness of existing research into human gesture for the design of a gesture interface within an authentic context of use.

A key methodological decision of this dissertation was to engage in the design of a gesture interface for an authentic context of use as part of the research approach. The motivation for this was to ground my discussion of the appropriateness of existing research into human gesture for the purposes of gesture interface design. Therefore, throughout the design process, I was familiarising myself with a range of gesture research (much of it discussed in this chapter) and of course, some of this had an influence on how I was engaging with gesture in the design process. However, I expressly did *not* take a pre-existing theoretical framework of definition of gesture as my starting point for how to approach the design. It was more the case that these ideas formed part of the background of knowledge, along with all the other information that was generated through the design process. I aimed to make the Tilt-Roll-Wave concept accountable to the needs of the context of the dental examination, as realised through an extended process of participatory design, rather than to any pre-existing theoretical view on gestures. The gestural interactions were arrived at through a process of observing the existing work of dentistry, engaging with the technology of gesture detection to understand what it's capabilities were, and working with dentists in the context of the dental surgery to see whether these interactions could be used to interact with their existing computer software.

6.5.1 The Tilt-Roll-Wave concept

The Tilt-Roll-Wave concept is designed to address one particular problem within the work of the dental examination, which to allow the dentist to select and annotate teeth on the electronic patient record when working close to the mouth of the patient. The literature in this chapter has been drawn in to a much broader discussion of the roles that gesture plays in helping explain aspects of the teeth and jaw to the patient, the coordination of the work of the dental examination and the idea that gestures can be conceived of as lying on a continuum from more communicative to more manipulative kinds. It would be unrealistic to expect that a single, specific design response to embody such a broad range of ideas, but nevertheless there are some links we can make between the design concept and some of ideas that have been discussed in this chapter.

The gestural interactions that the Tilt-Roll-Wave prototype employed were a mixture of tilting gestures, used to select a particular tooth on the patient record and 'waving' gestures, used to make a particular annotation on the tooth. As such, it combined aspects of manipulation and semaphoric gestural interactions, which are typical of gesture interfaces (Quek et al., 2002), but these were decidedly not the gesticulations that McNeill takes as his focus and it is hard to imagine how McNeill's research could be made applicable to this particular design. This provided a motivation for trying to develop a broader conception of gesture from existing research into human gesture, as presented in the previous section. What I want to do now is return to my design process and reflect on the final design concept that emerged in the light of the broader views of gesture presented in the previous section. The purpose is not to look for post-hoc justifications for the design decisions, but rather to look for areas where the theory could give additional insight into the design, suggest areas for further investigation and shed light on findings from the final evaluation of the working prototype.

A distinctive characteristic of the Tilt-Roll-Wave prototype is that it is a *gestural instrument.* It is a physical artefact that people can pick up and gesture *with* to interact with a computer application, which contrasts with a style of gesture interface that emphasises *detecting* the gestures that a person makes, either through the use of computer vision techniques or through the use of sensors worn on the body. As a gestural instrument, then, the Tilt-Roll-Wave concept in some way embodies the idea of continuity between communicative and manipulative gestures. This is a valuable perspective for gesture interface design, because it allows for gesture interfaces to be positioned as not just sensing systems that detect and respond to communicative gestures, but also as systems that provide resources with which people can act in gestural ways. This is an area in which the broader conceptions of gesture developed in the previous section are particularly applicable.

The work of Ingold is especially relevant, because it highlights the close link between skilled gesture and tool-use. Consider the finding from the collaborative design evaluations with the prototype of the Tilt-Roll-Wave concept that the absolute mode was preferred over the relative mode for changing a selection on the tooth. Whereas with the relative mode, the dentist would hold the instrument at an angle to move the selection cursor one tooth at a time in the direction of the tilt, in the absolute mode each tooth in the mouth was mapped to a separate angle, so a tooth could be selected directly by tilting the instrument to the correct angle. Even with a relatively simple difference such as this, it seems the skill involved plays out in subtly different ways. Recall how one dentist remarked of the absolute mode that it would be like playing the violin. He suggested that one could learn to select the teeth by angle in the same way that a violinist finds the positions for notes on the neck of the instrument. In contrast, with the relative mode of selection, one of the dentists soon discovered that the instrument could just be held at a constant angle and the selection cursor moved a tooth at a time with a single button press. This relates quite clearly to one of Ingold's points about skill – that skill involves not only the application of manual force, but qualities of care judgement and dexterity (Ingold, 1997). Thus, although the absolute mode of selection would require more precise control over the angle at which the instrument is held, there would also be the possibility for building a skill with the interaction, such that each gesture is also able to *do* more.

Another finding from the evaluation, which seems relevant in this respect, is the importance that all the dentists placed on the *sensitivity* of the instrument. Taking another of the points about skill made by Ingold, the skilled gestural activity of the dentist is not a property of his hands alone, but of a total field of relations (Ingold, 1997). The instruments that the dentist uses as part of the work of dentistry are therefore a part of the field of relations that allow a dentist to *be* skilled. A gestural instrument needs to work well *as* an instrument if a dentist is to work well as a dentist.

The ideas presented in the last section about how gestures are made around artefacts and the bodies of other people are also relevant, given that the Tilt-Roll-Wave concept presents us with an artefact that can be gestured with. Streeck's observation that people working in manual domains build repertoires of gestures based on their practical manual activities is interesting. Dentists already engage in fine tilting movements as part of their work. So Streeck's ideas would provide some support for the idea of taking these as the basis for another kind of gestural interaction. This is not to naïvely assume that the tilting gestures a dentist makes for the benefit of a computer application will be anything like those that he makes as a part of his current work. But it does seem reasonable to assume that by virtue of the dentist's practice and skill at engaging in these kinds of movements, that he would be well placed to engage in similar (physically) kinds of movements for other purposes. It would bear further investigation to assess how this would play out in actuality.

Ingold's identification of the processional phases of skilled activity would also be useful, for thinking about *when* and *where* the movements employed by the Tilt-Roll-Wave concept would fit within the stream of skilled activity of the dental examination. This would suggest that we should go and observe the way the work unfolds during the parts of the examination where the instrument would be employed.

Examining the tooth Dictating the observation Explaining to the patient

Figure 59: Rhythms of examining, dictating and explaining.

In the case of the Tilt-Roll-Wave concept, it was intended that the dentist would make use of the interface during the initial examination of the teeth. The rhythm of work was quite different during this phase of the work, the dentist followed rhythm where he first looked in the patient's mouth to examine some part of the teeth, then looked up to the computer screen as he dictated an observation to the assistant before finally turning to the patient to explain what this meant. Each of these different parts of the activity occupied a different space in the surgery, had a different posture and different kinds of movements (Figure 59).

A main design motivator for this project was that the interactions between the dentist and the computer are clumsy and disrupting to the flow of the work. It would be better, it is assumed, if the dentist could be given a way to interact with the computer that was not such an interruption to the other activities. A rationale for the Tilt-Roll-Wave concept would therefore be that it could 'move' some of the work of recording an observation about the teeth closer to the part of the work where the dentist is examining the teeth (Figure 59, left). Specifically, by allowing the dentist to keep his hands close to the mouth of the patient while changing the selection cursor on the electronic patient record. In terms of the phases identified by Ingold discussed in the previous section, the aim would be to make the tilting and waving gestures of the instrument part of the 'finishing-up' of each bout of examination of the mouth. Questions about how this would practically be achieved were a feature of the evaluations and a finding from these were that dentists had a clear preference for directions of tilt within the mouth (Figure 45). Ingold's work would suggest a more detailed examination of how these gestures would be made as part of the procession of skilled gestures within the mouth as the dentist looks at the mouth each time.

Another idea discussed in the previous section that relates to this is the idea of front-stage and back-stage aspects of the work of the dental examination and the roles that gestures play in managing the distinction between these parts of the work. From this perspective, the sequence of activity within which the Tilt-Roll-Wave concept is intended to be used contains elements of both front-stage and back-stage work (Figure 59, middle). When the dentist dictates information to be entered into the computer, it is in the language of dentistry, employing specialist dentistry terms and the tooth-numbering system to identify which tooth is being annotated. Though this talk is done 'in front' of the patient, the fact that it is carried out in a language that the patient is not familiar with means that in some sense it is also a 'back-stage' activity. From this perspective, allowing the dentist to control the selection of the cursor on the patient record with the tilting gestures would move this part of the interaction more to the 'back-stage', because the dentist would no longer have to say aloud the tooth-numbers and could instead make the selection with a more subtle tilting gesture.

In contrast, the waving gestures would remain quite visible to the patient and it would be worth investigating whether these raise more questions than just saying the annotations aloud. For instance, by saying something like 'pro-gnathic', the dentist has a verbal token that he can refer to in subsequent explanation to the patient. He can introduce his explanation by saying, "what that's saying there is". If language such as this were replaced by gestures, what would the dentist have to refer back to ('that gesture there means')? This resonates with the finding from the evaluation that the dentists preferred 'waving' gestures to be discrete and unobtrusive. One suggested quick small directional flicks. Another suggested a small set of letter codes that could be 'drawn' with the head of the instrument.

The final point I want to discuss with respect to the Tilt-Roll-Wave concept is how in more general terms, the examples discussed in the previous section were all concerned with the roles that gestures play in relation to the coordination of the work of dentistry. The common theme of coordination of work was a convenient way of comparing a range of different kinds of gestures, from communicative to manipulative in relation to a single aspect of the work of dentistry. Though the Tilt-Roll-Wave concept was not itself developed with a central concern for *supporting* the cooperative nature of the work of the dental examination it is likely that given the intensely cooperative nature of the work of the dental examination, any new interface created for this context would need to be brought into the cooperative aspects of the work. For instance, the device is not intended as a replacement for the keyboard and mouse and so there would still be a role for the assistant in entering notes into the computer. Considering Hindmarsh and Pilnick's studies of coordination between anaesthetists and their assistants, it would bear further investigation into the ways that assistants and dentists might coordinate their activity around the instrument.

The discussion of this section has suggested some areas in which the broader conceptions of human gesture from existing theory can be useful for design. I have shown elements from this research can be used to explain findings from the evaluation of the design, reason about the kinds of interactions that a gesture interface might involve, and suggest areas for further investigation. However, as is the case with the research of McNeill, the research discussed here was not developed for designing gesture interfaces, so we must be somewhat circumspect with respect to the claims we make for this research in relation to design. Though we can find ways to apply ideas from this research to design, it seems that in terms of the criteria for discussing the appropriateness of theory presented at the start of the chapter, the strength of these broader views of gesture seems mainly to be on their descriptive and rhetorical power. They help us to understand and describe gestures as they occur in existing settings. There would also seem to be considerable rhetorical power in a concept such as *skill,* which is not only a central part of Ingold's view of gesture, but also a core value in the participatory design approach (Ehn, 1993)

6.6 Chapter Conclusion: Theory as a contingent resource for design

The aim of this chapter has been to reflect on the appropriateness of existing research into human gesture for gesture interface design. I took the work of McNeill as a starting point, because of his prominence within gesture interface research relative to other research into human gesture, and because the argument has been made in the gesture interface literature that the kind of gestures that McNeill takes as his focus would also be a better goal for gesture interface design than the kinds of gestures it has employed up until now, because they would be more natural and intuitive for people to use (Cassell, 1998; Quek et al., 2002).

I believe that this argument is flawed and limiting for gesture interface design. The argument is flawed, because it is likely that as soon as we employ 'natural' human gestures for computer interaction, the nature of those gestures will change. They will evolve into more stable sign-like forms as people tailor their gestures to the recognition abilities of the computer. The argument is limited, because it cuts out a range of gestural interactions could usefully be employed in gesture interfaces. Rather than narrowing down to a single pre-existing definition of what kinds of movements to consider for gesture interfaces, we would do better to open up for a range of views from existing research into human gesture that have, as yet, barely been considered in gesture interface research. It is hoped that the discussion of this chapter contributes a small step in this direction.

It must be emphasised this is emphatically an argument in favour of bringing more voices to the table, so to speak – not a rejection of one strand of research for another. As I showed in the first part of the chapter, McNeill's theoretical framework can be usefully applied to analysing some of the gestures of the dental examination. I also showed how it could be applied to further developing one of the design concepts from early in the design process. In terms of the criteria for discussing theory presented at the start of the chapter, McNeill's work stands out for it's descriptive power. Even though the taxonomy of gestures that he presents is not a central part of his work, it is very useful to have a small set of relatively easy to understand categories for distinguishing different kinds of gestures made during gesticulation.

In the second half of the chapter, I introduced a range of broader conceptions of gesture and discussed these in relation to the examples from the previous chapter on the roles that gestures play in relation to the coordination of the work of dentistry. Because the object of this section was to give as diverse a view of gestures as I could, I took a line from communicative to manipulative gestures as an organizing principle. Whereas much gesture research uses a dichotomy between communicative and manipulative movements to define communicative gesture as *separate* from manipulative movements (Nespoulous et al., 1986), the aim in my discussion was to conceive of a *continuum* of different kinds of gesture. I drew on existing research to show how this could be usefully applied to understanding the kinds of gestures that took place in these examples. Again, in terms of the criteria for discussing theory, this research seemed to have strong descriptive power. Concepts of front-stage and back-stage from Hindmarsh and Pilnick along with Ingold's identification of the phases of skilled activity were particularly useful distinctions for thinking about and describing gestural interactions. In Ingold's case, the notion of *skill* also seems to be useful for its rhetorical power. Naming some aspect of interaction as *skilled* is a powerful statement, which suggests for design that care should be taken to preserve these aspects of the work or find ways to support them with future systems. The broader view offered by these conceptions of gesture would also seem to have implications for *how* we carry out design, which relates to the idea of application power. They suggest the need to engage with the context in which gestures are produced in order to understand how they are situated, how they flow one from another, how they relate to the materials and artefacts of the setting, and how people employ them to coordinate their activities. This would support a design approach such as participatory design, which emphasises direct engagement with the people and context of design (Greenbaum & Kyng, 1991).

As part of the process of discussing the findings of the last chapter in relation to this range of existing theory, the view of the role that gestures play in the dental examination was developed further and several new insights emerged. The notion of gesture repertoires was further developed and related to other kinds of communicative gesture on Kendon's continuum. Based on insights from the development of home signing, it was suggested that an important interactional dynamic in the development of gesture repertoires is that the dentist must perform them anew for each patient, which 'pushes back' against them evolving into more stable language-like gestures. The idea of unified gestural performances was also analysed in detail with respect to the front-stage/back-stage metaphor so show how the actions of the dentist and assistant *together* cue the patient to action. The way that artefacts and instruments support gesturing was also explicated with reference to Streeck's studies of the gestures of car mechanics, and Ingold's work was used to structure a detailed analysis of the fine manual gestures involved in the process of four-handed dentistry.

The focus of this chapter has been squarely on theory, but it is important not to lose sight of the fact that it was *through a process of design* that I arrived at the Tilt-Roll-Wave concept. The discussions of this chapter have shown that there are some areas in which existing research into human gesture can help understand the role of gestures in the context of the dental examination and suggest possible further avenues for design development with the Tilt-Roll-Wave prototype and the earlier 'tooth-stone' concept.

Yet my design process turned up a good deal of specific and design-relevant information about the work of dentistry *without* explicit recourse to theory. As was pointed out earlier, while I was engaged in the design process, I was familiarizing myself with existing research into human gesture and this can be thought of has forming a background against which the design was undertaken, but this research was really only one of the resources informing my design activity. I was also guided by my knowledge of design methods, familiarity with existing research into gesture interfaces, by going out and learning about the practice of dentistry, and by engaging in a participatory design process with dentists to investigate gesture as a mode of interaction for their work.

Theory is just one of a number of possible resources that can be brought to bear on a design process. It is vitally important that in discussing theory, we do not lose sight of this fact and fall into the naïve view that simply adopting some pre-existing theoretical view of gesture from other field will somehow guarantee that gesture interfaces will be better or more natural for people to use. Indeed, it may be significant that many of the more successful theoretical approaches within HCI (e.g. Distributed Cognition, Activity Theory, Grounded Theory) are those that incorporate a strong commitment to ethnographic practice as an integral part of their research methods. This raises the possibility that the efficacy of these theoretical approaches is as much to do with this methodological commitment to 'go where the action is' rather than the theoretical constructs and frameworks themselves (Halverson, 2002).

Though my attention throughout the thesis has been focussed on the work of McNeill, it is important to emphasise that this as an issue for the adoption of *any* pre-existing theoretical framework for gesture interface design. The point of course is not that theory cannot be useful for gesture interface design – clearly it can. Theory should be assessed in the context of its role in the larger design process (Rogers, 2004). The usefulness of theory will therefore be *contingent* on the purposes to which it is put and the particulars of the design context.

This suggests that designers should view existing theory as a *contingent resource* for design. This view should not be controversial, even if it is sometimes forgotten. As Rogers notes, "…it is foolish to assume or hope that theories 'do design', however much the proponents of the theoretical approach would like" (Rogers, 2004, p. 129). This entails an approach toward existing theory whereby gesture interface designers are prepared to assess each setting anew and seek out those aspects of the work that are unique to their context of application. Theory is just one of the resources available to designers to support them in their endeavours, alongside design methods, technical means, access to willing domain experts and their own skill as designers. These resources should be seen as interdependent and mutually supporting. In practice "…theories must be made actionable through relevant tools, methods and processes" (Forlizzi & Battarbee, 2004, p. 261) and like any of these resources, becoming competent in theory "…takes learning and experience, and sensitivity for the particulars of the context" (Rogers, 2004, p. 106).

The role of existing theory is still important. Their role should be seen as to sensitise designers to some of the variety and complexity of gestures they are likely to encounter. How we frame movement for gesture interface design is a centrally important topic for gesture interface research. The discussion of this chapter has tried to demonstrate that choosing a theoretical frame has direct implications for what is or is not considered a gesture. By drawing the frame tight, it may be possible that we gain some descriptive power, but the danger is also that gestures that could usefully add to people's abilities for skilled action are dismissed out of hand. There is a *rich diversity* of views of gesture available to gesture interface design from existing research into human gesture, not just a few well-known researchers.

Chapter 7: Conclusions and Implications

The field of gesture interface research has so far been dominated by a technical research agenda. For the most part, it has focussed either on solving the challenges of detecting and recognizing gestures, or exploring the possibilities for interaction made possible by technical advances. The related questions of (1) how to design gesture interfaces for authentic contexts of use and (2) how existing research into human gesture can inform design have received much less attention. It is to these neglected areas of gesture interface research that this dissertation is targeted. It makes four main contributions.

First, it contributes to the practice of gesture interface design with methods for engaging participants in dialog about gesture for the design process and by demonstrating the value of designing for an actual context of use. In addition to demonstrating the appropriateness of existing methods from the tradition of participatory design, new methods were developed to analyse gestures, to investigate spatial relations, to explore relations between gestures and notions of professionalism in dentistry and to make sensing technologies available for design process participants to experience and discuss.

Second, it provides a model for employing design as an integral part of the research process. If gesture interface research is to move beyond a technical focus, it is vitally important that researchers begin to engage more seriously in design for authentic contexts of use and report on their experiences of this as part of their research. This thesis proposes a model of *design-engaged research* where design forms a foundation for research activities and a grounding for subsequent detailed analysis.

Third, it contributes a detailed analysis of the role that gestures play in the accomplishment of a dental examination. This analysis reveals the astounding breadth and detail of gestural interactions that comprise dental work and emphasises the situated nature of gestures within the context of their production. This suggests that further studies of the role of gesture in authentic work contexts can enrich gesture theory.

Fourth, it contributes to the field of gesture interaction research with a broader conception of gestures from existing research into human gesture than has been the case until now. Through a reflection on the work of the prominent gesture researcher McNeill, I showed that though there are some useful aspects of his theoretical framework for gesture interface design, there are also significant limitations because of the way it focuses in on one particular kind of gesture – gesticulation. A range of broader views on gesture were offered, which are more appropriate to understanding the roles of gesture in a cooperative work context such as dentistry and in relation to skilled gestural activity.

7.1 Starting with Design

The point of departure for this dissertation came with a recognition of the differences in the ways that 'gesture' has been conceived between the fields of gesture interface research and research into human gesture. Others have also highlighted these differences (Quek et al., 2002; Cassell, 1998) and proposed that gesture interface research could benefit from existing research on human gesturing. Notably, Cassell made profitable use of the theoretical framework of McNeill to inform the design of so-called 'Embodied Conversational Agents'. Whereas other researchers have approached this question by starting with theory and investigating how it can be applied to design, I have worked in the other direction. I first engaged in a process of designing a gesture interface for a particular work context and then used this experience as to ground a detailed analysis of the role of gestures in current work practice and reflect on the appropriateness of existing research into human gesture for the design of gesture interfaces.

7.1.1 Designing for the Dental Surgery

I undertook to design a gesture interface to support the work of the dental examination. The dental surgery proved to be a highly appropriate setting within which to carry out the research project. First, it provided a plausible setting for the design of a gesture interface, since there were clear problems with the use of existing computational technologies that gesture-based interfaces seemed suited to address. Second, it provided a rich environment within which to study the role of gestures in the achievement of practical work.

In a dental surgery, the dentist and assistant work with specialised instruments within an environment carefully structured to support their practice. The work of dentistry is intensely cooperative. The dentist, assistant and patient must all coordinate their actions for the successful achievement of dental procedures. Dentists and assistants also use refined physical movements in the operation of their instruments. When explaining concepts to the patient, dentists employ elaborate gestures to illustrate aspects of the teeth and mouth. The patient responds with talk and gestures of their own, demonstrating understanding, or inviting further elaboration.

Software systems that provide support for information management aspects of dentistry are a relatively recent addition to this work context. Functions provided by such systems include the maintenance of patient records and treatment plans, management of billing and scheduling, tracking of material usage and support for patient education. Despite the utility of these features, a key problem for the use of specialised dental software systems is that they are designed to run on office computers using standard input devices such as keyboards and mice. This interface configuration is suited to use by a single user who has access to a flat stable surface, can maintain a restricted set of movements and is able to focus on a narrow range of pixels. In comparison, the dental surgery context lacks readily available flat stable surfaces, has various competing items of attention, is often cramped and requires practitioners to follow infection control procedures. Input devices developed for an office-work environment are not well suited to the dental surgery.

The difficulty of using traditional office input devices in the dental surgery is especially apparent during the updating of the patient record during a dental examination. Dentists must find a way to interact with the computer system without violating infection control procedures, which prohibit moving directly from the patient's mouth to an input device such as a keyboard or mouse. Dentists interviewed for this research project demonstrated several ways to overcome this problem. One method was to employ removable covers for input devices that could be replaced or wiped clean between examinations. Another method was for the assistant to remove their gloves and 'drive' the interface while the dentist dictated observations. Neither of these is an entirely satisfactory solution. The former solves the problem of infection control by introducing additional procedures and requires the dentist to put down his instruments and transfer attention away from the patient to the mouse and keyboard. The second reduces the assistant to the task of responding to dictations when he or she could otherwise be preparing for upcoming procedures.

In the face of these interaction difficulties, I investigated the possibility of using gesture as an alternative input mode to aid in the access and updating of the electronic patient record. I saw gestures as attractive for the possibility that they might:

- Allow for more freedom for dentists in terms of how they move and arrange themselves in space
- Be responsive to the dentist's existing abilities for skilful movement
- Allow dentists to interact with the electronic patient record without violating infection control procedures.

7.1.2 Design Process

In my design project, I took a participatory design approach to investigate the possibilities for employing gesture as an input modality in the context of the dental surgery (Greenbaum & Kyng, 1991). For me, this approach was particularly important in terms of the attitudes it takes to how designers should engage with the people they design for. From a gesture interface design perspective, I found the focus of participatory design on acknowledging and respecting the skill of participants especially useful (Ehn, 1993). It helped me to see the gestures that the dentists made as entwined with a skilled professional practice and not simply manifestations of a more general gestural behaviour. In more concrete terms, this design approach also provided a suite of proven design methods from which I was able to draw in engaging with the dental surgery. I carried out field studies where I observed and recorded instances of dentistry, interviewed dental practitioners about their work, developed prototypes and scenarios for their use, discussed these with dental practitioners and engaged them in collaborative design activities to move the design concepts further.

A particularly interesting finding that would bear further investigation, was the way these methods were able to engage the *gestural* abilities of design process participants. For instance, engaging design process participants in developing and acting out scenarios was an effective way of scaffolding their ability to generate and reflect on gestures. Similarly, providing participants with prototypes not only allowed for discussion of prototype form and features, but also supported discussion of how one might gesture with them, because it gave participants something to gesture *with.* The implication of this for participatory design practice is that the design process is itself an activity involving gestures of various kinds. Re-considering well-known design methods as ways for entering into a gestural dialog would seem a promising avenue for further research and might shed new light on the reasons for the more general utility of these methods.

I also developed new methods specific to the design problem I was engaged in. The Meaning in Movement activity was developed to enquire into how professional values of dentistry could be reflected in the movements and gestures of dentists. The value of the exercise was not only in the stated objective, but also in how it served as a test-bed for engaging design process participants in a discussion about gestures. It highlighted the importance of carrying out such exercises in the context of a dental surgery and relating to dental practitioner's knowledge of the processes of dentistry. The importance of the physical setting within which gestures are made and the knowledge that people have of their work when they gesture became important themes in my subsequent analysis.

A second method I developed was to present the sensing technology that my prototype used so that it would be easier for participants to experiment with the new movements that a gesturally sensitive instrument would enable and suggest alternative configurations. I developed a removable package containing acceleration sensors that could be easily attached to prototype instrument forms along with software to receive and decode signals from the sensor package and several simple representations of this data in both graphical and audio form. This approach of making technology more available for experience would seem worth exploring in any interaction design project where new technologies play an enabling role.

7.1.3 Design Concept 'Tilt-Roll-Wave'

The final design concept I arrived at in this design process was for a gestural instrument that the dentist could use to make selections and simple annotations on the electronic patient record. I called this concept Tilt-Roll-Wave after the movements that it responded to. Tilting the mirror from side to side would change the selected tooth on the patient record. Rolling the mirror back and forth could then select a surface on the tooth. Waving the instrument by performing one of a small number of pre-defined gestures could make a notation on the record for the tooth. The concept was developed into a working prototype and evaluated in three separate dental surgeries. These evaluations showed that the concept was a promising approach for interaction with an electronic patient record, and provided detailed findings about requirements for such a system. There are several notable aspects of this design concept that bear highlighting here.

Firstly, the design concept consists of an instrument with which the dentist must actively gesture rather than a system that unobtrusively detects the dentist's gestures. The latter approach is rather more common in gesture interface research. Usually gesture interfaces are designed with the aim that the gesture sensing technology should be as unobtrusive in its activation as possible. Typical technical configurations in this vein are camera-based systems where the user must simply be in line of sight of the camera (e.g. Bauer & Kraiss, 2002) or systems where the user wears the gesture sensing technology, such as in glove-based systems (e.g. Sturman & Zeltzer, 1994). The rationale for this approach is that gestural interactions should be as natural as possible. Therefore, a goal is for open-handed interactions and systems that can automatically detect gestures from an on-going stream of movement data. However, the flip side of this is that the user must rely on the system interpreting which of his or her movements are to be directed towards the system as gestures. The alternative I took of providing an instrument that the user must actively gesture with means that the act of using the instrument is itself a signal that the associated gesture is intended for the computer.

A second interesting characteristic of the design concept is that the movements it uses are based on observations of and discussions with dentists about the kinds of movements that are available when they are working in the mouth of a patient during an examination. It attempts to respond to dentists' skill for fine positioning and tilting adjustments of the mirror when working in the mouth of the patient. Also, the switch in posture when moving from the tilting and rolling actions to the waving action is based on observations of the typical posture of the dentist's hand when holding the mirror in the mouth of the patient and their ability to quickly change the way the mirror is held in their hand. An aim for the concept is that it would fit within the flow of skilled gestural activity of the dentist's examination of the patient's teeth (Ingold, 2006b).

The design concept is not intended as a wholesale replacement of dental practitioners' existing use of computer and mouse interfaces for updating the electronic patient record. Instead it is envisaged that keyboards and mice would continue to be used in the surgery but that such a gestural instrument would provide an additional resource around which the dentist and assistant could interact with the computer and coordinate their work.

Finally, by including the tilting and rolling movements along with a limited number of pre-defined gestures the design concept draws together movements that would normally be considered as different types by most definitions of gesture (such as McNeill's). An important notion here is that movements such as tilting or rolling can attain gestural import by virtue of their placement in the unfolding of the work. It is envisaged that the tilting, rolling and waving movements of the design concept would in many cases be carried out in concert with talk by the dentist and in concert with the coordinated actions of the assistant, who might for example be engaged in making supplemental notes on the patient record. The physical location and discernable adjustment of a gestural instrument would be available to experience and orient to in a communicative and more typically gestural way (Hindmarsh & Pilnick, 2002).

The design process undertaken and design concept developed in this dissertation demonstrates the value of carrying out gesture interface research in an actual context of use. Until now, gesture interface research has been dominated by a technical research agenda, and often the actual interfaces designed have been more demonstrations of technical achievements than interfaces designed with consideration for an actual context of use. This is not to pitch design research in opposition to technical research, but rather to emphasise that gesture interface research as a field needs to do more to address the challenges of design along with the questions of technology and theory. Indeed, I see it as particularly valuable for research projects to look at how these different kinds of research questions can inform and enrich one another and that is the kind of approach I have taken here.

7.2 Engaging design as an integral part of research

Methodologically, the design project described above plays an unorthodox role in this dissertation. It was used to provide a ground against which a detailed analysis of the role of gestures could be made and the appropriateness of existing research into human gesture discussed. In a gesture interface research project more focussed on developing novel interface concepts or solving technical challenges, one would expect design to play a different role. Rather than providing the grounding for analysis, it would constitute the processes by which the interface concept is created or technical challenge met. The main research question of this thesis was to enquire into the appropriateness of existing research into human gesture for gesture interface design, so design needed to play a different roll. It served as grounding for a detailed analysis of the role of gestures in a dental examination and subsequent discussion of existing research into human gesture for gesture interface design.

This reverses the relationship between design and detailed analysis of work we might normally expect. Rather than carrying out analysis prior to design with the results of analysis presented as implications for design, in this thesis detailed analysis of the role of gestures in a dental examination was not undertaken until near the end of the design process. Rather than analysis providing implications for design it was more that the knowledge and experiences built through the design process provided motivations and grounding for the analysis. These motivations followed two main lines. First, I was motivated to develop a broader conception of gestures than McNeill's focus on gesticulation. I had seen that dentists' gesturing ranged across categories of communicative and manipulative movements and my design concept was built on this premise. Second, developing a design concept to support the specific work of the dental examination prompted me to see the specific ways that gestures related to this. I was motivated to give an account of gestures that acknowledged their situated nature (Suchman, 1987). This ranged from seeking to relate gestures to the temporal and spatial context of their production as well as to larger aims of dentistry, such as patient education, which had emerged as important concepts in the design process.

In the emerging field of design research, the validity of competing research approaches is currently much contested. The relationship between design and analysis in this dissertation is a novel approach to relating synthetic design activities to analytic undertakings. Through an analysis of debates within design research and HCI on the relation between research and design, I distinguished my research approach as *design-engaged research*, to capture the idea that this is research involving both an engagement *with* design as part of the research question and an engagement *in* design as an integral part of the research process. In terms of the commonly stated trio of research *for*, *about* and *through* design it is probably closest to research *through* design (Zimmerman et al., 2007), but it takes a slightly more conservative approach, since the analysis is made based on primary field data rather than a design response as such. One might rather say research motivated and informed by design. In this way it offers a useful alternative model for carrying out design research.

7.3 Understanding gestures in a dental examination

This dissertation contributes to the understanding of the role that gestures play in authentic work practice with a detailed analysis of one episode of activity from the context of a dental examination. After having carried out an extensive program of design engagement as outlined above, I undertook a detailed analysis of one recorded episode of dental work where a dentist and dental assistant performed an examination and cleaning of the teeth of a patient. The purpose of this analysis was to show the role that gestures (broadly conceived) played in the interaction and achievement of the examination.

I paid particular attention to two aspects of the role of gestures in the dental surgery. The first was the way the dentist used gestures to explain aspects of the teeth or jaw to the patient (tooth gesturing). The second was, the role that gestures play in how the dentist, assistant and patient coordinated their actions in the surgery.

The dentist used gestures to explain aspects of the teeth and jaw to the patient. I called this 'tooth gesturing' and showed how it related to what dentists called 'patient education'. Patient education encompasses the idea that by communicating concepts of dentistry to the patient and making them more knowledgeable about their teeth, the patient is better able to care for their teeth and understand the necessity of particular treatments. I also proposed that dentists are able to build and draw up on a *repertoire* of gestures when explaining aspects of the teeth and jaw to patients, a finding which is echoed by research in other contexts (Kendon, 2004; Streeck, 2002).

The work of dentistry is deeply cooperative. The dentist, assistant and patient all need to work together to successfully complete an examination. Gestures also play an important role in supporting the dentist, assistant and patient in coordinating their actions. People are able to coordinate their actions both through explicitly communicative gestures and also because of the gestural nature of practical actions (Hindmarsh & Pilnick, 2002). This provides a rather different view on the nature of coordinative mechanisms than is usually taken in studies of coordinative work in HCI, which often focuses on the informational artefacts around which coordination is done (e.g. Bardram & Bossen, 2005).

7.4 Broadening our conception of gesture

Given its prominence, the theoretical work of McNeill is likely to be many gesture interface researchers' first point of contact with existing research on human gesturing (McNeill, 2000). McNeill presents a clear and understandable taxonomy of gestures, which is in broad agreement with the classifications of other gesture researchers (Kendon, 2004, chap. 6). Further, researchers in the gesture interface researchers have profitably used his framework (Cassell, 1998) and McNeill has himself collaborated with gesture interface researchers (Quek et al., 2002). As yet the direction of travel between gesture theory and gesture interface design has largely been one-way: from theory to application and the awareness of research into human gesture from gesture interface research is mostly of communication-focussed gesture researchers such as McNeill. Where in-depth use of this theory has been made, the mode as been to use theory to suggest the form that gesture interfaces should take. In contrast, the process this dissertation presents moves in the other direction, from a particular design project back to a reflection on the appropriateness of theory.

I found that McNeill's theoretical framework was useful for describing some aspects of gesturing in the dental surgery in ways that would be useful for gesture interface designers. Especially in highlighting the different kinds of gestures, the different roles that these play in the gesturing, and the different forms that they take. Sequences of movement which one might normally refer to as 'hand gesturing' are likely to consist of intricately woven combinations of different kinds of gesturing. This is relevant for gesture interface design because it challenges the technical feasibility of detecting such movements, highlights areas for further investigation, and suggests alternative design approaches.

In other respects, I argued that McNeill's framework is limited for use by gesture interface designers in attempting to respond to a work context such as the dental surgery. Through a detailed discussion of several examples of gesturing related to the cooperative work of dentistry, I developed a view of gestures as ranging on a continuum from more communicative to more manipulative kinds. Relevant literature was brought into this discussion from traditions of ethnographic studies of work (Hindmarsh & Pilnick, 2002), studies of gesture in practical domains of activity (Streeck, 2002), developmental psychology (Messinger & Fogel, 1998) and anthropology (Ingold, 2006b). The range of literature and views on gesture that this opens up is vast and it has only been possible to give the barest sketch of the range of research that it might encompass here.

Of course, a difficulty of engaging with a wide diversity of research for gesture interface design is in knowing *which* parts to engage. In this, there seems a role for gesture interface researchers in exploring this diversity to begin to understand the kinds of design problems and contexts that different strands of existing research are suited to support. A long-term aim should be the development of organizing frameworks within which different strands of gesture research could be compared. Gesture interface design is a holistic and integrative process. This suggests that a research program aimed at better understanding and supporting gesture interface design be organised along similar lines. This is likely to require sustained program of research in which gesture interface designers try out and reflect upon gesture theory across a range of design projects.

A view that would be beneficial for gesture interface researchers to adopt in this undertaking would be to see theory as a *contingent resource* for design, along with all the other resources they have at their disposal. In order to build a sense of the range of contingencies that different theoretical framings will face as well as those aspects of the role of gesture that are more stable from setting to setting, studies of gesture interface design across a range of settings are required. Admitting that any theoretical framing is likely to be insufficient to capture *all* relevant aspects gesture for *all* design contexts, we must ensure that investigations into theory are carried out along with the development of methods, skills, supportive technologies and interface concepts. Designing for authentic contexts of use therefore needs to become an integral part of gesture interface research.

The point of all this is, in the end, to support the creation of computer interfaces that allow people more freedom in the ways they interact with computers and appropriate them into their work. If gesture interface researchers are to deliver interfaces that really are more natural, intuitive, expressive and enjoyable to use, then we must move beyond the narrow technical focus that has dominated our field. To achieve this, we must *broaden* the range of views for helping to understand gesture and *engage* in design with people in actual contexts of use, to find out which of these views are useful for design.

Chapter 8: Bibliography

Alexander, C. (1975). *The Oregon Experiment*. Oxford University Press, USA.

Alexander, C. (1979). *The timeless way of building*. Center for Environmental structure series ; v. 1. Oxford University Press US.

Alexander, C., Ishikawa, S., & Silverstein, M. (1977). *A pattern language: towns, buildings, construction*. Oxford University Press US.

Anderson, R. J. (1994). Representations and Requirements: The Value of Ethnography in System Design. *Human-Computer Interaction*, *9*(2), 151.

Archer, B. (1995). The nature of research. *Co-design*, 6-13.

Armstrong, D. F., Wilcox, S., & Stokoe, W. C. (1995). *Gesture and the nature of language*. Cambridge ; New York: Cambridge University Press.

Bardram, J. E., & Bossen, C. (2005). A web of coordinative artifacts: collaborative work at a hospital ward. In *Proceedings of the 2005 international ACM SIGGROUP conference on Supporting group work* (pp. 168-176). Sanibel Island, Florida, USA: ACM. doi:10.1145/1099203.1099235

Barthelmess, P., & Anderson, K. (2002). A View of Software Development Environments Based on Activity Theory. *Computer Supported Cooperative Work (CSCW)*, *11*(1), 13-37.

Bauer, B., & Kraiss, K. (2002). Towards an Automatic Sign Language Recognition System Using Subunits. In I. Wachsmuth & T. Sowa (Eds.), *Title: Gesture and Sign Language in Human-Computer Interaction: International Gesture Workshop, GW 2001, London, UK, April 18-20, 2001. Revised Papers*, Lecture Notes in Computer Science (Vol. 2298, pp. 64-75). Heidelberg: Springer-Verlag.

Benford, S., Schnädelbach, H., Koleva, B., Anastasi, R., Greenhalgh, C., Rodden, T., Green, J., et al. (2005). Expected, sensed, and desired: A framework for designing sensing-based interaction.

ACM Trans. Comput.-Hum. Interact., *12*(1), 3-30. doi:10.1145/1057237.1057239

Billinghurst, M. (1998). Put that where? voice and gesture at the graphics interface. *SIGGRAPH Comput. Graph.*, *32*(4), 60-63.

Binder, T., Brandt, E., Horgen, T., & Zack, G. (1998). Staging Events of Collaborative Design and Learning. In *5th ISPE International Conference on Concurrent Engineering* (pp. 369-378). Tokyo Metropolitan Institute of Technology, Tokyo, Japan.

Blomberg, J., Suchman, L., & Trigg, R. H. (1996). Reflections on a work-oriented design project. *Hum.-Comput. Interact.*, *11*(3), 237-265.

Blumer, H. (1954). What is wrong with social theory. *American Sociological Review*, *18*, 3-10.

Bødker, S. (1990). *Through the Interface: A Human Activity Approach To User Interface Design* (1st ed.). Lawrence Erlbaum.

Boehner, K., Vertesi, J., Sengers, P., & Dourish, P. (2007). How HCI interprets the probes. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 1077-1086). San Jose, California, USA: ACM. doi:10.1145/1240624.1240789

Bolt, R. A. (1980). “Put-that-there”: Voice and gesture at the graphics interface. In *Proceedings of the 7th annual conference on Computer graphics and interactive techniques* (pp. 262-270). ACM Press.

Borchers, J. O. (2001). A pattern approach to interaction design. *AI & Society*, *15*(4), 359-376. doi:10.1007/BF01206115

Braa, K., & Vidgen, R. (1995). Action Case: Exploring the middle kingdom in information system research methods. In *Proceedings of 3rd Decennial Conference Computers in context: Joining Forces in Design* (pp. 50-60). Århus, Denmark.

Braffort, A. (2002). Research on Computer Science and Sign Language: Ethical Aspects. In I. Wachsmuth & T. Sowa (Eds.), *Gesture and sign language in human-computer interaction: international Gesture Workshop, GW 2001, London, UK, April 18-20, 2001 : revised papers* (pp. xi, 321 p.). Berlin: Springer.

Brandt, E. (2007). How Tangible Mock-Ups Support Design Collaboration. *Knowledge, Technology & Policy*, *20*(3), 179-192. doi:Article

Brandt, E., & Grunnet, C. (2000). Evoking the future: drama and props in user centered design. In T. Cherkasky (Ed.), *PDC 2000, proceedings of the Participatory Design Conference, New York, NY, USA, 28 November - 1 December 2000* (pp. 11-20). Palo Alto, CA: Computer Professionals for Social Responsibility.

Brereton, M., Bidwell, N., Donovan, J., Campbell, B., & Buur, J. (2003). Work at Hand: An Exploration of gesture in the context of work and everyday life to inform the design of gestural input devices. In R. Biddle & B. Thomas (Eds.), *Fourth Australasian User Interface Conference (AUIC2003)*, ACM International Conference Proceeding Series (Vol. 18, pp. 1-10). Adelaide, South Australia: Australian Computer Society Inc.

Brereton, M., & Buur, J. (2008). New challenges for design participation in the era of ubiquitous computing. *CoDesign*, *4*(2), 101-113. doi:Article

Buchenau, M., & Suri, J. F. (2000). Experience prototyping. In *Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques* (pp. 424-433). New York City, New York, United States: ACM. doi:10.1145/347642.347802

Burns, C., Dishman, E., Verplank, W., & Lassiter, B. (1994). Actors, hairdos & videotape - informance design. In *Conference companion on Human factors in computing systems* (pp. 119-120). Boston, Massachusetts, United States: ACM. doi:10.1145/259963.260102

Buur, J., Binder, T., & Brandt, E. (2000). Taking Video beyond 'Hard Data' in User Centred Design. In *Participatory Design Conference*. New York: CPSR.

Buur, J., & Søndergaard, A. (2000). Video Card Game: An augmented environment for User Centered Design discussions. In *Designing Augment Reality Environments* (pp. 63-69). Elsinore, Denmark: ACM.

Buxton, W., Baecker, R., Clark, W., Richardson, F., Sutherland, I. E., Sutherland, W. R. "., & Henderson, A. (2005). Interaction at Lincoln laboratory in the 1960's: looking forward -- looking back. In *CHI '05 extended abstracts on Human factors in computing systems* (pp. 1162-1167). Portland, OR, USA: ACM Press.

Campbell, B. (2010). *Designing context-aware applications for complex environments* (Ph.D. dissertation). The University of Queensland, Brisbane, Australia.

Campbell, B., & Brereton, M. (2004). Designing to maintain human agency in context-aware systems. In *Artful Integration: Interweaving Media, Materials and Practices.* (pp. 97-100). Presented at the The Eighth Biennial Participatory Design Conference, Toronto, Canada. Retrieved from http://espace.library.uq.edu.au/view/UQ:100788

Campbell, B., Cederman-Haysom, T., Donovan, J., & Brereton, M. (2003). Springboards into Design: Exploring Multiple Representations of Interaction in a Dental Surgery. In S. Viller & P. Wyeth (Eds.), *OzCHI2003: New Directions in interaction, information environments, media and technology* (pp. 14-23). Brisbane, Australia: Information Environments Program, University of Queensland.

Carroll, J. M. (1996). Encountering Others: Reciprocal Openings in Participatory Design and User-Centered Design. *Human-Computer Interaction*, *11*(3), 285. doi:Article

Cassel, J., & McNeill, D. (1999). Speech-gesture mismatches : Evidence for one underlying representation of linguistic and nonlinguistic information. *Pragmatics & cognition*, *7*(1), 1-34.

Cassell, J. (1998). A framework for gesture generation and interpretation. In R. Cipolla & A. P. Pentland (Eds.), *Computer vision for human-machine interaction* (pp. 191-215). New York: Cambridge University Press.

Cederman-Haysom, T. (2009). *A Participatory Design Approach in the Engineering of Ubiquitous Computing Systems* (PhD Dissertation). The University of Queensland, Brisbane, Australia.

Retrieved from http://www.cederman.com/thesis.pdf

Cederman-Haysom, T., & Brereton, M. (2004). Designing Usable Ubiquitous Computing. In *Artful Integration: Interweaving Media, Materials and Practices.* (pp. 101-104). Presented at the The Eighth Biennial Participatory Design Conference, Toronto, Canada. Retrieved from http://espace.library.uq.edu.au/view/UQ:3016

Chalmers, M. (2004). A Historical View of Context. *Computer Supported Cooperative Work (CSCW)*, *13*(3), 223-247. doi:10.1007/s10606-004-2802-8

Checkland, P., & Holwell, S. (1998). Action Research: Its Nature and Validity. *Systemic Practice and Action Research*, *11*(1), 9-21. doi:10.1023/A:1022908820784

Coleman, M. L. (1969). Text editing on a graphic display device using hand-drawn proofreader's symbols. In M. Faiman & J. Nievergelt (Eds.), *Pertinent concepts in computer graphics : proceedings* (pp. 282-290). Urbana: University of Illinois Press.

Corradini, A., & Cohen, P. R. (2002). Multimodal Speech-Gesture Interface for Handfree Painting on a Virtual Paper Using Partial Recurrent Neural Networks as Gesture Recognizer. In *Proceedings of the International Joint Conference on Artificial Neural Networks (IJCNN'02)* (Vol. 3, pp. 2293-2298). Honolulu (HI, USA).

Corradini, A., Fredriksson, M., Mehta, M., Königsmann, J., Bernsen, N. O., & Johannesson, L. (2004). Towards Believable Behavior Generation for Embodied Conversational Agents. In *Computational Science - ICCS 2004* (pp. 946-953).

Crabtree, A., Hemmings, T., & Rodden, T. (2002). Pattern-based support for interactive design in domestic settings. In *Proceedings of the 4th conference on Designing interactive systems: processes, practices, methods, and techniques* (pp. 265-276). London, England: ACM. doi:10.1145/778712.778749

Crabtree, A., Nichols, D. M., O'Brien, J., Rouncefield, M., & Twidale, M. B. (2000). Ethnomethodologically informed ethnography and information system design. *Journal of* *the American Society for Information Science*, *51*(7), 666-682.

Dey, A. K., Abowd, G. D., & Salber, D. (2001). A conceptual framework and a toolkit for supporting the rapid prototyping of context-aware applications. *Hum.-Comput. Interact.*, *16*(2), 97-166.

Dietz, P., & Leigh, D. (2001). DiamondTouch: a multi-user touch technology. In *Proceedings of the 14th annual ACM symposium on User interface software and technology* (pp. 219-226). Orlando, Florida: ACM. doi:10.1145/502348.502389

Djajadiningrat, T., Overbeeke, K., & Wensveen, S. (2002). But how, Donald, tell us how?: on the creation of meaning in interaction design through feedforward and inherent feedback. In *Proceedings of the conference on Designing interactive systems* (pp. 285-291). ACM Press.

Donovan, J., & Brereton, M. (2004). Meaning in movement: a gestural design game. In *Proceedings of PDC2004 Artful Integration: Interweaving Media, Materials and Practices* (Vol. 2, pp. 163-166). Toronto.

Dourish, P. (2001). *Where the Action is: The Foundations of Embodied Interaction*. Cambridge Massachusetts: MIT Press.

Dourish, P. (2006). Implications for design. In *Proceedings of the SIGCHI conference on Human Factors in computing systems* (pp. 541-550). Montréal, Québec, Canada: ACM. doi:10.1145/1124772.1124855

Ehn, P. (1988). Playing the language-games of design and use-on skill and participation. In *Proceedings of the ACM SIGOIS and IEEECS TC-OA 1988 conference on Office information systems* (pp. 142-157). Palo Alto, California, United States: ACM. doi:10.1145/45410.45426

Ehn, P. (1993). Scandinavian design: On participation and skill. In D. Schuler & A. Namioka (Eds.), *Participatory Design: Principles and Practices* (pp. 41-77). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Ellis, T. O., Heafner, J. F., & Sibley, W. L. (1969). *The GRAIL project*. Santa Monica: Rand Corp.

Fallman, D. (2007). Why Research-Oriented Design Isn't Design-Oriented Research: On the Tensions Between Design and Research in an Implicit Design Discipline. *Knowledge, Technology & Policy*, *20*(3), 193-200. doi:Article

Farnell, B. (1999). Moving bodies, acting selves. *Annual Review of Anthropology*, *28*, 341-373.

Fitzpatrick, G. A. (1998, September 30). *The Locales Framework: Understanding and Designing for CooperativeWork* (Ph.D. dissertation). The University of Queensland, Brisbane, Australia. Retrieved from http://espace.library.uq.edu.au/view/UQ:158474

Floyd, C., Mehl, W., Resin, F., Schmidt, G., & Wolf, G. (1989). Out of Scandinavia: Alternative Approaches to Software Design and System Development. *Human-Computer Interaction*, *4*(4), 253-350.

Forlizzi, J., & Battarbee, K. (2004). Understanding experience in interactive systems. In *Proceedings of the 5th conference on Designing interactive systems: processes, practices, methods, and techniques* (pp. 261-268). Cambridge, MA, USA: ACM. doi:10.1145/1013115.1013152

Frayling, C. (1993). Research in Art and Design. *Royal College of Art Research Papers*, *1*(1), 1-5.

Friedman, K. (2003). Theory construction in design research: criteria: approaches, and methods. *Design Studies*, *24*(6), 507-522.

Gandy, M., Starner, T., Auxier, J., & Ashbrook, D. (2000). The Gesture Pendant: A Self-illuminating, Wearable, Infrared Computer Vision System for Home Automation Control and Medical Monitoring. In *Proceedings of the 4th IEEE International Symposium on Wearable Computers* (p. 87). IEEE Computer Society.

Gaver, B., Dunne, T., & Pacenti, E. (1999). Design: Cultural probes. *interactions*, *6*(1), 21-29. doi:10.1145/291224.291235

Goffman, E. (1959). *The presentation of self in everyday life*. Doubleday.

Goldin-Meadow, S. (1995). When does gesture become language? A study of gesture used as a primary communication system by deaf children of hearing parents. In K. R. Gibson & T. Ingold (Eds.), *Tools, language, and cognition in human evolution* (pp. 63-85). Cambridge, UK: Cambridge University Press.

Goldin-Meadow, S. (2005). *Hearing Gesture: How Our Hands Help Us Think*. Belknap Press. Retrieved from http://www.amazon.ca/exec/obidos/redirect?tag=citeulike09-20&path=ASIN/0674018370

Goodwin, C. (1994). Professional Vision. *American Anthropologist*, 2, *96*(3), 606-633.

Goodwin, C. (2000). Action and embodiment within situated human interaction. *Journal of Pragmatics*, *32*(10), 1489-1522. doi:doi:10.1016/S0378-2166(99)00096-X

Greenbaum, J. (1993a). A design of one's own: Towards Participatory Design in the United States. In D. Schuler & A. Namioka (Eds.), *Participatory Design: Principles and Practices* (pp. 27-37). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Greenbaum, J. (1993b). PD a personal statement. *Commun. ACM*, *36*(6), 47. doi:10.1145/153571.214816

Greenbaum, J. M., & Kyng, M. (1991). *Design at work : cooperative design of computer systems*. Hillsdale, N.J.: L. Erlbaum Associates.

Greenberg, S. (2001). Context as a Dynamic Construct. *Human-Computer Interaction*, *16*(2-4), 257-268. doi:Article

Halverson. (2002). Activity Theory and Distributed Cognition: Or What Does CSCW Need to DO with Theories? *Computer Supported Cooperative Work (CSCW)*, *11*(1), 243-267. doi:10.1023/A:1015298005381

Harrison, S., Tatar, D., & Sengers, P. (2007). The Three Paradigms of HCI. In *alt.chi*.

Heath, C. (2000). Configuring Action in Objects: From Mutual Space to Media Space. *Mind, Culture, and Activity*, *7*(1), 81. doi:10.1207/S15327884MCA0701&2_06

Heath, C., & Luff, P. (1992). Collaboration and control: Crisis management and multimedia technology in London Underground Line Control Rooms. *Computer Supported Cooperative Work (CSCW)*, *V1*(1), 69-94.

Henderson, K. (1991). Flexible Sketches and Inflexible Data Bases: Visual Communication, Conscription Devices, and Boundary Objects in Design Engineering. *Science Technology Human Values*, *16*(4), 448-473. doi:10.1177/016224399101600402

Hindmarsh, J., & Pilnick, A. (2002). the Tacit Order of Teamwork: Collaboration and Embodied Conduct in Anesthesia. *The Sociological Quarterly*, *43*(2), 139-164. doi:10.1111/j.1533-8525.2002.tb00044.x

Hinrichs, E., & Polanyi, L. (1986). Pointing the way: A unified treatment of referential gesture in interactive contexts. In *Proceedings of the Parasession of the Chicago Linguistics Society Annual Meetings (Pragmatics and Grammatical Theory). Chicago: Chicago Linguistics Society* (pp. 298–314).

Hoonaard, W. C. V. D. (1997). *Working with sensitizing concepts : analytical field research*. Qualitative research methods ; v. 41. Thousand Oaks: Sage Publications.

Ingold, T. (1995). Relations between visual-gestural and vocal-auditory modalities of communication. In K. R. Gibson & T. Ingold (Eds.), *Tools, language, and cognition in human evolution* (pp. 35-42). Cambridge, UK: Cambridge University Press.

Ingold, T. (1997). Eight themes in the anthropology of technology. *Social Analysis*, *41*(1), 106-138.

Ingold, T. (1999). 'Tools for the Hand, Language for the Face': An Appreciation of Leroi-Gourhan's Gesture and Speech. *Studies in the History of Philosophy Biololgy and Biomedical Sciences*, *30*(4), 411-453.

Ingold, T. (2001). Beyond art and technology: the anthropology of skill. In M. B. Schiffer (Ed.), *Anthropological perspectives on technology* (pp. 17-31). Albuquerque: University of New Mexico Press.

Ingold, T. (2006a). Up, across and along. *Studies in Environmental Aesthetics and Semiotics*, *5*, 21-36.

Ingold, T. (2006b). Walking the plank: meditations on a process of skill. In J. R. Dakers (Ed.), *Defining technological literacy: towards an epistemological framework* (pp. 65-80). Palgrave Macmillan.

Ishii, H., & Kobayashi, M. (1992). ClearBoard: a seamless medium for shared drawing and conversation with eye contact. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 525-532). Monterey, California, United States: ACM. doi:10.1145/142750.142977

Jensen, M. V. (2007). *Tangible Interaction in Industrial Plants* (Ph.D. dissertation). University of Southern Denmark, Sønderborg, Denmark.

Jones, J. C. (1992). *Design Methods*. John Wiley and Sons.

Jordan, B., & Henderson, A. (1995). Interaction Analysis: Foundations and Practice. *The Journal of the Learning Sciences*, *4*(1), 39-103.

Kendon, A. (1986). Current issues in the study of gesture. In J. Nespoulous, P. Perron, & A. R. Lecours (Eds.), *The biological foundations of gestures: motor and semiotic aspects* (pp. 23-47). Hillsdale, N. J.: Lawrence Erlbaum.

Kendon, A. (1990). Behavioral foundations for the process of frame-attunement in face-to-face interaction. In A. Kendon (Ed.), *Conducting interaction: patterns of behavior in focused encounters* (pp. 239-262). CUP Archive.

Kendon, A. (1995a). Human Gesture. In K. R. Gibson & T. Ingold (Eds.), *Tools, language, and cognition in human evolution* (pp. 43-62). Cambridge, UK: Cambridge University Press.

Kendon, A. (1995b). Gestures as illocutionary and discourse structure markers in Southern Italian conversation. *Journal of Pragmatics*, *23*(3), 247-279. doi:doi: DOI: 10.1016/0378-2166(94)00037-F

Kendon, A. (1997). Gesture. *Annual Review of Anthropology*, *26*, 109-128.

Kendon, A. (2004). *Gesture: Visible Action as Utterance*. Cambridge University Press.

Kirsh, D. (2001). The Context of Work. *Human-Computer Interaction*, *16*(2-4), 306-322. doi:Article

Kurtenbach, G., & Buxton, W. (1991). Issues in combining marking and direct manipulation techniques. In *Proceedings of the 4th annual ACM symposium on User interface software and technology* (pp. 137-144). Hilton Head, South Carolina, United States: ACM. doi:10.1145/120782.120797

Kurtenbach, G., & Hulteen, E. A. (1990). Gestures in Human-Computer Communication. In B. Laurel (Ed.), *The Art of Human-Computer Interface Design* (pp. 309-317). Reading, Mass.: Addison-Wesley.

Landauer, T. K. (1995). Let's get real: a position paper on the role of cognitive psychology in the design of humanly useful and usable systems. In *Human-computer interaction: toward the year 2000* (pp. 659-665). Morgan Kaufmann Publishers Inc. Retrieved from http://portal.acm.org.proxy1-bib.sdu.dk:2048/citation.cfm?id=212925.212986

Lanzara, G. F. (1991). Shifting Stories: Learning from a Reflective Experiment in a Design Process. In D. A. Schon (Ed.), *The reflective turn : case studies in and on educational practice* (pp. 285-320). New York ; London: Teachers College Columbia University.

Lehrdahl, E., & Pedersen, J. (2002). Space modelling and scenario play: Mastering complexity in the design of product networks. In *Proceedings of NordDesign*. Presented at the NordDesign, Trondheim, Norway: NTNU.

Lloyd, P. (2004). The paradox of the average: why users need designers but designers don't need users. *Design Philosophy Papers*, *1*, unpaged.

Löwgren, J., & Stolterman, E. (2004). *Thoughtful Interaction Design: A Design Perspective on Information Technology*. MIT Press.

Mackay, W. E., & Fayard, A. (1997). HCI, natural science and design: a framework for triangulation across disciplines. In *Proceedings of the 2nd conference on Designing interactive systems: processes, practices, methods, and techniques* (pp. 223-234). Amsterdam, The Netherlands: ACM. doi:10.1145/263552.263612

Matthews, B., Brereton, M., & Buur, J. (2001). Brick Games in Boardrooms: Making use context tangible. In *Proceedings of the 5th Design Thinking Research Symposium (DTRS 5): Designing in Context*. Delft: Delft University Press.

Maulsby, D., Greenberg, S., & Mander, R. (1993). Prototyping an intelligent agent through Wizard of Oz. In *Proceedings of the INTERACT '93 and CHI '93 conference on Human factors in computing systems* (pp. 277-284). Amsterdam, The Netherlands: ACM. doi:10.1145/169059.169215

McClave, E. (1998). Pitch and Manual Gestures. *Journal of Psycholinguistic Research*, *27*(1), 69-89.

McGarry, B. (2005). *Things to Think With: Understanding Interactions with Artefacts in Engineering Design* (Ph.D. dissertation). The University of Queensland, Brisbane, Australia. Retrieved from http://espace.library.uq.edu.au/view/UQ:8728

McNeill, D. (1992). *Hand and mind : what gestures reveal about thought*. Chicago: University of Chicago Press.

McNeill, D. (2000). *Language and Gesture*. Cambridge University Press.

McNeill, D. (2005). *Gesture and Thought*. University Of Chicago Press.

Messinger, D. S., & Fogel, A. (1998). Give and take: The development of conventional infant gestures. *Merrill - Palmer Quarterly*, *44*(4), 566-590.

Mistry, P., Maes, P., & Chang, L. (2009). WUW - wear Ur world: a wearable gestural interface. In *Proceedings of the 27th international conference extended abstracts on Human factors in computing systems* (pp. 4111-4116). Boston, MA, USA: ACM.

doi:10.1145/1520340.1520626

Morris, M. R., Huang, A., Paepcke, A., & Winograd, T. (2006). Cooperative gestures: multi-user gestural interactions for co-located groupware. In *Proceedings of the SIGCHI conference on Human Factors in computing systems* (pp. 1201-1210). Montréal, Québec, Canada: ACM. doi:10.1145/1124772.1124952

Moyle, M., & Cockburn, A. (2003). The design and evaluation of a flick gesture for 'back' and 'forward' in web browsers. In *Proceedings of the Fourth Australasian user interface conference on User interfaces 2003 - Volume 18* (pp. 39-46). Adelaide, Australia: Australian Computer Society, Inc. Retrieved from http://portal.acm.org.proxy1-bib.sdu.dk:2048/citation.cfm?id=820097

Nakaoka, S., Nakazawa, A., Yokoi, K., Hirukawa, H., & Ikeuchi, K. (2003). Generating whole body motions for a biped humanoid robot from captured human dances. In *Robotics and Automation, 2003. Proceedings. ICRA '03. IEEE International Conference on* (Vol. 3, pp. 3905-3910 vol.3).

Nespoulous, J., & Lecours, A. R. (1986). Gestures: nature and function. In J. Nespoulous, P. Perron, & A. R. Lecours (Eds.), *The biological foundations of gestures: motor and semiotic aspects* (pp. 49-62). Hillsdale, N. J.: Lawrence Erlbaum.

Nespoulous, J., Perron, P., & Lecours, A. R. (Eds.). (1986). *The biological foundations of gestures: motor and semiotic aspects*. Hillsdale, N. J.: Lawrence Erlbaum.

Newbury, D. (1996). Knowledge and research in art and design. *Design Studies*, *17*(2), 215-219. doi:10.1016/0142-694X(95)00025-M

Oviatt, S. (1999). Mutual disambiguation of recognition errors in a multimodel architecture. In *Proceedings of the SIGCHI conference on Human factors in computing systems: the CHI is the limit* (pp. 576-583). Pittsburgh, Pennsylvania, United States: ACM. doi:10.1145/302979.303163

Pausch, R., & Williams, R. D. (1990). Tailor: creating custom user interfaces based on gesture. In *Proceedings of the 3rd annual ACM SIGGRAPH symposium on User interface software and technology* (pp. 123-134). ACM Press.

Pavlovic, V. I., Sharma, R., & Huang, T. S. (1997). Visual interpretation of hand gestures for human-computer interaction: a review. *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, *19*(7), 677-695.

Pedersen, J., Buur, J., & Djajadiningrat, T. (2003). Field Design Sessions: Augmenting Whose Reality? *International Journal of Human-Computer Interaction*, *16*(3), 461. doi:10.1207/S15327590IJHC1603_5

Pentland, A. P. (2000a). Perceptual user interfaces: perceptual intelligence. *Commun. ACM*, *43*(3), 35-44. doi:10.1145/330534.330536

Pentland, A. P. (2000b). Looking at people: sensing for ubiquitous and wearable computing. *Transactions on Pattern Analysis and Machine Intelligence*, *22*(1), 107-119. doi:10.1109/34.824823

Pirhonen, A., Brewster, S., & Holguin, C. (2002). Gestural and audio metaphors as a means of control for mobile devices. In *Proceedings of the SIGCHI conference on Human factors in computing systems: Changing our world, changing ourselves* (pp. 291-298). Minneapolis, Minnesota, USA: ACM. doi:10.1145/503376.503428

Quek, F., McNeill, D., Bryll, R., Duncan, S., Ma, X., Kirbas, C., Mccullogh, K. E., et al. (2002). Multimodal Human Discourse: Gesture and Speech. *Transactions on Computer-Human Interaction*, *9*(3), 171-193.

Rabiner, L. R. (1989). A tutorial on hidden Markov models and selected applications in speech recognition. *Proceedings of the IEEE*, *77*(2), 257-286.

Rasmussen, J. (2000). Human factors in a dynamic information society: where are we heading? *Ergonomics*, *43*(7), 869 - 879.

Reeves, S., Benford, S., O'Malley, C., & Fraser, M. (2005). Designing the spectator experience. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 741-750). Portland, Oregon, USA: ACM. doi:10.1145/1054972.1055074

Rettig, M. (1994). Prototyping for tiny fingers. *Commun. ACM*, *37*(4), 21-27. doi:10.1145/175276.175288

Rogers, Y. (2004). New theoretical approaches for human-computer interaction. *Annual Review of Information Science and Technology*, *38*(1), 87-143.

Rogers, Y., Bannon, L., & Button, G. (1994). Rethinking theoretical frameworks for HCI: report on an INTERCHI '93 workshop, Amsterdam, 24\–25th April, 1993. *SIGCHI Bull.*, *26*(1), 28-30. doi:10.1145/181526.181530

Rogers, Y., & Muller, H. (2006). A framework for designing sensor-based interactions to promote exploration and reflection in play. *Int. J. Hum.-Comput. Stud.*, *64*(1), 1-14.

Roth, W., & Lawless, D. V. (2002). How does the body get into the mind? *Human Studies*, *25*, 333-358.

Schön, D. A. (1983). *The Reflective Practitioner: How Professionals Think in Action*. New York: Basic Books.

Schön, D. A. (1992). Designing as reflective conversation with the materials of a design situation. *Research in Engineering Design*, *3*(3), 131-147. doi:10.1007/BF01580516

Scroggs, C. L. (1981). The Use of Gesturing and Pantomiming: The Language of a Nine-year-old Deaf Boy. *Sign Language Studies*.

Sharrock, W., & Randall, D. (2004). Ethnography, ethnomethodology and the problem of generalisation in design. *Eur. J. Inf. Syst.*, *13*(3), 186-194.

Streeck, J. (2002). A body and its gestures. *Gesture*, *00002*(00001), 19-45.

Sturman, D. J., & Zeltzer, D. (1993). A design method for “whole-hand” human-computer interaction. *ACM Trans. Inf. Syst.*, *11*(3), 219-238.

Sturman, D. J., & Zeltzer, D. (1994). A survey of glove-based input. *Computer Graphics and Applications, IEEE*, *14*(1), 30-39.

Suchman, L. (1995). Making work visible. *Communications of the ACM*, *38*(9), 56-64.

Suchman, L. (2002). Located accountabilities in technology production. *Scandinavian Journal of Information Systems*, *14*(2), 91-105.

Suchman, L. A. (1987). *Plans and situated actions : the problem of human-machine communication*. Cambridge ; New York: Cambridge University Press.

Sutherland, I. E. (1963). Sketchpad: A man-machine graphical communication system. In *AFIPS Spring Joint Computer Conference* (Vol. 23, pp. 329-346). Detroit.

Sutherland, I. E. (1998). A head-mounted three dimensional display. In *Seminal graphics: poineering efforts that shaped the field* (pp. 295-302). ACM.

Tang, J. C. (1991). Findings from observational studies of collaborative work. *International Journal of Man-Machine Studies*, *34*(2), 143-160.

Tomasello, M. (2007). If they're so good at grammar, then why don't they talk? Hints from apes' and humans' use of gestures. *Language Learning and Development*, *3*(2), 133–156.

Varan, D., Turk, A., Bucolo, S., Polson, D., Brereton, M., Donovan, J., Montgomery, K., et al. (2006). Interactive lounge: an interdisciplinary approach to the design of a gestural interaction device. *Personal and Ubiquitous Computing*, *10*(2 - 3), 166-169.

Wakkary, R., & Maestri, L. (2008). Aspects of Everyday Design: Resourcefulness, Adaptation, and Emergence. *International Journal of Human-Computer Interaction*, *24*(5), 478-491. doi:10.1080/10447310802142276

Wang, J., Zhai, S., & Canny, J. (2006). Camera phone based motion sensing: interaction techniques, applications and performance study. In *Proceedings of the 19th annual ACM symposium on User interface software and technology* (pp. 101-110). Montreux, Switzerland: ACM. doi:10.1145/1166253.1166270

Weiser, M. (1991). The computer for the 21st century. *Scientific American*, 94-104.

Wexelblat, A. (1995). An approach to natural gesture in virtual environments. *ACM Transations on Human-Computer Interaction*, *2*(3), 179-200.

Wexelblat, A. (1997). Research Challenges in Gesture: Open Issues and Unsolved Problems. In I. Wachsmuth & M. Fröhlich (Eds.), *Gesture and sign language in human-computer interaction : International Gesture Workshop, Bielefeld, Germany, September 17-19, 1997 : proceedings* (pp. 1-11). Berlin ; New York: Springer.

Wolf, T. V., Rode, J. A., Sussman, J., & Kellogg, W. A. (2006). Dispelling "design" as the black art of CHI. In *Proceedings of the SIGCHI conference on Human Factors in computing systems* (pp. 521-530). Montréal, Québec, Canada: ACM. doi:10.1145/1124772.1124853

Wright, P., Blythe, M., & McCarthy, J. (2006). User Experience and the Idea of Design in HCI. In *Interactive Systems* (pp. 1-14). Retrieved from http://dx.doi.org/10.1007/11752707_1

Wu, Y., & Huang, T. S. (1999). Vision-Based Gesture Recognition: A Review. In A. Braffort, R. Gherbi, S. Gibet, J. Richardson, & D. Teil (Eds.), *Title: Gesture-Based Communication in Human-Computer Interaction: International Gesture Workshop, GW'99, Gif-sur-Yvette, France, March 1999. Proceedings* (Vol. 1739, p. 103). Heidelberg: Springer-Verlag.

Wyeth, G., Brereton, M., & Alexander, S. (2001). *Design of a Gesture Appliance for Ubiquitous Computing* (Technical Report).

Xiong, Y., & Quek, F. (2006). Hand Motion Gesture Frequency Properties and Multimodal Discourse Analysis. *Int. J. Comput. Vision*, *69*(3), 353-371.

Yeates, S., Holden, E., & Owens, R. (2003). An animated Auslan Tuition System. *MG&V*, *12*(2), 203-214.

Zimmerman, J., Forlizzi, J., & Evenson, S. (2007). Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 493-502). San Jose, California, USA: ACM.