A PARTICIPATORY DESIGN APPROACH IN THE ENGINEERING OF UBIQUITOUS COMPUTING SYSTEMS

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School of Information Technology and Electrical Engineering

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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No jointly-authored works.

Statement of Contributions by Others to the Thesis as a Whole

This work was supported by a Discovery grant from the Australian Research Council (DP0210470). The original research grant was submitted by Margot Brereton, Simon Kaplan and Helen Purchase as "An Empirically Derived Experimentally Validated Framework for Interactions in Information Environments". This grant provided the original research plan provided a context framed the research.

My thesis advisor, Margot Brereton, assisted in identifying the problem and opportunity for designing ubiquitous computing through exploring design ideas in the context of authentic and rich work environments replete with objects instruments, social and informational concerns. Dr Brereton also assisted with critical revision which helped guide the interpretation of the research.

The Discovery grant facilitated three separate projects, including the one presented in this thesis, which explored the research context of a dental surgery. In addition to the author's investigation, another focussed on gestural interaction (Dr Jared Donovan), and another on context aware applications (Dr Brett Campbell). This thesis focussed primarily on the area of the role of speech recognition, with findings distinct from the other projects. In early exploratory work in learning about the dental surgery and developing design activities, it made sense from the perspective of leading edge design practice to work collaboratively because the whole is greater than the sum of the parts. It is made clear within the thesis when design research presented involved parties other than the author.

Statement of Parts of the Thesis Submitted to Qualify for the Award of Another Degree

None.

Published Works by the Author Incorporated into the Thesis

Cederman-Haysom, T. and Brereton, M. (2006). A participatory design agenda for ubiquitous computing and multimodal interaction: a case study of dental practice, *Proceedings of the Participatory Design Conference* (Trento, Italy). The paper has been incorporated in a modified form into this thesis in the following sections:

- Section 2.3 paragraph 1
- Section 3.1 paragraph 15
- Section 4.1.3 paragraph 1
- Section 5.1 paragraph 3
- Section 5.2.1 paragraphs 2, 3, 4 and 5
- Section 5.2.2
- Section 5.2.4
- Section 5.2.6

- Section 5.2.10
- Section 5.2.12
- Section 6.1 paragraph 10
- Section 6.2
- Section 6.5
- Section 6.7 paragraph 3, 4, 5 and 6

Additional Published Works by the Author Relevant to the Thesis but not Forming Part of it

Campbell, B., Cederman-Haysom, T., Donovan, J. and Brereton, M., (2003). Springboards into Design: Exploring Multiple Representations of Interaction in a Dental Surgery. *Proceedings of OZCHI 2003* (pp. 14-23) (Brisbane, Australia, 2003), University of Queensland.

Cederman-Haysom, T. and Brereton, M. (2004). Designing usable ubiquitous computing. *Proceedings of Participatory Design Conference 2004 Vol. 2* (pp. 101-104), ACM Press.

Cederman-Haysom, T. and Brereton, M. (2004). Bridging technical and HCI research: Creating usable ubiquitous computing. *2004 Australasian Computer Human Interaction Conference (OZCHI2004)* (Wollongong, New South Wales), CHISIG.

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Abstract

Ubiquitous computing aims to make human-computer interaction as naturalistic and functionally invisible as possible through embedding computing potential within a particular context to support human activity. However, much of ubiquitous computing research is focussed on technical innovation due to the challenges involved with deploying embedded computing, thereby reducing the commitment to the philosophical ideals of ubiquitous computing in research. This dissertation describes the investigation of a participatory approach to technically-complex research in order to understand how our view of the engineering and human challenges changes when the two are approached hand-in-hand.

The domain chosen for this system was a dental surgery. Dentistry involves a complex workspace with computer interaction constrained by surgery hygiene. Ubiquitous computing offers a compelling interaction alternative to the keyboard and mouse paradigm in such an environment.

A multi-method approach that employed ethnographic research and design prototyping was undertaken with dentists from several different private practices. A series of field studies used ethnographic methods such as observation and interview. Design events explored prototypes with activities such as design games, contextual interviews, role-playing and contextual prototyping. Activities were devised with the aim of providing a level playing field, whereby both designers and participants feel they can contribute equally, with their respective disciplinary knowledge. It was found that methods needed to be carefully chosen, devised and managed, in order to communicate complex concepts with participants and to constrain the design to technically feasible options.

The thesis examines the design problem from the perspectives of a variety of different stakeholders within a participatory design framework, reflected upon by means of human-centred action research. Data was gathered through design speculations and observation, and explored using methods such as the Video Card Game and Video Interaction Analysis. Fieldwork was analysed using a multi-stage qualitative analysis process which informed further design collaboration with participants.

The analysis of data gathered during design studies with dentists also contributed to the development of a prototype system to validate methodological contributions. The resulting prototype utilised off-the-shelf hardware and software which allowed for innovative customisation and development. In-situ prototyping (defined by the author as “participatory bootstrapping”) and a comprehensive knowledge of the domain afforded the creative application of technology.

In addition to contributing to the prototype design, the interpretive understandings drawn from analysis identified how technical ideas were presented and utilised by participants of the studies, and how best to engage busy professionals. The final outcomes of the research were a multimodal ubiquitous computing system for interacting within a dental surgery; the development and implementation of a variety of methods aimed at communicating technical concepts and eliciting user motivations, practices and concerns; and a set of design principles for engineers engaging in design of systems for human use.

The research presented within this thesis is primarily part of the field of human-computer interaction, but provides evidence of how engineering development can be influenced by a user-centred participatory approach. The benefits that derive from inclusive methods of design are demonstrated by the evaluation of a prototype that employed such methods. The contribution of this thesis is to demonstrate and delineate methods for developing ubiquitous computing technologies for the context of human use. This led to a set of design principles for the engineering of systems for human use:

1. Technology needs to be robust and simple to appropriate. This allows users to give insights on technology developments and also to allow users to discover for themselves how they would use the technology.

2. An evolving and carefully considered set of methods are needed to elicit communication between practitioners and across disciplines. The gaps in understandings and the different representations that arise across the disciplines provide essential clues to next steps in design. These gaps and differences form tensions that can be exploited productively.

3. Context is important for determining which design steps to take. Rather than abstracting a problem in order to solve it, as is usual in engineering design, the problem should remain grounded in the context of use. It reveals what the real problems are that need to be solved rather than the imagined ones. This requires an appreciation of the situated nature of action and of the variability of work. In turn it also requires an appreciation of what the human can and does do and what the machine should support.

4. Accountability in design is required. There is a fundamental tension between trying to make something work and seeing what really does work; specifically it is necessary to understand when automation is worth it in human machine systems. While engaged in the design process, engineers should ask how much technology should reconfigure human practices because of a useful outcome, rather than attempting to automate and converge devices for its own sake. A clear understanding of the constraints and workings of the work space needs to be

balanced with the understandings of the limitations of the technology in order to design a system that improves work practice and empowers the practitioner.

Keywords

Participatory design, user-centred design, dentists, engineering design, ubiquitous computing, interaction design

Australian and New Zealand Standard Research Classifications (ANZSRC)

120304 100%

The research reported here has been approved by the Behavioural and Social Sciences Ethical Review Committee of The University of Queensland, clearance number 2003000449.

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1 Introduction

1.1 A personal background

For almost my entire life, I've been fascinated by computers. One of my earliest memories is of playing with Excel and BASIC in DOS 2.0, which seemed to have unlimited possibilities. Unlike a regular toy which had a limited range of functionality, I could program a computer to do a limitless amount of new things. From early dabbling in BASIC, my interest continued to grow throughout high school, where I became a member of a computer club and competed in several national programming competitions. I imagine this is how a lot of computer engineers find their calling - a hobby and source of entertainment and enjoyment for themselves which then evolves into providing a service for others.

However, therein lays the problem - these programs I was writing, while useful to others, were obvious and usable in their functionality primarily to myself. I wrote them to be something that was user friendly – but to only one person. Few others could interact with the applications I developed in a usable fashion. It is a difficult but honest admission that engineers develop for themselves primarily, and perhaps other engineers. From my first program as a child to my final year thesis as an undergraduate student, I never seriously considered how other people would perceive, utilise or interact with these programs. So long as they made sense to me, they were great applications. It was only when I started this thesis, as a computer engineer, that the concepts of usability and user-centred and participatory design were introduced to me.

This is a startling thing to reflect upon at the writing of this thesis. According to much of the literature and commercial practice, user-centred design and usability are now thought to be a common and necessary practice. User-centred and participatory design is employed in a variety of contexts for many different types of applications, and is recognised as an important, even essential, design methodology, with quintessential engineering companies advocating its use. My education was, I believe, a fairly typical engineering education experience, studying computer systems engineering for my undergraduate degree. The fact that someone so immersed in the field of software engineering hadn't heard about user-centred design (or considered the user perspective in his own time) speaks volumes for ‘traditional’ design processes and how engineers are trained and educated in general.

The education and viewpoint of engineers has ramifications for how user-centred and participatory design is employed within commercial design practice. It would seem (based on my personal education) that the way engineering is taught currently means that there is a strong technical (or rather, problem solving) focus. And why not? Engineering is all about solving hard problems. Engineers are given a requirement and derive satisfaction in finding the best fit for it. Engineers also tend to hold a strong personal interest in their field and in deriving optimal solutions for it. In adhering to the design specification given, whether it is then in turn usable to others, is not a primary consideration. When supposing how people might use their software, from my own experience software engineers either create a solution that works for them, or it is passed to user interface designers to refine methods of interaction and react to their later specifications. A greater proportion of design now attempts to design better interfaces as the first step in the design process, but in many projects it is not until after several iterative cycles with designers that a user-friendly interface takes shape. This is not a damning statement about engineers, but rather a reflection upon the integration of engineers into the design process with an emphasis on usability. What I've found during my education and research is that a gap between technical solutions and usable systems can and should be addressed.

To further explain my background it is worth reflecting on my transition from engineering as an art of ‘pure’ technical problem solving to that of a holistic view of a system and solving both technical and human-computer interaction problems.

Upon completing my computer engineering degree I applied to undertake a PhD in the field of human-computer interaction. My role was of the computer engineer to implement technical solutions for innovative means of multimodal interaction, and I would be working closely a multi-disciplinary team of designers, with backgrounds in design, engineering and computer science, all with an interest in exploring different forms of design practice. In another frank admission, when I began this research, I did so without realising that human-computer interaction was a well established field. The project was described as requiring a researcher to “investigate and design ways of interacting with the information infrastructure that maintain natural social interactions, take advantage of physical space and utilize our extensive human abilities and recognize and manipulate physical objects.” My primary interest was the use of ubiquitous computing to provide alternative modalities for computer input in an as-yet-unspecified context. I wanted to develop embedded devices that afforded new interaction modalities. While this was what attracted me initially, I soon found that this required considerations of problems, hinted at in this description, that went beyond recognition algorithms and new hardware.

I credit my advisor Margot Brereton and colleague Jared Donovan for fostering a new appreciation of what design truly entails. It wasn’t until I became part of a multi-disciplinary team that reflected upon the difficulties of interaction that the even more complex problem of providing an open and usable application became apparent to me. I was involved in new methods and ideas, such as ethnography and user participation, which seemed quite foreign to me. I initially lacked the foresight to see their benefit and felt we were “wasting our time” and should press at the problem at hand (to recognise gestures!).

It is in making that point I should also note that although there is a view that engineers “don't play well with others” and tend to exclude non-technical designers (as seen by my aforementioned reaction), there can also be difficulties in accommodating technical members to a team well-versed with qualitative design practices. Throughout the research, I tended to retain a deeper technical focus than other team members I collaborated with. New and unfamiliar concepts that I did not agree with meant there was occasional friction during design activities or when contributing to academic papers, and although the purpose of the research for all participants was to integrate technical and contextual understandings, my technical inclination affected integration within the design team. It is in understanding and accommodating these different perspectives on design that it became possible for me as a ‘classically’ trained engineer to rethink my contribution and involvement in the design process.

1.2 Motivation and aims

The research presented in this thesis aimed to develop innovative means of interaction to support ubiquitous computing systems in authentic work contexts, which considered a mix of physical, informational and social interaction. The aim was to develop a system which improved work practice for a practitioner by respecting and utilising their existing skills and tacit knowledge (rather than requiring learning new methods or complex new technologies). I was joining a team which had already outlined the methodological approach to the design problem. The initial investigation was to derive an "empirically derived, experimentally validated framework for interactions in information environments". My research scope was to find a way of supporting a range of interactions in a ubiquitous computing environment, and an expected outcome of the research was a theoretical framework which described the possible interactions that mediate information between the physical and virtual worlds. A prototype would demonstrate and validate naturalistic information transactions identified in the framework.

Given my lack of experience with ubiquitous computing systems and more specifically, the methodological approach employed, my first year was spent exploring existing research, identifying a domain, and reflecting on my research question. My initiation to both methodological and technical considerations was a workshop by Jacob Buur. Reflecting on the outcomes of this workshop I realise now that this was an important process for evolving my view of design research. As an engineer, I previously thought of design as the implementation of a system to solve a specific problem. My view was that in creating such a system, the problem's requirements would be defined both abstractly (i.e., as I came to realise, without a holistic consideration of the context of use) and subjectively by engineers, who then set about solving the problem. Buur's workshop impressed upon me the importance of user engagement and expanding the design requirements based on a detailed consideration of the context of use. Indeed, in my own experience, when reviewing videos of design studies, I critiqued the products being presented, while Buur critiqued the design process taking place.

As an example of this transition from engineer to designer (although such hard distinctions are a simplification), my undergraduate thesis was based upon the technical idea of facilitating wireless electronic transactions. My motivation for developing such a system was thus: there was a nascent technology becoming widespread (personal digital assistants, and later smartphones) and I wanted to find a way of utilising its newfound ubiquity and wireless capabilities. At the same time, the first "Internet bubble" was peaking and there was a great deal of hype about electronic payments. The system I set about designing was to utilise both these technical breakthroughs into a system that combined them into a useful service.

Apart from some extremely general use cases (for example, renting a video and paying using an electronic wallet), the focus was on implementing the technology to facilitate wireless secure transactions. Time was not spent reflecting upon *how* the product would be used, but rather *if* it could be used. This is how I learnt to approach design and solve problems. Therefore, this is the way I initially approached research presented in this thesis.

When beginning my research, work had already been completed by colleagues within the engineering school towards a gesture recognition system which afforded a wearable ring to be used as a gestural interface. The ring used accelerometers to measure movement, while using an embedded processor which had a pre-trained neural network system that determined the likelihood of a particular gesture. When discussing this system with the engineer who created the system, all our discussions centred on how the technology worked, never why it might be needed or useful.

While I am placing emphasis on my lack of user consideration, it is important to note that I am not advocating against research focussed on technical contributions. Such research provides technical advancement that plays an invaluable part of design, however it is the implementation of new technology that is problematic.

My initial efforts were to appropriate and improve the gesture ring technology. However my advisor in the meantime was encouraging me to explore different domains for potential use case scenarios. Even at this point I still had a strong disconnect between the technology and its application. I saw ethnographic studies as something I merely “had to do as part of the research”. I initially did not consider ethnography as part of the *design* process.

1.3 A shift in focus

The first eighteen months of this thesis were spent learning about neural networks, methods of pattern recognition, and how to interface sensors to learning networks. It became clear to me during this time that the scope of developing a more accurate system would require me to focus on technical breakthroughs and exploring the field of artificial intelligence. However, from my early studies with handwriting and speech recognition on personal digital assistants, I knew embedded pattern recognition was already a mature[1] field. I had seen firsthand what was possible with existing technology, and observed recognition systems which worked with a high rate of recognition in the laboratory which had not been implemented for a variety of reasons. Knowing this, I changed tack and focussed instead on why these existing systems were not being used and to investigate means of integrating them into a system in a manner that made them both usable and useful. Instead of technical development, I began to focus on what the user required and how their needs could be met with adapting off-the-shelf technology.

While gesture recognition is still a developing field (with the exception being the relatively mature touch-screen, or two-dimensional gestures, for example the Apple iPhone), handwriting and speech recognition are both fairly mature in their content and application. While handwriting recognition was not directly useful based on the domain studied and its requirements, I hoped to incorporate the technical lessons learned for two-dimensional space to three-dimensional space.

Speech is used in tandem with gesture by people while communicating, offering a further avenue of recognition for new systems. Speech recognition may be deployed to support interaction in an ambient fashion, and is a well studied and technically advanced field of research. Based on its possibilities, my intent became to develop

[1] By ‘mature’, I mean technically mature. Handwriting recognition systems were technically very good, but lacked an appropriate level of efficiency and error correction. This means that although the technical process of pattern recognition is mature, the technology still faces difficulty.

gesture recognition systems combined with the support of off-the-shelf speech recognition. The focus of the research therefore was to create a ubiquitous computing system to support work practice, while focussing on usability and limiting the time required for technical development. Indeed, a more technically comprehensive system would necessitate its own dissertation.

Through my exposure to and understanding of participatory and user-centred design, I also aimed to develop a system that satisfied the user from a personal and social perspective. The system prototyped needed to be integrated with the practitioner's work context, while supporting ready appropriation by an individual user; for example, supporting accent, word choice and functional expectations of such a system. I needed to consider localisation of the system, the context it was to be deployed to (to accommodate both the unique challenges of the environment it was used in and the expected interaction paradigm) in addition to the technical challenges faced. I began to realise that while engineers and designers may restrict themselves to a particular field, there was potential for overlap between the two.

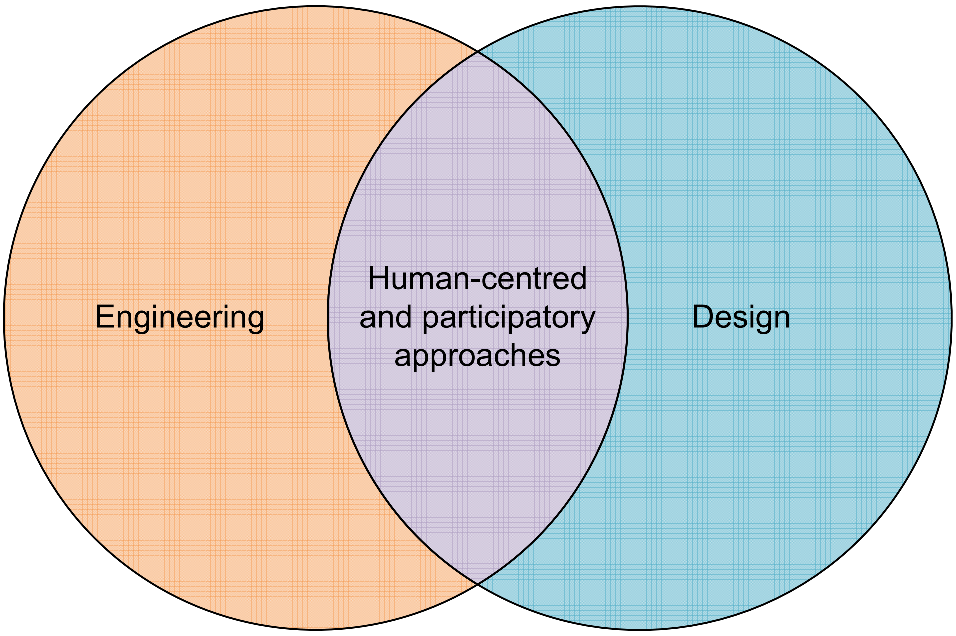


Figure 1: Where engineering and design meet

Engineering can be seen as the devising and analysis of systems of technical systems to solve problems, while design is the speculative and synthetic process to develop new products and services. Where these meet is in human-centred and participatory approaches which focus on human-experience and acknowledge human agency in human-computer systems.

Having to consider such a comprehensive range of constraints affected the design process. I realised it was not merely enough to provide a more technically advanced method of pattern recognition that afforded new interaction paradigms, I also needed to adapt and configure such a system for its context of use. The outcomes of my prototyping and design methodology are examined within this thesis. The culmination of these concerns led to my thesis question: how may engineers, designers and practitioners be better involved in and served by a design process for complex information systems that adequately addresses the needs of the practitioner?

Ultimately, during my research, I came to realise I had redefined my personal manifesto of design. Previously my manifesto would have read:

> *"I aim to do my best as an engineer to find solutions to a given problem that most adequately satisfy its specification."*

Given my new understandings from undertaking the design research within this thesis, my revised manifesto reads:

> *"In order to create both usable and useful design it is necessary to respect the tacit knowledge of the user, while using participatory design techniques to tailor a system to be its most effective for a particular work context."*

With this in mind, the contribution of this thesis is the exploration of the gap between engineering design and human use, and identifying principles for allowing engineers to connect this gap. These principles allowed for improving the integration of engineers in a design process which emphasises usability and participant empowerment, and this thesis reflected on the resulting process through the evaluation of a functional prototype. A more precise definition of my contribution to the existing corpus of research is defined within the discussion chapter.

1.4 Structure and argument of this dissertation

This thesis is structured in the following way: chapter 1 is this introduction and has defined my personal background and motivations as well as set the stage for the rest of the research discussed within.

Chapter 2 gives a survey of the state of literature for the fields relevant to this thesis. It begins with a discussion of participatory design, including its origins and philosophy. After a cursory analysis of the role of an engineer in participatory design, the case is made for greater integration of a technically-competent individual to a participatory design process in the field of ubiquitous computing. The history and current state of research for ubiquitous computing is explored. The dichotomy of approaches to ubiquitous computing systems design is presented, with a comparison of a philosophical or technical approach to design. The benefits and shortfalls of each are compared and examples from the field are examined. General design considerations for ubiquitous computing and the benefits for employing a participatory design approach are analysed. The field of participatory design and engineering design are explored and the research for this thesis is situated within these fields.

Chapter 3 discusses the methods available to support this research, and describes those used for design and reflection. Attention is paid to methods of collection, representation, analysis and nature of the data. The chapter discusses both the methods required for developing a prototype system for supporting innovative ubiquitous computing systems in information environments and those for reflecting and improving the process.

Chapter 4 describes the participants in detail, while also providing the motivation and background as well as the minutiae of the activities themselves. The outcomes of the studies and how they fit within the framework of the conclusions of this thesis are discussed and provide the necessary background for the lessons for design. Particular issues relevant to this thesis exposed by the research are presented, and the contribution of the participant is summarised.

Chapter 5 presents a case study of participatory design, describing a series of design events held in New Zealand towards the later stages of the ongoing studies performed for this research. The justification for how these studies were organised and run is described and a reflection upon the reaction of the practitioners and how the feedback further informed the research is made.

Chapter 6 presents lessons for design and grounds them with examples from the case study presented in chapter 5. These lessons are an attempt to generalise the research findings in the context of a broader sense of design studies, and draw methodological conclusions based on the qualitative research completed.

Chapter 7 concludes this thesis and discusses the contributions made by this research and the implications for ubiquitous computing systems and participatory design. Suggestions for further research and design activities are suggested and concluding statements made.

2 Research Review

This chapter first outlines the considerations of the body of research relevant to this thesis, and how my research relates to existing studies.

For this thesis, there are three relevant fields to consider. The position of this research is then presented in relation to these fields. This dissertation describes my participation as a technical consultant in the process of using participatory design to create usable ubiquitous computing systems. To date there have been few projects that consider the implications of combining the three fields of ubiquitous computing, participatory design and engineering design work. Therefore it is necessary to consider each of them separately and also their combination for systems design.

The first field to consider is that of engineering design. When I use the term ‘engineer’ in this thesis, I am generally referring to a “technically proficient designer”. Essentially, this is a designer whose core curriculum has been that of problem solving and understanding technical details. In this way, “engineering design” refers to the approach used by designers focussed on technical problems. There have been difficulties in reaching implemented or commercial systems for research projects that make use of current approaches to participatory design (Nilsson et al, 2000), likely due to the reduced technical resolution. While many participatory design projects have been technically finished, as a whole, the engineering profession is still largely unaware of participatory design approaches, particularly for leading-edge technologies, such as ubiquitous computing. A hypothesis explored by this thesis is that these difficulties in completing an appropriate design may be managed by incorporating technical knowledge into a participatory design approach. In addition, practitioners’ requirements should be managed according to the technical capabilities of the potential system.

While there are alternative design processes posited to the traditional waterfall approach (Bauer, 1972), such as agile development (Martin, 2002) (Beck), they do not address the core problem of finding a suitable method for evolving practitioner requirements whilst remaining resource appropriate (both in terms of time and expense).

The second field of consideration is ubiquitous computing. This thesis considers that by employing ubiquitous computing, practitioners have the ability to dramatically change how they utilise computers in their workplace: by allowing a more naturalistic[2], versatile and efficient means of human-computer interaction. However, while the application of ubiquitous computing has incrementally increased over the years, it has yet to find widespread acceptance and deployment as envisioned by Weiser (1991), in which computing fades into the background. It has been argued by Bell and Dourish (2006) that the ubiquity of mobile phones and screens is demonstration itself that ubiquitous computing has arrived. Still one can argue the extent to which these technologies fade into the background. Weiser's definition and its appropriateness will be further considered as part of this chapter.

The final field is that of participatory design. Participatory design has been adopted as a philosophy for design increasingly in past years, as witnessed by the popularity of events such as the Participatory Design Conference (Computer Professionals for Social Responsibility, 2007). Originally participatory design emerged from Scandinavia in 1960s. Discussions about the relationship between work and democratic values led to an industrial democracy program in Norway for the empowerment of workers, creating a strong political climate for participatory design. Scandinavian research also continues to be at the forefront of the field. Participatory design is not about designing more sophisticated technology per se, but instead focuses on empowering the practitioner. While this may be deemed unsuitable for many types of technical design, I believe it suits the philosophical ideals behind ubiquitous computing. To date, apart from Good's (1992) early efforts in Presence (a synonym for ubiquitous computing), there have been but a few attempts to employ participatory design for the design of ubiquitous computing systems, such as recent research such as Bødker and Buur's (2002) and Binder and Warren's (2003). The disconnect between participatory design and ubiquitous computing is explored in

[2] By 'naturalistic', I am referring to when a means of interaction is practiced or is easy to adopt such that it becomes natural to the user. It is suggested that by definition, designing for naturalistic interactions allows for easier adoption by a practitioner.

greater detail within this chapter and the relationship to the research is considered in the discussion chapter.

Potential new ubiquitous computing systems can be far more complex and error prone than previous systems. It is necessary to design such systems so that the practitioner understands the technology to a point where they can troubleshoot it themselves, and have the ability to self-configure and adapt the systems as required. Many systems (ubiquitous computing or not) have workarounds or means of personalisation and configuration in place so that the practitioner can adjust them to work in a way that suits them. Understanding, supporting and extending this existing knowledge becomes a priority for new design methods.

Furthermore, given the subtleties of human-computer interaction, divorcing the practitioner and the engineer means that when a set of specifications are presented to an engineer, what is produced may not be what is actually required from a holistic view of the system, yet still meet the specifications. For example, while a speech recognition system might suitably recognise enough speech to complete a task, it may not provide appropriate error correction and feedback sufficient to maintain the system's usefulness and usability.

A common perception is that engineers can be difficult to work with when taking into account holistic considerations and using inexact or ambiguous specifications. Given current engineering education, engineers are trained as problem solvers. They gather resources and apply them the best way they know how. The difficulty for engineers in improving knowledge flow with outside sources is in understanding the problem context and communicating the technical possibilities. There may be trust and communication issues with those from outside their domain of expertise. These stem from different disciplines producing different skill-sets, vocabularies and priorities. Particularly in the corporate world, there need to be new ways to account for this and to incorporate engineers and their skill sets into user-centred research and marketing functions in order to increase design quality and effectiveness.

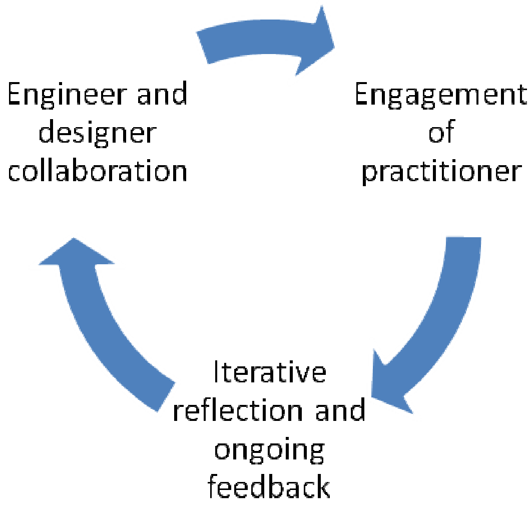


Figure 2: An iterative participatory design process

This thesis explores how technical and use centred approaches can be better integrated in order to improve these processes and the resulting usability and usefuness of the product. It is posited that engineers can contribute to educating the practitioner, and also help to more closely understand the environment of use by being suitably informed of the idiosyncrasies of the domain and work practice. Through action research and participatory design, undertaking the process illustrated in Figure 1, this thesis investigates the challenges and characteristics of such a process leading to a set of underlying principles for the engineering design of systems for human use.

2.1 Engineering design

> *"And so it is that the new utopians retain their aloofness from human and social problems presented by the fact or threat of machined systems and automation. They are concerned with neither souls nor stomachs. People problems are left to the after-the-fact efforts of the social scientists." (Boguslaw, 1965 p. 3 from Greenbaum and Kyng, 1991)*

I view engineering design (as an engineer myself) as 'traditional' design. A common view held, even by those who subscribe to the philosophies of participatory design, is that traditional design involves supplying user needs (through whatever is the most efficient and effective method) to the designers, whose resulting design is then supplied to the engineers, who then manufacture the product, as discussed by Reich et al (1996). This final outcome is then passed back to the user, with mainly their ongoing use of the product informing further design changes. This is a method of design that I have witnessed on numerous occasions as a professional engineer, and it is a method of design instilled within me as a student. Emphasis is placed upon technical problem solving – dictate a set of parameters and create a system that satisfies them so that the problem is solved. The development of customer needs in a traditional process is illustrated in Figure 3, while a generic development process is illustrated in Figure 4.

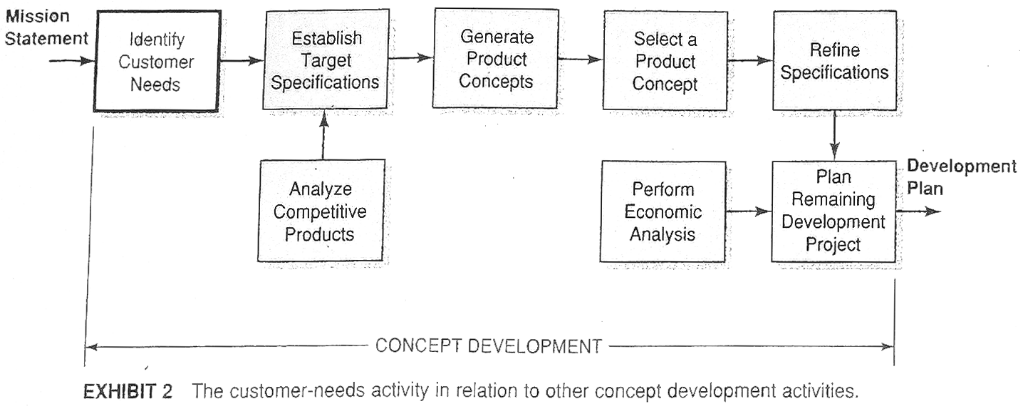
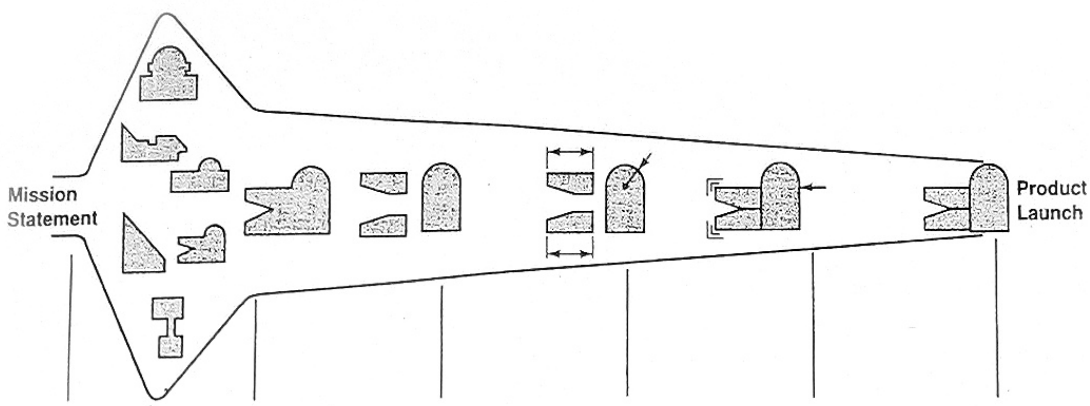


Figure 3: Customer needs development (Ulrich and Eppinger, 1995)



	Concept Development	System-Level Design	Detail Design	Testing and Refinement	Production Ramp-Up
Marketing	• Define market segments. • Identify lead users. • Identify competitive products.	• Develop plan for product options and extended product family.	• Develop marketing plan.	• Develop promotion and launch materials. • Facilitate field testing.	• Place early production with key customers.
Design	• Investigate feasibility of product concepts. • Develop industrial design concepts. • Build and test experimental prototypes.	• Generate alternative product architectures. • Define major sub-systems and interfaces. • Refine industrial design.	• Define part geometry. • Choose materials. • Assign tolerances. • Complete industrial design control documentation.	• Do reliability testing, life testing, and performance testing. • Obtain regulatory approvals. • Implement design changes.	• Evaluate early production output.
Manufacturing	• Estimate manufacturing cost. • Assess production feasibility.	• Identify suppliers for key components. • Perform make-buy analysis. • Define final assembly scheme.	• Define piece-part production processes. • Design tooling. • Define quality assurance processes. • Begin procurement of long-lead tooling.	• Facilitate supplier ramp-up. • Refine fabrication and assembly processes. • Train work force. • Refine quality assurance processes.	• Begin operation of entire production system.
Other Functions	• Finance: Facilitate economic analysis. • Legal: Investigate patent issues.	• Finance: Facilitate make-buy analysis. • Service: Identify service issues.		• Sales: Develop sales plan.	

Figure 4: A generic development process (Ulrich and Eppinger, 1995)

The philosophy behind this approach is described by Corbett (1992) as hard-systems thinking. Hard-systems thinking regards problems as clearly defined and solvable in a linear fashion. As it can be seen in from Figure 4, such a design flow allows for comprehensive planning and segmented design teams. However, such isolation means that considerations of the practitioner are left to the judgement of the engineer, with the technical solution being the overriding concern. Edwards et al (2003), in analysing how software infrastructure can be better appropriated to user-centred design noted that many features in design are determined largely by “designer’s experience and intuition”.

Darses and Wolff (2006) noted that this approach to users is partly education and the culture of traditional design:

> *"Another fact that mitigates against the designers integrating the user as a full dimension of design is that their professional training does not promote user-centred approaches." (Darses and Wolff, 2006)*

Kuhn (1996) is one of several researchers to recognise the problems for systems resulting from this type of design. She describes the need instead for a "human-centred design", whereby the end users are viewed as central to the system, with technology recognising and making the best use of human skills. Kuhn also advocates the use of participatory design to allow for workplace democracy, but recognises the tension between worker satisfaction and worker efficiency.

There has been little accounting for when innovative technical development through hard-systems design is both appropriate and beneficial (Brandt, 2001). Sometimes it is necessary to allow for a combination of both philosophies, and to negotiate a compromise that satisfies productivity (and usefulness) and usability. A common difficulty in the world of professional design is the need to 'satisfice' (Klein, 1998) to achieve this.

Another difficulty with traditional design is that it can, and in many cases, does, restrict user involvement and contribution to only the time before and after the design process takes place. Apple engineers who designed the first Macintosh PC describe driving to various computer dealers after releasing it to watch how people used the new machine (Horn, 2004) - it was after viewing this behaviour that the first bug fixes and operating system modifications took place.

As represented by this example, the methodologies of engineering design are dominated by scenic fieldwork (Button, 2000) whereby future improvements are based on post-deployment observations. In this way, scenic fieldwork aims to produce a strong description of what occurs within a given context. Engineering designers consider the results of the scenic fieldwork and solve problems as they are presented to them. While there are a variety of practices for revealing this information to the engineers, the engineer typically has little or no contact with the user and learns of their needs and requirements through third parties.

Button (2000) also describes analytic fieldwork as part of traditional design which attempts to resolve the deeper meaning behind actions and events within a context. Unforeseen consequences always emerge from design; however this can be exacerbated without the detailed analysis of such methods. Participatory design is a means of helping engineers interpret and contribute to analytic research. Both the methodology and discussion chapter of this thesis further explore how this can occur.

It is worth noting that one of the best known engineering design frameworks, presented by Pahl and Beitz (1995) in their book on systematic approaches to design fails to refer to the end-user at any time as a direct concern in the design process. The same trend is observed in recent research in engineering design as presented at the International Conference on Engineering Design. Out of the 200 papers presented during the 14th edition of this conference (Folkesson, 2003), only six mention the term ‘user’ in their title.

Terry Winograd and Fernando Flores (1986 from Kyng and Greenbaum, 1992) describe the three steps which can be thought of as an engineer’s design process:

1. Characterise the situation in terms of identifiable objects with well-defined properties.
2. Find general rules that apply to situations in terms of those objects and properties.
3. Apply the rules logically to the situation of concern, drawing conclusions about what should be done.

In other words, the problem is usually broken down in such a way as the engineer can relate it to themselves. Then, as trained, they go about the process of solving the problem, *as they understand it*, until it is ‘fixed’. This was how I personally completed my work, both academically and commercially as a computer engineer. Ehn (1989) describes his view of the engineer’s lack of knowledge for the context being designed for:

> *"The prototypical Cartesian scientist of system designer is an observer. He does not participate in the world he is studying, but goes home to find the truth about it by deduction from objective facts that he has gathered." (Ehn, 1989)*

The contrast between participatory design (or Scandinavian design) and engineering design was explored by Floyd et al (1989), who delineated the approaches as shown in Figure 5. This representation supports the gap seen empirically by myself and other researchers.

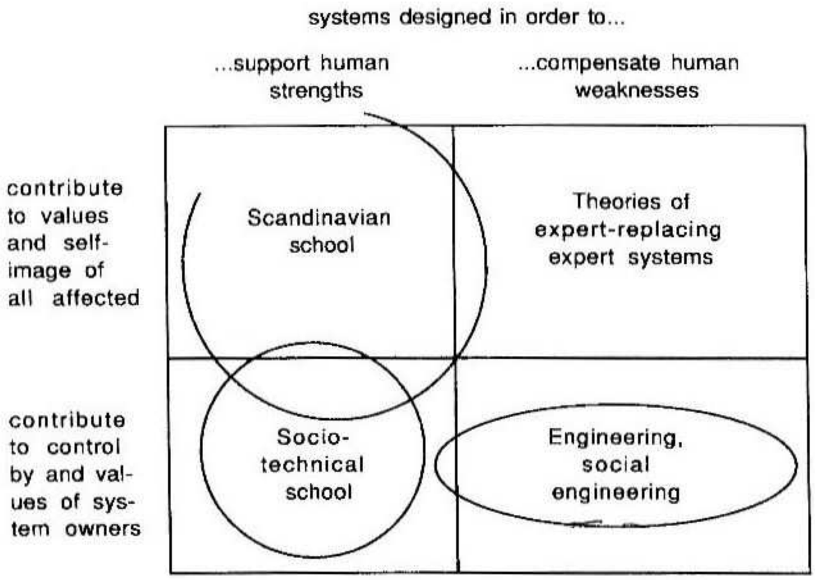


Figure 5: Design approaches (Floyd et al, 1989)

Although there appears to be a gap between methods, change is beginning to emerge within the field. McGarry notes that engineering design research is shifting from "think-aloud protocol analysis, and contrived, task based studies of individuals conducted within artificial settings, towards qualitative gathering and reflection." (McGarry, 2005). However, companies that could be said to be on the cutting edge of innovation, such as Google (2007) and Apple (2006), still rely on these traditional methods.

This reliance may be because most engineers that they employ are not educated to consider the users of their products as part of the design process. Indeed, this only removes time spent satisfying a specification and introduces ambiguity to a product. It may be difficult to shift such a culture – there is a natural tendency to associate understanding of human activity with the other human sciences of psychology and sociology. As a result, expansion of investigation of use practices by companies has led to hiring people from the human sciences to articulate user needs and test user interfaces. This is an encouraging progression. However a need remains for synthesis and design skills to move toward and into the user exploration space. Human scientists and anthropologists aim to understand and articulate, but a fundamental tenet is not to intervene and change. Anthropologists come from traditions that analyse people, rather than intervening and synthesising with them. A combination of design skills should be reached and to realise this, it is necessary to consider the integration of engineers into a participatory design process.

2.2 Ubiquitous computing

> *"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it." (Weiser, 1991)*

2.2.1 History

Ubiquitous computing had its beginnings in 1987 (Weiser et al, 1999), when members of the Xerox Palo Alto Research Center Electronics and Imaging Laboratory (Xerox PARC) proposed creating large, wall-sized, flat-panel computer displays. These displays were also planned to function as input devices, with the ability to interact with digital pens and the ability to scan documents. The research vision behind this, to create a computing system as simple to use as a whiteboard with computational power and networking ability, was a radical departure from the then current "one person-one desktop computer" paradigm. This prototype was the foundation for the concept of deploying computing potential ubiquitously throughout different contexts of use.

At the same time, anthropologists such as Suchman (1987) were observing the way people really used technology, going beyond how people self-reported their use of technology. While people do not mean to falsely represent their use of technical artefacts, retrospective summaries from a practitioner's perspective offer a different level of granularity from the details of interaction observed directly. Suchman's research spurred researchers such as Mark Weiser from PARC (Weiser, 1993) to think beyond the technical requirements of computing and towards the situational use of technology within the complex social framework of daily activity.

Ubiquitous computing as a research field could be said to have begun with Weiser's (1991) seminal paper entitled "The Computer for the 21st Century", which defined a new paradigm for interaction with computers. This paper both coined the term "ubiquitous computing" and defined the philosophy and implications for such a dramatic shift in interaction.

Research towards new computing modalities in the late 1980s and early 1990s trended towards the paradigm of virtual reality. Regardless of the enthusiasm for what was touted as a naturalistic and efficient means of interaction, by the late 1980s there was already discontent with the required infrastructure as well as what was found to be a highly restrictive and formalised means of interaction.

Virtual reality was described by some researchers as merely "a gadget for rich countries" (Ditlea, 1989). Virtual reality required the user to be immersed in the world of the computer, often in hooded or enclosed spaces, using large headsets, goggles and gloves, all tethered by wires. While there was recognition for the potential of computer transparency in virtual reality, the excessive overhead and infrastructure required for this means of interaction ultimately defined and propelled the direction of Weiser's vision of invisible computing.

Weiser attempted to shift research from the concept of "virtual reality" to that of "embodied virtuality" (Weiser, 1991). Rather than pursue the paradigm of users immersing themselves into the world of computers, he was one of the first to posit that perhaps it would be better for human-computer interaction to shift computers into our everyday world, by embedding and distributing computing potential within.

During the late 1990s, other visions of human-computer interaction were put forward, such as Ishii's (1997) Tangible Bits. However, while Ishii's tangible user interfaces are novel and have provided different ways of thinking about interaction, Ishii's research has not sought to deploy new forms of interaction into real work practice contexts with real users. In my investigation of the field, this has been a recurring theme in ubiquitous computing research.

Weiser's initial descriptions of ubiquitous computing defined it as a logical progression in computing, which he compared to the transition of the written word from a privileged few to the masses (Weiser, 1991). Through an exponential growth of new means of accessing and manipulating knowledge, like those afforded by the printing press, Weiser believed that ubiquitous computing offers a similar movement forward from the existing computing paradigm.

It is clear when watching the difficulties faced by a person when using a computer for complicated tasks, or in an environment that does not suit the keyboard and mouse paradigm that there are deficiencies in the current predominant means of interaction. By embedding technology where it is needed and providing more naturalistic interfaces, the cognitive load for the practitioner may be reduced and for the computer to become 'invisible'. From the practitioner's perspective, they do not have to adjust and tailor their thinking, work practice and body movement around the conventional interface.

One of the primary aims of ubiquitous computing is to provide a more naturalistic and efficient means of interaction, divorced from the restrictions of the keyboard/mouse/monitor paradigm (Weiser, 1991). Ubiquitous computing should instead draw upon the physical world and people's natural skills as a means of presenting and interacting with the interface. Separate from the field of ubiquitous computing, this multimodal interaction (utilising multiple physical interaction techniques) has been recognised as offering several benefits in a variety of applications in computing, particularly greater efficiency and usability (Oviatt, 1999). However the efficiency brought by such interaction methods is not always tempered with respect for people's existing skills and abilities, which is in contrast to the aims of participatory design in empowering practitioners and supporting their tacit knowledge.

Early attempts to define and develop the field remain a product of their time. Weiser and his colleagues at Xerox PARC (Want et al, 1999) drew upon up-and-coming technologies which would result in defining the portable digital assistant (PDA). In this way they defined a hardware based description of ubiquitous computing, which by Weiser's own admission did not fit the ideals of the invisible computer (Weiser, 1993). The technical capabilities Want et al (1999) deemed to provide the ubiquitous computing paradigm (i.e., touch screen display, embedded microchips, numerous displays), while useful for exploring the field as to identify potential technical grounding points, do not automatically furnish the "invisible computer" due to a lack of consideration for social requirements.

The emphasis of the technical push for ubiquitous computing was evident throughout Weiser's (1991) work, with such systems initially describing and prototyping (Want et al, 1999) ubiquitous computing as being by the "foot, yard and inch" and made up primarily of different sized displays. This vision of ubiquitous computing continues to heavily influence research in the field. Based on the existing computing paradigm, this has been an attractive goal; however such systems have ultimately proved unsatisfactory (a topic more closely examined in this chapter) for significantly improving the interaction paradigm. This influence upon ubiquitous computing has proved to be problematic in satisfying practitioner requirements and thus supporting its uptake. Therefore as the field has matured, a philosophical definition of ubiquitous computing has slowly evolved with a less technical definition of invisible computing.

However, the desire to continue to define the field with new technology has remained. Research in ubiquitous computing tends to fall into one of two camps; either the focus is to create a computing paradigm that subscribes to the philosophical underpinnings of ubiquitous computing, or instead the efforts focus on technical advances based on an abstract concept of what might be useful for the field. Although some of the technical approaches provide important new directions for ubiquitous computing, many tend to reconsider existing applications of technology and find a new problem for the solution (Weiser, 1993; Langheinrich, 2001; Hightower and Borriello, 2001). Others still merely describe new methods of embedding computing with only a superficial consideration of the philosophy of ubiquitous computing.

In some ways it could be said that ubiquitous computing infrastructure is "finding its course" without significant intervention from researchers. The world of computers has naturally progressed towards wireless, interconnected devices taking advantage of embedded computing (such as laptops, PDAs, tablet PCs, mobile phones), without a stated goal of ubiquitous computing. Although some researchers (Schmidt, 2002) believe this alone is enough to achieve a paradigm of "disappearing computing", others such as Sokoler (2004) feel that not all these new technologies take us towards a more balanced relationship between humans and computers. Sokoler argues that "going beyond the desktop computer" is still as relevant as it was when first posited by Weiser.

Based on such concerns (which are expanded upon in the discussion chapter), it is my opinion that that research in the field would do better to apply these popularly accepted technologies towards achieving the philosophies of ubiquitous computing rather than attempting to create new hardware infrastructure from scratch. Without these first steps at philosophically achieving ubiquitous computing, realisation remains merely a technical problem and the social considerations remain unaddressed. It is therefore necessary to consider the benefits and shortfalls of a technical approach to ubiquitous computing, in order to conclude lessons for design and apply them towards achieving a new paradigm of computing.

2.2.2 Technically driven ubiquitous computing

> *"Can you imagine putting your address book and photo album on in the morning along with your socks?" (Marks, 2005)*

Much of the initial and ongoing research into ubiquitous computing has been focussed on technical achievements, in particular, using the generic "office environment" as a use scenario. The issue of such a limited context of use is noted by other researchers such as Binder and Warren (2003). Weiser, the founder of the ubiquitous computing movement has on occasion revealed his own bias (emphasis added):

> *"We believe that people live through their practices and tacit knowledge so that the most powerful things are those that are effectively invisible in use. This is a challenge that affects all of computer science. Our preliminary approach: Activate the world.*

> *Provide hundreds of wireless computing devices per person* ***per office.****" (Weiser, 1994)*

With this generic assumption of a problem space, researchers may focus design work on innovative technologies. Partly because of this, there are many examples of ubiquitous computing systems that demonstrate potentially useful technologies but that lack a sense of practitioner involvement and have not generally explored how such technologies will actually be embedded into practice (Abowd et al, 2002). While these projects have strong technical contributions, their use scenarios are often impoverished, and the emphasis is on solving technical challenges, rather than integrating technology successfully. These projects may exhibit technology in search of a problem. This is best explored with some case studies.

Mannings and Pearson (2003) researched the use of clothing as a means of supporting ubiquitous computing, and envisioned individual articles as becoming part of a "personal area network". In the research the personal area network was a "digital bubble", in which personal electronics embedded in clothes can communicate with devices such as mobile phones, personal digital assistants, or other people's bubbles. While such technology would be useful in certain scenarios, its motivation and implementation is problematic Mannings and Pearson state:

> *"You could have a wireless data exchange between bubbles, perhaps between people's intelligent jewellery in a bar. You might transmit info on your likes and dislikes to help find a compatible date all the quicker." (Mannings and Pearson, 2003)*

While such research may allow explorations of technology, it is not a useful attempt to stimulate the acceptance and ubiquity of embedded computing. There may be a group of people who would indeed appreciate using computing embedded in jewellery to network in social situations, but without adequately exploring this scenario, and instead positing it as something that "might be useful", it does not adequately address the social complexities of such a scenario.

An example based in an office context is the research undertaken by the Xerox Research Centre Europe, which explored what a future office may be like (Andreoli et al, 2003). The aim presented was the creation of an "affordable enabling infrastructure" for ubiquitous computing (a goal shared with myself), with a basic assumption that technology in the imagined scenarios would be both inexpensive and readily available. While this assumption may yet hold true, the paper does not consider the scenario from the point of view of the practitioner within their "Augmented Office".

The office imagined would have been based around a new technology (Xerox DocuShare™), which uses RFID tags embedded into printer paper. An example scenario given by the researchers describes a practitioner attempting to print a document. RFID tags embedded into the paper would allow the practitioner to locate their document faster and more efficiently. If a practitioner attempted to print a document when a large file was already being printed, the option to negotiate printer priority would be available. The printer would initiate a phone call to the owner of the large print job to facilitate this.

What is lacking from the scenario presented by the research is an exploration of business practitioners' impressions and experiences in locating a job by RFID tags, or an examination of what level of expense for such a system might be considered worthwhile. While application of the RFID tags is described, a more detailed design approach may reveal things such as alternative more useful applications for RFID tags (or other technology), the difficulty of logistics of tagging each piece of paper with an RFID tag, practitioner privacy issues, under what circumstances office workers would be happy to be interrupted from their work to negotiate time on the printer and so on. By focussing on the technology, design possibilities that can arise from practitioner knowledge and context remain unexplored.

Given the aims of ubiquitous computing for supporting multiple different means of manipulating computing potential, many projects focus on achieving a particular technical contribution. For example, a recurring theme in ubiquitous computing research is the idea of networked surfaces (e.g., Lifton et al, 2002) for devices to communicate with each other to allow distributed computing. Research into this field has investigated using the surface of everyday furniture such as desks and note-boards as a means of communicating between sensors and other machines. This allows the devices to both receive power and to communicate without requiring bulky components within their own package to facilitate this independently.

Conceptually, this fits nicely with ubiquitous computing's ideals, by integrating the technology in such a way that it is invisible to the practitioner, while providing a cheap and reliable means of communication between devices. However examples of networked surfaces research in the field tend not to consider what level of technology is required to be useful in a particular context, and instead focus on solving a "technically sweet" challenge. Focussing on a specific technical problem may also reduce the potential of such interfaces. The PinandPlay project (Laerhoven, 2002) made use of the surface only as a source of power and not for communication between devices. Lifton and Paradiso's (2002) Pushpins meanwhile are limited by their range of only ten centimetres.

While the effect of these technical concerns may or may not affect their integration to a work place, the technical focus leaves practical use by a practitioner unconsidered. In these examples, there are several factors that could be explored through participatory design. By engaging participants, it would be possible to examine the context in which such surfaces would be used and consider issues such as: which items use the surface for communication, which simply need it for power, how other technologies such as wireless technologies compare, how communication range issues affect usability, other imagined use of the surfaces, and costs. It may be that such technical limitations do not affect the usability or potential of the products, but ultimately this possibility is not explored in the research.

Another area of development for ubiquitous computing is the aim to imbue entire rooms with computing abilities. By embedding computing potential into furniture and walls, computing abilities are argued to be ready-at-hand. This allows a complete ubiquitous computing system from scratch, rather than augmentation (and its associated limitations) of existing infrastructure. The i-LAND project (Streitz et al., 1999) makes use of tables as scanners, desks as collaborative spaces and walls as computer screens. While this system did make the transition to a commercially available ubiquitous computing product, it represented a significant potential cost. Having been built as a specific technological platform and product for a generic, yet subjectively chosen use, its adopters must either find specific problems that fit the technological product or adapt the technology to meet user practices and contexts. In order to accommodate a specific technology configuration that is not designed with their work practice in mind, users typically need to undertake large shifts in work practice. While this may be considered desirable, the alternative work practices are untried and unknown.

In contrast to expensive and generic systems such as i-LAND, Binder and Warren (2003) describe the Atelier Project that explored technology adaptation and adoption. The Atelier Project is noteworthy in that it utilised simple and off-the-shelf technology, which allowed rapid and widespread appropriation and integration. As part of the research, architectural students were given both barcodes and RFID transceivers to use as design tools and as part of the interactive artefact being designed (Ehn, 2004). These technologies were used primarily for interacting with animated design artefacts connected with multimedia files. The project made use of participatory design approaches not just in the design process but also for developing the design tools.

During the project, Binder and Warren (ibid) noted that barcodes and their associated readers were more easily appropriated as tools for interaction than RFID transceivers and readers. The suggested cause was that while barcodes and barcode readers have a place in everyday public lives (and therefore a common understanding of their use), the technology of RFID does not have common examples of use that contextualise its interactions, and thereby provide vehicles for imagining new uses. Put simply, RFID does not readily afford its interaction potential. The lack of familiarity restricted its use, highlighting the need for effective communication of technological ideas to the designers in order to extend design possibilities.

Conversely, another difficulty in designing new ubiquitous computing systems may occur when a project attempts to make use of known and familiar paradigms to support the integration of such systems. Wellner (1993) created a digital desk in an attempt to create a complete ubiquitous computing system. The digital desk described is a standard office desk which uses a video projector and camera to provide a computing interface on the surface of the desk. However Wellner’s configuration made use of equipment that was bulky, expensive, and proprietary.

With technical developments, such as large LCD displays and digital cameras becoming affordable and widely available, Wellner's desk is certainly easier to implement commercially now than when first prototyped. However, similar projects remain in the realm of research, or used as technology demonstrations.

While such a setup may afford a more natural and comfortable work space than using a keyboard, mouse and monitor for some scenarios, it is being designed as a generic interface replacement. It appears there is no specific interaction difficulty it is trying to improve upon, other than to move the interaction methods from a screen with a keyboard and mouse to a physical interface on the desk surface. The motivation was that a physical interface has more natural affordances than a digital one. For ubiquitous computing projects such as this to be successful, there should be an incentive to the practitioner to appropriate the technology. An examination of how desks are actually used in specific work contexts and the types of tasks that are difficult due to constraints from existing configurations would be likely to give a keener insight into how to configure a new kind of desk.

Indeed, as Weiser (1991) himself discussed, the difficulties of designing ubiquitous computing are not due to technical challenges alone but also the "very difficult integration of human factors, computer science, engineering, and social sciences." As seen by examples in this section, these problems may manifest themselves in infrastructure costs, deployment difficulties, practitioner training needs and the difficulties from systems being designed from a technical vision.

In learning from the issues encountered in other projects, it is necessary to consider both the practitioner interactions, practices and capabilities (such as the ability of practitioners to integrate devices into their practices), and the characteristics of technology and its underlying infrastructure. This suggests that rather than develop a complete concept for a ubiquitous computing environment and then build a research prototype that is removed from a work practice context, a participatory bootstrapping approach is needed (Cederman-Haysom, 2004). Participatory bootstrapping at its core is in-situ prototyping with the practitioner, combining design studies and execution. How this was applied in my own research is further discussed in section 6.1.

In using a participatory bootstrapping approach designers reveal the capabilities and characteristics of technology and technical infrastructure to practitioners in intelligible ways by continuing prototype and development in the practitioner's work space. It facilitates immediate feedback, allowing the designer to inform and *trial* system design in an immediate fashion, while the practitioner can observe how new systems are created. Practitioners can often find the details of infrastructure both mundane and baffling. By allowing practitioners to observe the development of such technologies, as well as trial and explore the possibilities, they are able to enhance their work practices immediately in the context of their actual work environments. Designers ensure the technology is intelligible by making core concept prototypes appropriate to the context, and immediately testable. The technology can then be interrogated in reasonably short timeframes, as most practitioners are busy people. The emphasis then shifts from the technical capabilities of the system to the effectiveness of the philosophy behind the design.

Ultimately, what these examples show is that while technical research is useful for testing new technology, it does not necessarily provide new perspectives on design or push the boundaries of how we conceive of the possibilities for these systems. In my previous research (Cederman-Haysom, 2004), it was suggested that these boundaries should be explored through conversations with practitioners about ubiquitous technology in the context of use. This was facilitated by "Wizard of Oz" techniques (Dahlbäck et al, 1993), and low-fidelity prototypes that represented key interaction abilities or core technologies. New perspectives and understandings were explored by finding a common currency of language and understanding between practitioners, designers and engineers. Holistic requirements for designing ubiquitous computing should be addressed through considerations such as these, shifting the design emphasis to the philosophical ideals of ubiquitous computing.

2.2.3 Philosophically driven ubiquitous computing

In Weiser's later research of ubiquitous computing systems (Weiser and Brown, 1995), he defines ubiquitous computing in a manner that transcends a technically defined paradigm. Given the far-reaching ambitions of the field, a technology-independent definition is required to establish its long-term direction. Weiser (1994) successfully put aside the initial point of focus, of inadequacies with existing interaction paradigms, described as the "graphical user interface (GUI) problem". Instead he examined the "relationship problem" – how computers and people relate to each other. It is this greater emphasis on the relationships between people, their work, and computing that defines philosophically driven ubiquitous computing.

In later research, Weiser referred to the goal of ubiquitous computing as being "calm computing" (Weiser and Brown, 1995). Calm computing attempts to remove the practitioner's focus from direct interaction with a computer, instead using the centre and periphery of their attention. Weiser described the problem of supporting the tasks of the practitioner as being of balance:

> *"We must also find the balance between control and simplicity, between unlimited power and understandable straightforwardness, between the seduction of smooth digital mediation and the immediacy of those complex fellow workers called humans. But in the end, it is hard to imagine a more important task for twenty-first century technologists." (Weiser and Brown, 1995)*

What is notable in the ongoing research in this area is the consistent emphasis for making use of ethnography or ethnographically-inspired fieldwork (see section 3.1.7 for details of these methods) in order to suitably explore and understand the context of use to find this balance. While a typical design approach may be to identify use scenarios for a new technology, an alternative approach is to reflect more generally how ubiquitous computing may improve a particular context. By using ethnographically-inspired fieldwork to gather information and reflect on the complexities of the interaction taking place, a system that supports the tacit skills and knowledge of the practitioners can be created.

An example of how these methods are used for ubiquitous computing design is Tolmie and Pycock et al (2002), who specifically defined the goal of their Unremarkable Computing project as making technology "invisible in use", focussing on the philosophy of ubiquitous computing. To do so they studied a variety of everyday people in the aspects of their lives using ethnographic techniques. They noted that it was in the mundane features of their studies that the most interesting design opportunities presented themselves.

Specifically, Tolmie et al (2002) looked at how ubiquitous computing may benefit domestic environments. In one study, the mother of a household would appear to ignore a clock-radio alarm going off. Later actions revealed that the event was a significant, but not externalised, placeholder in the routine of her life. If this situation was viewed from a more simplistic viewpoint, the conclusion may be drawn that the alarm was simply superfluous and thus is duly ignored, given the lack of reaction; however it is important to understand the reasons why this failed to elicit an externalised action. The alarm was actually mentally noted by the mother, but she acted upon it (by waking up her children) when it fit appropriately in her routine.

This type of hidden meaning was something that was revealed within the research presented in this thesis. As further discussed in chapter 5, it is by understanding the entire context, including things such as a person's routine and tacit knowledge, that motivations for a person's activities are revealed.

Calde (2003) gives the example of designing an irrigation management tool for golf course superintendents. The superintendents reported they took many notes on their laptops as they travelled around the golf courses, checking for problems. In reality, the laptop remained stored in the back of their golf cart throughout the entire inspection process. If a problem was found, it was either fixed on the spot or the superintendent radioed for someone else to fix it. Notes were completed at the end of the inspections. The gap between what practitioners say they do and what they actually do remains an important problem to address. It is difficult to identify these gaps through mere questioning – many actions evolve spontaneously and must be discovered through intense observation.

Ultimately existing literature rightly identifies that when employing an ethnographically-inspired field study utilising participatory design, there is a need to properly understand the context of deployment (and its practitioners). It is then appropriate to adjust the technical expressions of the design to suit the human needs and practices.

2.2.4 Considerations for research in ubiquitous computing

Given the problems with existing approaches to designing ubiquitous computing systems, it is important to reflect upon what the most important areas of consideration for design really are. In my opinion, these concern four specific areas.

The first is attempting to achieve the goal of invisible computing. Doing so satisfies the philosophical requirements of ubiquitous computing, and provides an interface that does not distract the user, and adequately accommodates the context of use.

The second is appropriately making use of context in a ubiquitous computing system. It is necessary to draw upon and react to the context of a situation in order to satisfy the social effects of new systems. These effects refer to how a system may alter work practice or communication. For example, speech recognition systems must be carefully designed so they do not interfere with regular communication while completing normal work practice, and such that the context of use does not interfere with this method of interaction.

The third consideration is the use of multimodal interaction in such a system to support the desired means of interaction. How the practitioner physically uses the ubiquitous computing system has far-reaching effects on work practice, and assumptions should not be made as to what appropriate means of input are.

The final consideration is the commercial suitability of the design. An often overlooked aspect of ubiquitous computing is whether it is economically useful, and for a design to be successful it must make financial sense to support its uptake. The following sections discuss each of these concerns and how they are currently addressed by research relevant to the field.

2.2.4.1 The invisible computer

> *"A good tool is an invisible tool. By invisible, I mean that the tool does not intrude on your consciousness; you focus on the task, not the tool." (Weiser, 1994b)*

Weiser (1994) explains that the invisible computer does not refer to the visual invisibility of a computer, although this may be a useful property of a ubiquitous computing system. Instead, the invisibility refers to the practitioner perceiving that they are accomplishing the task themselves, rather than focussing on driving the interface to have the computer accomplish the task. Weiser states:

> *"Whereas the intimate computer does your bidding, the ubiquitous computer leaves you feeling as though you did it yourself." (Weiser, 1993)*

Tolmie et al (2002) refer to this as the *unremarkable*, rather than the *invisible* computer to help differentiate the alternative interpretations of invisible ubiquitous computing. The Equator project (ibid) outcomes suggest that it should be the actions, not the artefacts, that should be augmented with ubiquitous computing to support unremarkable computing. Emphasis should be placed upon existing interactions rather than designing devices to allow new interaction techniques.

The ideal invisible computer is fairly loosely defined. Weiser has given several revised definitions on what invisible computing entails which can be summarised to two different viewpoints. The technical definition of invisible and ubiquitous computing defines it as extensive embedded microprocessors. Weiser compares this to the use of solenoids in cars, a technology that is widely used, but a component of the system that is not obvious to the user. In his definition, the computing is both physically and functionally invisible, whereby the computing is not done with a direct interface, and the embedded processors are invisible from sight. A later and more mature definition refers to the socially invisible computer. In using this definition scenario, the person making use of ubiquitous computing is aware of only of the task at hand. These definitions actually complement each other; however it is an important distinction. One places emphasis on hiding the computer, while the other places emphasis simply on the user being unaware of the computer. Within both definitions, Weiser is consistent in his reference to the requirement of human agency (as also discussed by Campbell, 2004), which keeps the computing potential within the control of the practitioner to reduce their frustration.

An example of agency and invisible computing is the use of anti-lock braking systems (ABS) in cars. This is a technology that takes a simple command (hard braking) and applies a complex yet well defined response (intermittent braking depending on the conditions) to provide the driver with the required action automatically. The driver does not have to bring up a display to turn on the ABS control, nor do they need to adjust any settings for it. It "just works", and to the driver they merely braked. Although this is a relatively simple (and niche) example, it provides a description of invisible computing with an appropriate level of agency. By augmenting a situation to the controls of a device without focusing attention on the computer, invisible computing is attained. However, as the situation becomes more complex, there is a need for increased agency and further feedback. It is balancing these properties that become a key consideration in designing usable ubiquitous computing systems.

In one such attempt to achieve this balance, Chalmers and Galani (2004) created a mixed reality system with the aim of creating a seamless mix of technology to support invisible computing. They suggest that designers should reveal differences and limitations of systems to assist the user's understanding, and thus the transparency, of an interface. However this concept is suggested primarily for supporting social interaction (such as friends sharing an interesting museum experience) rather than supporting work practice. What is useful about what Chalmers and Galani showed in a social context is that exploring the boundaries and deficiencies of a system with a practitioner provides them with a complete expectation of how the system will work. Simultaneously, it provides insight into potential means of appropriating the system into existing work practice: the feedback from revealing the limitations gives insight into better means of integrating new systems from the practitioner feedback.

Most importantly however, when the user understands how the system functions from a technical viewpoint, they are able to better predict how it will behave. Paradoxically, by adapting to system deficiencies, the system becomes more invisible. As explored in the discussion chapter of this thesis, appropriate feedback mechanisms are necessary to continue informing the practitioner of system limitations to allow them to further adapt.

Also discussed by Chalmers and Galani (2004), is the importance that the interface behaves predictably to avoid breaks in attention and to aid the practitioner's understanding of the system. If the system behaves erratically, the practitioner cannot predict behaviour, leaving them unable to adapt to system deficiencies. For example, if software is imbued with "common sense" (as determined by the developer) whose workings are unknown to the user, it may incorrectly interpret what a practitioner is attempting to do. This results in the system behaving unpredictably, making it difficult to think ahead when time is spent continually checking that it does what is expected.

When attempting to integrate basic context recognition for dentists, I encountered this reaction to unpredictability in my own studies (Cederman-Haysom and Brereton, 2006). During design studies it was found that if a charting program tried to guess where the dentist would like to chart next, the dentist began spending all their time checking that the chart was where it should be, requiring the contextual detection to be tweaked in some areas and removed in others. Through understanding what the system was attempting to do, the practitioners were able to adapt to it and advise on adjustments that improved the system's ability to improve their work practice. The issue of a ubiquitous computing system responding appropriately to context is one faced by many researchers.

2.2.4.2 Context recognition

To achieve usable ubiquitous computing, context recognition is likely to be required, and much has been made of the use of context detection to augment ubiquitous computing systems. However, in considering this aspect of ubiquitous computing, the first difficulty is the conflicting definitions of context. Dourish (2004) delineates them into two approaches. The first definition is the representational problem, or how context can be encoded or displayed. Dourish defines it thus:

> *"Context is something that can be known (and hence encoded and represented much as other information is encoded and represented in software systems)*

Context is delineable. We can define what counts as the context of activities that the application supports, and do so in advance.

Context is stable. The precise elements of a context do not vary from instance to instance of an activity or an event.

Context and activity are separable. Activity happens 'within' a context. The context describes features of the environment within which the activity takes place, but which are separate from the activity itself." (Dourish, 2004)

Dourish here describes what context is for the purpose of considering its use within a system. Such a definition makes it a more tangible property of the design space and something which can be utilised. The second view of context is that of context as an interaction problem:

"Rather than considering context to be information, contextuality is a relational property that holds between objects or activities. It is not simply the case that something is or is not context; rather, it may or may not be contextually relevant to some particular activity.

Rather than considering that context can be delineated and defined in advance, the alternative view argues that the scope of contextual features is defined dynamically.

It argues that context is particular to each occasion of activity or action. Context is an occasioned property, relevant to particular settings, particular instances of action, and particular parties to that action.

Context arises from the activity. Context isn't just 'there,' but is actively produced, maintained and enacted in the course of the activity at hand." (Dourish, 2004)

What is also important to consider here is the effect of context recognition, and the associated automation on user agency. Much has been made of the potential of ubiquitous computing devices to converse with each other and make decisions based on contextual input (Langheinrich et al, 2000), and the benefits show a lot of potential for assisting task automation. While such automation can improve efficiency and usability, and reduce the need for complex system configuration, the concern is that too much may complicate or impede the predictability of a system, degrading the practitioner's experience.

Predictability for systems was discussed by Suchman (1987) who concluded that it is not possible to know with complete certainty what action is best to take at all times, particularly when making use of incomplete knowledge of the circumstances. One infamous failed example of a system attempting to plan the best course of action by system context is 'Clippy', the virtual user assistant that supported the Microsoft Office suite of products (Settings, 2007). Clippy was an animated paperclip which attempted to automate tasks for the user, often to their consternation, and was subsequently removed from future versions of Microsoft Office. One suggested means of obviating such user frustration is to allow the practitioner a level of agency appropriate to the task at hand (Campbell and Brereton, 2004). Campbell (ibid), in research that studied the same group of dentists as this dissertation, notes that many difficulties with existing systems could be improved by a greater sense of agency for the practitioner. While designing a context-aware patient charting system for dentists he achieved this through close consultation and multiple design studies with dentists, creating an instrument table attached to the patient's chair aware of the task at hand.

In-roads have been made into designing other contextually aware ubiquitous computing that allows suitable agency, such as Persson's (2001) "social ubiquitous computing", which aims to reveal the context awareness to users and reduce the artificial intelligence of said devices to an 'appropriate' level. It is in identifying and achieving the level that is appropriate for a particular context which is difficult. Campbell (ibid) noted the large number of design activities required to do this.

Indeed, attempts to integrate context detection in a socially useful manner to ubiquitous computing projects have had many difficulties. Persson describes GeoNotes, a system that allows people to leave notes for other people based on GPS co-ordinates. Such a system has potential, but for users to participate socially in such a system, all must have the technology required. Another concern is that leaving the actual deployment and consequences of such technical capabilities unexamined leaves the system open to potential abuse and user difficulties. While the technical capability would certainly be useful *in the right circumstances*, the approach is essentially of a technological function seeking a purpose, and also requires almost no contextual decisions to be made. Further design activities would help to address these concerns.

Persson's (2001) Family Link project uses position, temperature, altitude, biometrics, writing activities, calendar entries, social proximity and contextually aware objects to create "family awareness". The scenarios touted for such contextual information are shopping lists and family safety. In comparison, while Persson describes social ubiquitous computing as a minimally configurable solution to mobile computing, Family Link requires complex alarm configuration - "If it is Thursday and John passes the door of the house, send him the following SMS: 'Don't forget your trumpet for your music school, honey!'" (Persson, 2001). While configuration and customisation of complex systems is important, providing a system that requires ground-up, highly detailed programming (although it respects user agency) does not fit the tenets ubiquitous computing.

It is the requirement of complicated input and equally complicated information displays that are problematic. Successful recent social Web 2.0 applications that transcend the web (Flickr, 2007; Google, 2007b; del.ici.ous, 2007) have straightforward and streamlined interfaces that automatically derive context from the content and usage and successfully create social awareness through sophisticated extraction algorithms which respect user agency. For example, sites such as Flickr.com make extensive use of embedded meta-tags from photos, allowing spontaneous grouping of photos, and self sorting sets of images based on their details (such as location of photo, camera type, comments, upload group, etc). The number of views, as well as an algorithmically-derived 'interestingness', allow social exploration and a unique insight into the reception of photos by other users. This provides the tools for the user to better interact with their photos, while still not mandating a particular means of interaction or use.

By recognising the difficulties in incorporating context, particularly the need to allow the practitioner a level of agency, it is possible to minimise their frustration and maximise the design by adhering to invisible computing ideals.

The next concern relates to interaction techniques that suit a particular context. Given that ubiquitous computing systems allow computing potential in many devices as part of supporting invisible computing, there are many more options for interaction than the simple keyboard/mouse/monitor paradigm. Considering the focus of study for this research in the dental surgery and the limitations of interaction within (further discussed in chapter 4), design explorations for improving interaction focussed on multimodal interfaces that allow hands-free computer interaction, with particular emphasis on speech recognition.

2.2.4.3 Multimodal interaction

Speech recognition has been a well-known modality alternative for many years now, yet it has not achieved widespread adoption. Barksdale (2001) claimed in 2001 that "this is the year" for medical and dental voice recognition solutions to gain maturity, however to date this has not been realised. This can be attributed due to several design issues. The first design limitation for consideration is accuracy of word recognition (Mullins, 2005):

> *"…the North American market for speech-recognition software will grow by more than 25 per cent each year between 2005 and 2008 yet commercially available programs, such as IBM's ViaVoice or ScanSoft's Dragon NaturallySpeaking, fail to recognise a significant proportion of words. Manufacturers claim they miss around 2 percent of all words, outside experts say it is nearer 5 percent. In contrast a person can expect to recognise all but 0.05 percent of words."*

However, accuracy will continue to improve with time (Deng and Huang, 2004), and importantly, has not restricted the deployment of speech recognition to niche applications. The more important, and often overlooked, issue with speech recognition and other types of multimodal interaction is error correction. Brown et al (2001) found that users of speech recognition software spend two-thirds of their time correcting errors and that efficient error handling is one of the key design considerations for successful speech recognition. Karat and Halverson (1999) also claim that poor uptake for speech recognition systems is due primarily to error correction rather than initial entry of text into the systems.

One difficulty with overcoming this limitation is that it is recommended by Karat et al (2000) is to not use speech as a correction mechanism. While this may be a good rule of thumb for some contexts, in the dental surgery other modality options are limited due to existing interaction (such as foot controls), or infection control (such as keyboards and mice). It was also found that gestures for error correction were too disruptive to allow multimodal correction techniques given the existing usage of hands and feet for completing tasks. As explored in the discussion chapter of this thesis, the resulting multimodal system used in this research used speech recognition. As recommended by Karat, commands for correction and error feedback needed to be carefully managed such that the users understood how the error reporting and correction systems worked and could adjust appropriately.

How multimodal interfaces are integrated can be problematic. Aside from when speech is the only available modality (for example, when a disability precludes alternative interaction), many systems that make use of speech recognition do so for improving productivity rather than interaction (Karat et al, 2000). In this context, productivity is defined as the amount of data processed as part of work practice. In reality, the actual productivity of a person (i.e., the amount of work they can complete in a given amount of time) will decrease with the use of speech recognition. The benefits are usually gained through reduction of data translation. When considering numbers alone for improving usability, user frustration and integration difficulties may frustrate attempts at introducing new systems (Karat, 2000).

One example of the complexities of successful integration is presented by Lai and Vergo's (1997) investigation of the productivity benefits of multimodal interaction in health care. They created a continuous speech recognition system called MedSpeak which allowed application navigation and report dictation. The system was sought after because in addition to removing the task of transcription for patient reports, the doctors that it was developed for, radiologists, are paid per report produced. As such, report creation is streamlined to minimise the time involved since it is the most expensive aspect of radiology.

What was found in implementing the new system was that a cut-off point exists, where a system's difficulties outweigh its usefulness. This cut-off is reached sooner when there are alternatives that do not frustrate the practitioner and are just as viable at producing a system that is both usable and efficient and are well-known to the practitioner.

What differs with Lai and Vergo's project to that presented in this thesis is that the radiologists involved did not directly benefit from the system being introduced. The radiologist already dictated the results which were then transcribed by a staff typist, a process that they were satisfied with, and that allowed them to complete their work in an efficient manner. The primary benefit was reducing the cost of requiring a hired transcriber, but in turn this created new difficulties in adopting an unfamiliar system to the practitioner. When designing a new system for interaction, requiring the practitioner to detrimentally alter their work practice is a problematic approach. In this case, it required the development of new and otherwise non-applicable skills in addition to changes in procedure and additional responsibilities such as proofreading reports.

While the MedSpeak project also addressed other usability concerns, including minor issues such as icon colours and toolbar organisation, Lai and Vergo also recognised the greater importance of error correction in the usability of such a system. A complex on-the-fly error correction ability was created and tested with the radiologists, who ultimately rejected it due to the increased task complexity, cognitive load and interruption it introduced to their work practice. Lai and Vergo noted these concerns and instead shifted error correction to take place at the end of the report using a simpler system. However, it was reported that even with high accuracy levels for the speech recognition, practitioners were still dissatisfied with the lack of predictability in accuracy and correction with the modified application.

The lesson from the MedSpeak project is that after defining the goal of the software, the design team focussed on fixing technical problems, rather than redefining what is required to allow the system to be appropriated by the practitioners. While questionnaires were used to gauge user satisfaction, they were not used to adjust the software functionality, nor was there any attempt at medium fidelity usability testing.

One concern with the methodology of the project is the use of quantitative data to support its outcomes. While it is claimed such a system reduced the transcription time by 99.6% (i.e., if a set of transcriptions used to take 100 hours, they would now only take 24 minutes), this calculation is inclusive of the time that used to be taken to send the dictation to transcribers. The concurrent gains (or losses) were not considered by the authors, although it is shown that the system took on average twice as long to generate a report in MedSpeak compared to dictation. This extra time agreed with Karat (2000), who found users were less productive with automatic speech recognition than with a keyboard and mouse on a variety of tasks – taking almost twice as long to complete the same task.

As reported by the authors, MedSpeak was not completely successful in its implementation of continuous speech recognition for report dictation, however Lai and Vergo did have more success with discrete speech recognition for application navigation. Practitioners reported being satisfied with the command recognition and found it useful to adhere to a single modality of speech alone rather than speech and keyboard.

One difficulty that Lai and Vergo suggested improving in future work was the implementation of alternative phrases for commands. Appropriate alternative grammar is a necessary practice for commercial interactive voice response (IVR) development. Therefore within my research, in addition to error avoidance and correction, I attempted to allow a suitable variety of recognition for alternative command phrasing. Once implemented, this method reduces the amount of time required by the practitioner to learn commands, and in turn reduces errors due to pausing or incorrect words much faster than forced training with a restricted command-set.

Ultimately, systems implemented in a way similar to MedSpeak would be sought after by managers and administrators hoping to improve efficiency, rather than sought by the practitioners themselves. While the stated goal for MedSpeak was to create a highly usable system, instead it focussed on satisfying the requirements for removing the need for transcription, rather than how to improve and augment the radiologists' work practice.

Another consideration for research into multimodal interfaces is the use of well established approaches to design in the field. Reeves et al (2004) published a list of guidelines for creating natural and intuitive multimodal interfaces. Many of these guidelines are appropriate in almost all circumstances, such as consistency in the interface, ensuring privacy and security, maximising human cognitive and physical abilities and suitably handling and preventing errors. However, it is also advocated that interfaces are designed for the "broadest range of users and contexts of use". Kraal (2003) noted this is a common theme in multimodal literature. My own experience with using commercial speech interfaces is that they allow the broadest approach possible in an attempt to improve usability.

This approach is contrary to what other researchers (Kraal and Collings, 2004) advocate for improving the adoption and usefulness for multimodal interfaces. Instead, user acceptance and satisfaction increased through appropriating the interface to their particular work context. Almost counter-intuitively, by restricting the recognition parameters, practitioners become more accustomed to the limitations, while the system itself is better able to cater to a better defined scenario for use.

An example of a successful speech interface is the use of speech recognition for grammatically-constrained phone queries, called interactive voice recognition systems (IVRs). These are usually designed for a specific target audience, with an information architect outlining the flow of the speech application while the speech input is derived from both system specifications and user interviews. The requirements for this interface are well known (a fairly consistent speech input of a known quality and a context-specific enquiry), which in turn allows the tailoring of a speech engine specific to the application. A Gartner study (2003) found that speech was preferred by respondents to the study over touch-tone interfaces by a factor of six to one. While the study did not examine potential frustrations caused by such an interface, the study did record that the deciding factors for success were the accuracy, convenience and speed of the interface. The IVRs examined were tailored for a particular market and a specific product, allowing appropriate constraints upon the system that improved the accuracy and speed. It could be concluded that people are content to adapt practices for a robust interface.

Karat et al (2000) concluded from their research the following regarding the successful achievement of an "all purpose" automatic speech recognition interface:

> *"For the existing human-computer interaction paradigm of workstation interaction, we do not expect to see a mass user declaration of keyboard obsolescence in the near future." (Karat et al, 2000)*

An appropriate design guideline for a generic product might be to offer customisation to specific requirements. There is a constant tension in ubiquitous computing of designing for the generic use case and for the specific scenario.

Finally, it could be questioned as to whether the application of speech recognition can be defined as a type of ubiquitous computing. I feel that better design may take place by striving to match the philosophical underpinnings of ubiquitous computing, even if this means reapplying existing technology. Weiser himself states:

> *"Like the personal computer, ubiquitous computing will enable nothing fundamentally new, but by making everything faster and easier to do, with less strain and mental gymnastics, it will transform what is apparently possible … ease of use makes an enormous difference." (Weiser, 1991)*

Therefore given the appropriate considerations and integration of such a speech recognition system, it adheres to the ubiquitous computing ideals and can be said to be at least a part of a complete ubiquitous computing system. Further, by paying attention to how to achieve a useful and specific interaction, lessons can be learnt for broader application.

2.2.4.4 Commercial viability

An issue often unconsidered in research in the field of ubiquitous computing is the commercial viability of implementing new systems. For a system to be useful to a business, it must make fiscal sense, and for research to shift to commercial endeavours, or to be useful to budget-minded practitioners, it must remain within the realm of affordability.

Designing complete ubiquitous computing systems would also be easier if unique components within the system were commercially produced and readily available, so that designers could experiment with configuration and integration for contexts of use.

While it is not always possible to create an entire system using off-the-shelf equipment, avoiding “reinvention of the wheel” should be encouraged.

Because of the new technology involved and the cost of introducing new infrastructure and software, it is a debateable over whether ubiquitous computing can ever achieve commercial success outside of unique and customised systems.

Regardless, there have been efforts by several companies to release commercially viable ubiquitous computing which adheres to the ideal of computing embedded at hand. What has been lacking so far is the release of cohesive products that allow complex inter-coupling. Many standalone embedded computing devices exist that allow distributed computing, but without standards that support appropriation by practitioners, they do not support ubiquitous computing as it is defined. Weiser recognised this difficulty, and explained why ubiquitous computing is not a PDA:

> *“Unlike PDAs, ubiquitous computing envisions a world of fully connected devices, with cheap wireless networks everywhere; unlike PDAs, it postulates that you need not carry anything with you, since information will be accessible everywhere.” (Weiser, 1993)*

Siemens (Tsakiridou, 2002) and Philips (2007) are two companies that are representative of the current commercial approach to ubiquitous computing. Siemens aim to utilise PDAs and large displays to facilitate ubiquitous computing to support communication in a corporate environment. Philips hopes to incorporate ambient contextual information in the home with products that can communicate with each other. In this way, they are both providing systems that are tailored for a particular context. This is a necessary stepping stone to ubiquitous computing gaining a foothold as an accepted paradigm of computing, and the approach taken for my research.

Embedded computing as it is currently designed does not adequately support the ideals of ubiquitous computing. Ubiquitous computing systems need devices to be designed so that they are usable on their own as well as in a ubiquitous computing context. For example, a digital pen should allow itself to be used in tandem with a variety of devices - such as writing a note to be sent via a mobile phone, annotating a document on a computer, or for writing in a notebook that then allows for searching from a desktop later. Many devices, such as the Logitech iO digital pen (Logitech, 2007), support only a wired, USB interface, or proprietary wireless communications (or at best, customised Bluetooth interfaces) which do not support inter-device communication. This means they must be tethered to a PC to achieve any data communication and tasks involving more than one device cannot be accomplished in real time.

Furthermore the data sent must be received by driver software, meaning that manipulation of the data is usually restricted to what the official software can accomplish. One particular difficulty hampering commercial success, as alluded to previously, is the lack of open communication standards. While USB has made great inroads to allowing devices to be interoperable, ubiquitous computing requires devices to be independent. With wireless standards like Bluetooth, this is achievable, although rarely pursued.

The all-encompassing uses (indeed, many consider it a necessary paradigm shift from computing as it is currently perceived) that ubiquitous computing is intended for means that there will never be a single system that is realised and establishes a universal new system for computing. Like other ambitious, pervasive projects, such as the Internet, it will require a set of open standards that are reproducible by everyone yet are designed to be flexible enough to support growth and extended use. How this will be implemented and take place remains to be seen.

One thing that can be established with surety is that ubiquitous computing must go beyond “smart displays” and “smart coffee cups” and focus on solving difficult interaction problems that will allow the practitioner to simply accomplish work. To do so, it is necessary to reassess the approach to ubiquitous computing design, with an emphasis on both reusing existing technology and understanding the context of deployment.

2.2.5 Rethinking ubiquitous computing design

Ubiquitous computing requires new directions and alternative methods for design instead of more traditional design methods in order to achieve its philosophical ideals. For this reason, Abowd and Mynatt (2000) advocate the "living laboratory" approach. They state that ubiquitous computing should be used and tested as it is designed by the researcher. Weiser and his colleagues also used this approach (Weiser, 1991; Weiser, 1993). While this may provide a seed for potential use scenarios, it either results in testing the system in a context radically different from its intended use (the researcher's laboratory instead of the practitioner's work context) or finding a problem (within the researcher's laboratory) for the solution. This approach also encourages engineering design, where the engineer customises a system according to the problems that they see. There are some benefits to such an approach, with Schmidt (2002) arguing that the living laboratory is a useful setup in that it allows:

- Regular prototype testing
- Thorough exploration of the design space
- Further understanding and inspiration for technical development
- Managing and documenting limitations

However, if the goal of a researcher is to create a usable system (in Schmidt's (2002) words "a system that is usable without manuals and training"), then it is problematic to believe that customising the prototype for the researcher will allow the system to be deployed without the same stumbling blocks in other contexts. Furthermore, such a goal ignores the fact that often times complex systems require a degree of practitioner experience and skill for effective use. Abowd and Mynatt (2000) state that a living laboratory approach must eventually progress to deployment in the context of use. However, appropriation by the practitioner in their context of use happens after the main exploration of the design space, and once the design is finished by the designer (Suchman, 1987), limiting its effectiveness.

As already argued, ubiquitous computing design also requires a shift in emphasis from solely seeking new technical directions towards incorporating existing hardware and software, and then successfully combining and adapting these to the use that is required. In this way, more time can be spent successfully appropriating a system to satisfy the philosophical requirements of ubiquitous computing and creating a system that appropriately addresses the practitioner's needs.

Edwards et al (2003) talk of using software infrastructure as a means of supporting user-centred design. Software infrastructure is an existing set of code libraries and runtime processes that support generic functions. By providing a common and well-used set of functions, systems that utilise it can be more adaptable and rapidly adopt changes according to user requirements. Hardware infrastructure may also be viewed in the same way, with different sensors and devices providing a functional equivalent. While individual toolkits (Sutton et al, 2002) seek to achieve hardware infrastructure, hardware reusability remains immature compared to software patterns and frameworks. This is ultimately because hardware, by its nature, is less flexible than software. While inroads have been made at making hardware reusable and reconfigurable, it remains far more difficult to readapt than software.

While Edwards (2003) focussed on better ways to design software infrastructure, many of the lessons derived from their experience are applicable to appropriating hardware and software for ubiquitous computing. Particular emphasis should be placed on finding hardware solutions that do not require proprietary solutions that mandate design virtually start from scratch.

The most relevant lesson for design from Edwards et al is that it is best to build a minimal system first to test core design ideas. Once ideas are validated, user feedback is then elicited to progress the system functionality. When creating complex systems it is important to get the basic functionality and potential correct. By building a simple yet testable system it is possible to determine early in the prototype development whether a design contribution has potential. Edwards et al also found simple scenarios in the context of the practitioner's work place were best for determining this.

Edwards' approach is one that applied to the prototyping presented in the methodology and discussion chapters. However it should be mentioned that by employing design games and role-playing, lightweight prototype explorations in the context of the practitioner's workplace were possible for my own research. Interesting, albeit flawed, ideas could be quickly discarded and the most relevant and useful areas for design intervention could be identified. By doing this in the practitioner's workplace, it is possible to quickly discover contextual difficulties that preclude the prototype which is preferential to risking missing problems by 'faking' data about the context in scenarios. The use of techniques such as "Wizard of Oz" means that even when the technology for particular application is not available it can at least be auditioned in the context of use.

Ultimately, Edwards et al found that the more sophisticated prototypes they created provided "less return on investment" (ibid). Lightweight prototypes based on software infrastructure maximised the development efficiency and allowed shaping by the practitioners early in the design process.

Sumner and Stolze (1997) also note the benefits of using a software infrastructure approach, but with a participatory, rather than user-centred design approach (see section 2.3.2.2 for the distinction). They refer to the use of 'toolbelts' – collections of off-the-shelf software tools in a type of participatory design called "participatory evolutionary development".

The main concerns for participatory evolutionary development are similar to issues found within my own research. While much of Sumner's and Stolze's work relates to creating effective toolbelts, they refer to the importance of empowering the practitioner. This is done through communicating the design to the stakeholders: its constraints, abilities, how it works, and ways of customising and adapting it. For this they primarily used flow charts and tables to communicate the information.

Techniques for communicating the necessary information will vary depending upon the design context and what is most interpretable to the practitioner. However, while communication methods such as flow charts and tables are important for documenting and visualising a design, this should not be a replacement for in-context communication. Not all practitioners benefit from trying to visualise a design based on a flow chart or a quantitative representation of design, and if a practitioner is able to actually use a prototype and speak directly to the designer and engineer who created it, the subtleties of the design can be revealed as required. This is further addressed in the discussion chapter of this thesis.

The effective application of participatory design techniques can assist the communication required to suitably inform the practitioner. However, "participatory design" encompasses a wide range of philosophies and techniques, and it is necessary to consider the field as a whole to determine the best approach. In the next section I discuss what participatory design is, the various methodologies it encompasses and how it relates to ubiquitous computing design.

2.3 Participatory design

> *"The audience itself must understand the power it has to shape, develop, and share in our society's creations." (Schlossberg, 1998)*

Participatory design has its roots in the Scandinavian tradition (Schuler and Namioka, 1993; Greenbaum and Kyng, 1992), which sought to empower the worker and allow for democratic expression in the design process. The essence of participatory design is to develop mutual trust and respect and effective communication and collaboration between all parties involved in and or affected by the design efforts, so that resulting designs best support users and use. This section disseminates the motivation and history of participatory design and how it informs the research presented by this dissertation.

2.3.1 History

The starting point for user participation in system development was in Scandinavia circa 1960 (Gustavsen, 1986). A large action program for industrial democracy, with the aim of improving working life and empowering workers, was conducted by the Norwegian Federation of Trade Unions. The outcome was the "Worker Protection and Working Environment Act", which stated:

> *"…workers and their representatives shall be kept informed about systems used for planning and performing work, and about planned changes in such system." (Levity, 1998)*

It has been said that participatory design is a natural product of Scandinavian culture, and is often called "the Scandinavian approach" (Floyd et al, 1989).

> *"An essential feature in Scandinavia is, above all, what appears to outsiders as a far-reaching and widely supported fundamental concern with the building and development of a society in which each individual may live in dignity and in conditions conducive to personal development." (Floyd et al, 1989)*

Given the strong and well organised associations of employers and trade unions, the ties between trade unions and the social democratic parties (Gunzberg, 1974), in addition to the early emphasis by the unions on job satisfaction and workplace design (Floyd et al, 1989), the historical situation in Scandinavia provided the ideal origins for participatory design.

Participatory design as it is used today found its roots in the "Collective Resource Approach" (CRA) (Ehn, 1992 from Kuhn, 1996), originally developed in the early 1970s in Norway. The CRA is a means of system development that recognises the importance of multiple expertise viewpoints, while promoting democracy and collaboration between designers and users. It recognises that a multidisciplinary approach allows for a more collaborative understanding of a particular context, while recognising the issue of democracy in design resulted from concerns over the consequences of computer systems for work conditions. The outcome was that workers were able to assert control of the design of new technology and decisions regarding the workplace.

One of the first modern examples of participatory design involving information systems was Ehn's (1983) work on the UTOPIA project. UTOPIA used role-playing and low-fidelity prototypes to engage workers from the Nordic Graphic Workers' Union to design a system for assisting in image processing and page layout for newspapers. UTOPIA was developed into a commercial product called TIPS which was used by several different newspapers, showing that participatory design could be adopted commercially for creating new computer systems.

Research has since progressed from Scandinavia to the rest of the world, albeit with varying degrees of success (Bjerknes and Bratteteig, 1995). In the process its intentions and practices have become diverse and some confusion has emerged as to what actually entails participatory design and how to employ it properly. It is therefore necessary to examine the different ways participatory design is approached and the alternatives.

2.3.2 Defining participatory design

> *"You could imagine a future in which companies scrapped their [research and development] departments entirely and simply proposed questions for the global collective intelligence to mull." (Grossman, 2005)*

Participatory design is a diverse, multidisciplinary field and as such it is difficult to pin down a single theory or approach to practice that is 'best' (Slater, 1998). There are a wide range of methods that may be used for participatory design activities, with the choice depending on the type of project, experience of the researcher, and context of the design. What one person deems a necessary aspect of participatory design may be disregarded by another. While participatory design practices are diverse, what is important is that there is consistency in the respect given to the practitioner and the understanding the context of work practice. There have been attempts to define the essential tenets of participatory design across all methodological approaches (Greenbaum and Kyng, 1992; Schuler and Namioka, 1993). The description of ideals that is most closely followed by this research is those as defined by the Computer Professionals for Social Responsibility (Brigham, 2005):

- Respect of practitioners, regardless of workplace status, technical abilities or financial influence. Every participant must be viewed as an expert in what they do and a stakeholder to be listened to.
- Providing a way of addressing more than the technical system. Participatory design considers people, practices and technology in their context.
- Recognition of the importance of the system's context. Ideally systems should be tested in the workplace of the practitioner.

- The use of practitioners as a valuable resource through collaboration to address systems requirements and innovate.
- The discovery and resolution to problems within the practitioner's domain as identified by the practitioner themselves rather than problems 'seen' externally.
- Recognition of the designer's role and experience in the participatory design process.

This thesis does not aim to prescribe a particular ideology to follow for participatory design, nor establish an all-encompassing best practice, but instead the intent is to respect the core tenets of participatory design, examine how they have been applied and suggest improvements for their interpretation.

2.3.2.1 Diversity of participatory design

As mentioned, the field of participatory design has a diverse range of methodologies and draws upon many disciplines. Muller et al (1992) attempted to provide a brief guide to the range and suitability of different methods and provided guidance as to the suitability for particular circumstances, as illustrated in Figure 6.

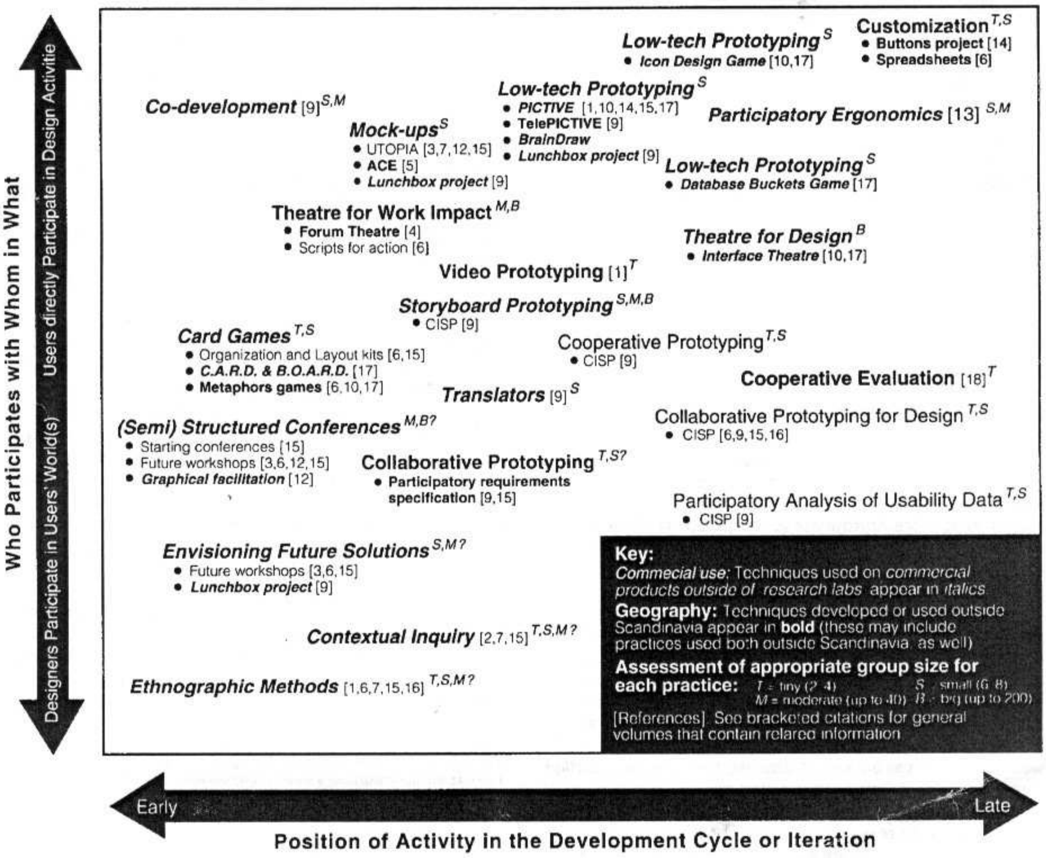


Figure 6: Taxonomy of participatory design (Muller et al, 1992)

The sheer variety of participatory design can be daunting for researchers unfamiliar with the field hoping to utilise its philosophies and benefits for research purposes, leading to the view by some that participatory design is an "all or nothing" approach. Reich et al's (1996) work goes as far as describing participatory design simply as the "antithesis of traditional design", traditional design being the "engineering design" described in section 2.1. This is due to the stark differences in approaches, particularly with how the practitioner is involved in the methods. However, participatory design, depending on the approach of the designer, can either complement or replace traditional design.

Although participatory design can describe a methodology that mandates user participation from start to finish, its application should be approached philosophically rather than a prescribed set of methods. While the particularities of methods may vary, what is of overriding importance is the ethical consideration of the practitioner and the knowledge that grounding design in use contexts improves the design process from a humanistic viewpoint.

Technically complex systems can be designed with little to no user participation (for example when designing a type of computer processor), and in many projects, given the resources available there is little-to-no alternative (Brandt, 2001), other than employing a more contextually sensitive and holistic methodology. However it is possible to then use participatory design to allow the appropriation of the technology by the practitioner regardless of the original technical design process.

A designer who carries participatory design tenets in the back of their mind should know when they are "watering down" the process and potentially compromising it. Given the concerns such as time and cost, the designer must make choices and the process ultimately reveals these priorities legitimately. How participatory design influenced this research and the benefits and shortfalls of the methods used are more closely examined in the methodology section of this thesis, and further reflected upon in the discussion section.

But first, the distinction should be made as to what entails participatory design as opposed to user-centred design. At first glance, they may appear similar, if not the same; however user-centred design offers its own benefits and shortcomings, as discussed in the following section.

2.3.2.2 User-centred design

User-centred design is a popular method for considering the needs of users in the design process. While user-centred design is sometimes confused with participatory design due to similar goals of empowering the user's role in the design process, a simplistic delineation is that user-centred design could be said to create a more usable design through user consideration, but not necessary participation (Preece et al, 1994).

The concept of user-centred design became well known through Norman's (1988) book "Psychology of Everyday Things", and is now widespread in commercial employment. Norman defined the seven principles essential to user-centred design:

- Use both internal and external knowledge – take advantage of both the user's knowledge and the context of use.
- Simplify the structure of tasks – remove the load on short and long term memory.
- Make things visible – the user should be able to see their actions having an effect.
- Get the mappings right – the actions being performed should relate to the task at hand.
- Use constraints – help guide the user towards a specific goal.
- Design for error – people (and programmers) make mistakes, so allow for these in the design.
- Standardise the design – if people are used to a particular way of doing things, stick to it.

These have been updated and improved upon by Schneidermann (1987) and Nielsen (1993; 2001), but essentially remain consistent. While these may be useful rules to follow to improve usability during design, they do not address whether the system will help the practitioner achieve what they want. The emphasis remains upon whether an existing solution maps to the user requirements, and does not include early practitioner involvement or empowerment in approaching a solution.

To summarise, and reiterate, while user-centred design and participatory design may seem to be fairly similar approaches to design (based on the emphasis on the practitioner in the design process), there is a strong philosophical difference. Participatory design is focussed on *empowering* the worker, and finding a better fit between design and work practice in doing so, while user-centred design aims to *improve usability*, primarily by focussing on the human aspects of design. The emphasis however remains on the users' "needs and desires" (Norman, 1988) rather than a *brokered design* (one that is mutually informed by the practitioner and the designer) that accounts for the designer's knowledge and the practitioner's work practice.

Indeed, there is another subtle difference between participatory and user-centred design that relates to their terms of 'practitioner' and 'user'. Participatory design aims to design for a practitioner. The use of the term 'practitioner' implies tacit knowledge and skill, which reflects the tenets and aims of participatory design. This contrasts with what Kyng and Greenbaum (1992) think of the description 'user'. They describe it as a rough term which fails to adequately address the inherent skill in that person. Therefore in participatory design, the distinction is made between users and practitioners and how these descriptions affect the design methodologies. Whereas 'user' implies the only skill to recognise in the design process is that of using and interacting with the system, 'practitioner' better recognises a person's competence in their field and how that competence may be incorporated into the resulting design. It also identifies the need for acknowledging the social aspects of design, for instance that users do not just have human factors to account for, but are human *actors* in the process. Such a distinction means that while there are aspects unique to the practitioner that affect the system, the holistic view of the system means that the practitioner is an actor within such a system, and the system as a whole must be considered.

2.3.2.3 Usability testing

Usability testing is closely related to user-centred design, and by definition is seen to be a subset of it since it focuses on how the user interacts with the design. Usability testing is commonly employed, particularly by commercial organisations. The general approach for usability testing offers several benefits (primarily being that it identifies difficulties encountered by the user by directly involving them), however its application differs significantly from participatory design. There are five goals that describe the aims of usability testing (Dumas and Redish, 1993):

- Improve the usability of the design
- Involve users in product testing

- Use real tasks for testing
- Observe and record the participants' actions
- Analyse the resulting data and design according to these actions

The primary purpose of usability testing is to help find usability problems; not to solve them, merely to account for them (Ehn, 1988). In addition there is an emphasis on laboratory work that does not completely reproduce the richness of true work context, while time restrictions further limit exploring the long term effects of the design (Schneidermann, 1998).

Therefore while usability testing is a necessary component of both user-centred and participatory design, commercial efforts usually focus on identifying problems and fixing them rather than learning from how the design may better suit the practitioner. While efforts are made to make the product more usable, design changes tend to be made without the sense of democratising the choice of the changes. The focus is of making the product more usable "as it stands" rather than facilitating the two-way flow of ideas. Changes to the design at this stage are usually minimal and are unable to accommodate complex social and physical interactions contingent on the practitioner's work context.

User-centred design also advocates objective data, which is reflected in how usability testing takes place, with neutral usability researchers to be kept a distance. This may be accomplished using methods such as an isolated booth with one-way mirrors and quantitative data recording. This contrasts with participatory design, where the design is brokered between the designer and user, allowing them to combine their respective knowledge.

Buur and Bødker (2000) are critical of the user-centred design process and traditional usability testing for these very reasons, and instead advocate the use of a "design collaboratorium". This is an alternative to a usability laboratory, while still being suitable for larger companies that do not wish to use participatory design due to internal reasons such as politics or budgets. For the design collaboratorium, instead of a testing laboratory, a dedicated room is supplied that houses the usability evaluation sessions. Usability professionals, designers, engineers and the users all meet in the room which acts as a work space for the design team.

As opposed to the comparatively sterile environment of a usability laboratory, Buur suggests that the design collaboratorium should reflect the use context and the evolving design, and should act as a source of inspiration for design ideas and discussion forums.

While the design collaboratorium is a useful alternative for companies running long term design projects in-house, or for external usability consultants, it is less useful for companies who are unable to provide a permanent or even semi-permanent space for a collaboratorium. Furthermore it requires the users to leave their work context and participate in an approximate context.

While there are many benefits to a dedicated space, in my own studies, creating a temporary design environment within the design space removed the need for stakeholders to provide expensive or simply unavailable facilities. By shifting the design collaboration to the context of the practitioner’s workplace, it allowed busy professionals to engage in the design process without requiring otherwise unnecessary commitments.

Such trade-offs often occur within the participatory design process, and it is important to anticipate and accommodate compromises. The next section addresses some of the primary concerns for undertaking participatory design.

2.3.3 Participatory design caveats

One concern raised consistently for participatory design is that by considering only the needs and desires as described by the users, new innovative technologies may be unintentionally ignored (Agostini, 1998). Trying to satisfy the user using only their understanding of technology and design potential may limit new methods of interaction. This was the first personal concern I had with employing a participatory design approach, and when beginning my design studies, I felt it was difficult to be true to the philosophy of participatory design and appropriately respect the user, while still designing innovative and usable methods of interaction. Concessions must be made within the process, a concern analysed in the discussion chapter as to the true nature of participatory design.

Stemming from attempts to obviate this, there are times where there may be confusion as to what participatory design actual entails. Misunderstandings of the philosophies behind participatory design may restrict its use or effectiveness. Axup (2006) is representative of the concerns researchers may have with participatory design, and it is worth addressing these concerns individually in order to explore the limitations and potential of participatory design.

Axup (2006b) states that participatory design is a framework that “advocates user involvement and a political stance advocating worker rights”. While somewhat true, this description is misleading. Participatory design recognises that workers have skills and attempts to utilise these skills as part of the design process. While there is some research that uses participatory design purely as an agenda to champion worker rights above all else, much does not. Good participatory design empowers the practitioner and recognises their knowledge, using these to create a more suitable design. The support of worker rights is something that spawned participatory design methodologies, and if in utilising such a process it is possible to continue improving the workplace rights of a practitioner then it is an added bonus.

The tenets of participatory design may be construed by some as asking the practitioner to design the interface themselves. The “practitioner as designer” mindset has been problematically employed by inexperienced designers who believe that since the practitioner is using the product and know how they would like to use it, they should design it. Another more subtle problem is in adopting the stance that if the practitioner advocates an addition to the design, then it should be included, since the “practitioner knows their work practice best”. What must be remembered is that the designers are called designers for a reason and are there as more than just mediators for laymen to communicate their wishes to engineers.

By involving participants with both engineering and design skills, and thus with a larger corpus of design knowledge than the practitioner, it is possible to identify potential problems the practitioner is unable to. The "user as designer" paradigm is also flawed due to the designers having a broader knowledge of what does and doesn't work based on experience in other contexts. Participatory design advocates practitioner involvement and respect, but does not expect the design to be solely driven by the practitioner.

Axup argues that new technologies cannot be explored in a participatory design. He states that in most cases participants are unable to accurately imagine their use, but can through known technologies. While it is important to use existing technology as a building block to creating new systems, this does not mean it is necessary to use a technical system that is already known to the practitioner.

Following this, while it is not possible to have a designer (without technical expertise) trying to engage the user as a sounding board for technical direction, this does not preclude the involvement of an engineer that can understand the difficulties and capabilities of different types of technology who can help constrain and propel the design using their knowledge. The need for technical experts is a recurring theme in some participatory design literature (Bødker and Buur, 2002), and is addressed directly in the discussion chapter.

Another concern that Axup raises is that practitioners should not be relied upon to predict the usage of a new system. While it is not possible to predict future behaviour with certain accuracy, role-playing and future-use scenarios are good approximates, and give participants a voice as to how new systems make and affect work practice. The problem of understanding future use must be managed regardless of the methodology.

Furthermore, many participatory design projects (Buur and Bødker, 2000) advocate testing prototypes in-situ as they are developed. By developing the prototype in a real context with continual testing, the future use is revealed continuously throughout the design process. It is not possible to say with certainty how a new system will be used, and it is inevitable that use will shift over time. However, the aforementioned methods allow the closest approximation, and are in many ways superior to usability testing, which simplifies the context being designed for even further.

Another consideration that Axup discusses is that in many applications participatory design requires the practitioner to consider the design “from scratch”, without direction from the designer. Early design activities in a participatory design process may use blue-sky brainstorming and the like in attempt to re-imagine how a particular scenario may be improved, however it is important that the designer and engineer provide input and direction at this stage. It is true that a participant may need assistance in both drawing upon and attempting to put aside their experience and knowledge of existing systems. This suggests a need to provide scaffolding to help the practitioner engage in the design process. As Axup states, discussion and brainstorming is more effective when centred upon tangible ideas.

A difficulty raised for employing participatory design is the expectation that participants *want* to contribute. Participatory design does require skill in engaging participants and it would be unrealistic for a designer to expect participation without taking significant trouble to articulate the value of engaging in the process. The type of design required and the complexity of the project affects the ease in which participants are engaged. There are methods for encouraging contribution (such as creating a sense of ownership in the design), but it should not be expected to receive equal contributions from all participants in the process.

However, using different techniques, it may be possible to entice disinterested participants to become involved and offer useful contributions through effective design activities that encourage ownership, respect the practitioner’s existing work practice and draw upon their skill-set. The issue of gaining participation is a primary consideration for the participatory design process and one that must be effectively managed. Ultimately, it may not always be possible to gain effective practitioner participation, in which case one reverts to other design skills.

A valid concern is small numbers of users greatly impacting design. Attempting to involve all people potentially affected by a design outcome is an acknowledged problem in participatory design (Reich et al, 1996). Furthermore, when designing for particular workplaces or stakeholders, participants may become alienated if they do not feel they have contributed to the design (Whyte, 1991). Participatory design is more suited to a finite group of practitioners that is well-established but not excessively large. Certainly, participatory design needs to be well managed, possibly with a clear consultation process established for enterprise level deployment in large organisations. Methods of managing this are beyond the scope of this thesis.

Axup also considers design where focus is placed on what participants design instead of what they need. If the tenets of participatory design are held above all else, inexperienced or idealistic designers may feel the need to centre design only on what practitioners help define. As previously discussed, there is need for the designer to maintain their role as such, given their experience. In my own research there were occasions where practitioners made unrealistic or inappropriate design recommendations. A design professional is responsible for the design outcome and employs participatory design processes to realise a design they feel suits the practitioners' needs.

Axup states that the participatory design equates the ability to create successful systems with suitably educating participants on how to contribute to the design process. While practitioners do need to learn through the design process, it should be in areas where they are able to help rather than a catch-all education of design. For example, if a participant is better able to understand limitations of a particular technology, then they are likely to be able to make more realistic design suggestions. Again, this difficulty rests upon the approach the designer takes in employing participatory design, rather than an inherent fault with the process itself. It should remain the responsibility of the designer to interpret the data and interactions for creating the design, not to train the practitioner as a designer.

Axup feels that too much emphasis is placed in participatory design on creating systems that satisfy the originating ideals of participatory design which avoid "dehumanising technology" and require the development of systems that respect political gains. Overemphasis on social and political improvements can remove emphasis of usability of a design – however it is hardly a pitfall to create a system that creates a workplace that is humane. Creating a design that respects the practitioner's work practice while empowering them within the design process should remain a primary concern of participatory design, and is indeed what differentiates it as a design process.

Finally, Axup states that traditional participatory design advocates are conservative in their views of what is and isn't participatory design. This is probably due to some design methods that claim to be participatory approaches, when what is actually employed is user testing. While it can be subjective, the issue of what activities define participatory design remains a pertinent issue. Participatory design should offer methods for design that suitably respect and involve the practitioner.

Having disseminated the general concerns for employing participatory design, it is worth more closely considering its applicability to ubiquitous computing. The next section reflects on the possibilities and benefits of such an approach for ubiquitous computing systems design, and previous research utilizing such an approach in this field.

2.3.4 Participatory design in ubiquitous computing

Participatory design has the potential to address many of the philosophical concerns in designing ubiquitous computing. While participatory design approaches have been used for designing ubiquitous computing (Nilsson, Sokoler et al. 2000), the benefits as well as the difficulties of doing so have not been fully explored.

González, Favela and Rodríguez's research (2004) briefly examines how participatory design can help design more usable ubiquitous computing systems. They recognised the complexity of a ubiquitous computing system and the need for a thorough understanding of the domain in which it is to be deployed.

While it is true that participatory design allows a thorough understanding of a domain it is just as or more useful in providing a thorough understanding of the practitioner, particularly their skills and how the system both impacts and can be appropriated by them. In turn, this leads to systems that are less obtrusive (‘invisible’) to the user, hence fulfilling the philosophical ideals of ubiquitous computing.

My research goal has been to create better interfaces for information work in the social and physical workplace. There have been several projects that have designed ubiquitous computing systems for authentic contexts using participatory design techniques to attempt to fully understand work practice.

Good (1992) undertook participatory design of ubiquitous computing whilst actively engaging engineers and designers. Good aimed to create a novel and useful method of testing enzyme inhibitors, and was influenced by the then-popular field of virtual reality. With a very similar motivation to my own, Good asked:

> *“How might we take presence technology beyond gadgetry and make it useful for diverse people doing different types of work?” (Good, 1992).*

The system Good designed was to allow physical modelling of the bonding of enzyme inhibitors. As described by Good, enzyme inhibitors are small molecules that bond with large enzymes which then block or inhibit an undesirable chemical reaction. However, neither the enzyme nor the inhibitor are rigid, and can twist into many different conformations. The challenge for the practitioner (a chemist) was to explore the conformation space to find low energy dockings between molecules to allow easier docking. Computing modelling of this process was found by Good to be unintuitive and removed the chemist from their physical understanding of the molecules. In addition to this problem, existing modelling software was found to be expensive, a major barrier to many chemists in the field. Thus Good’s work attempted to provide the chemists with an ability to both visualise and explore different conformations, while also improving usability and reducing cost.

It is interesting that in the process of using participatory design to create a virtual reality based system that facilitated this, the resulting system was what is now described as ubiquitous computing. In the context of Good’s work, he defined virtual reality and similar technologies as ‘presence’ - essentially a multi-sensory virtual reality. He further defined presence as satisfying the practitioner’s need for focussing on their work, rather than their computer interface. The resulting prototypes can now be more accurately described as multimodal ubiquitous computing devices.

For Good's project, a force-feedback based physical interface was created that allowed the chemist to feel resistance based on the energy curve of the molecules. Good found that creating an all-purpose force feedback interface was, in essence, overkill. More complicated and general force-feedback devices were not necessary to create the required manipulations. By constraining the design space, a far more portable, cost effective and useful prototype was created which still provided enough flexibility to be adjusted for use (articulated) by the practitioner. By investigating the domain of the practitioner and how they would actually use a device, more time could be spent on improving the usability of the technology instead of improving the technology itself.

The methodology applied by Good was quite sophisticated and his methods consisted of five steps:

1. Build relationships with the practitioner.
2. Conduct contextual enquiry of the practitioner's domain.
3. Brainstorm with the practitioner.
4. Storyboard to propel the design.
5. Employ an iterative cycle of prototype design.

In the first stage, Good attempted to involve computer engineers with the chemists in order to familiarise them with presence technology. This step was quite important and can be overlooked using traditional design methodologies, due to problems such as a lack of interest (or foresight) from the designers or budget constraints.

The contextual inquiry conducted then allowed the designer to familiarise themselves with the practitioner's work and domain. In Good's example, computer engineers who had studied maths and science were used which fortuitously allowed better understanding of the needs of the chemists. Another key step was to have the computer engineers explore the chemists' workspace; however the design process itself took place in conference rooms. Hence while the engineers had the ability to visualise the workspace (itself an improvement), all design work was removed from the context of use. In turn, while brainstorming took place both in the context of use as well as in 'traditional' design spaces, storyboarding was used as a surrogate for designing in the domain.

Through active engagement of the engineers with the chemists, positive reactions to the technology came early in the project, and the technology fitted with expectations from the beginning. Good quotes the chemists as reporting that the system "feels great to me … this is really neat" (Good, 1992).

Once the prototype was created and the chemists began using the system they started finding different uses for it and the application of the system changed from the expected outcome. Initially the result expected was to allow torque detection of the molecule's energy, but the physical interface allowed better understanding of the molecule that, when coupled with the GUI, allowed much faster ways to examine the conformation space.

Another interesting aspect of the project was the ability of Good to successfully discard technology suggestions he had made. Good's initial idea was to create a head mounted display, which the chemists quickly confirmed would not work. This early intervention was a boon to reducing the need to invest excessive amounts of time in technical development.

While Good brought together engineers and users, my own work aimed to bring together engineers, users and designers. The difference is subtle. In my research I remained in an active role in design games and workshops that engineers would normally not be part of. Good describes what are essentially contextual interviews and prototype demonstrations. These are essential to shaping the engineer's design of the prototype, but integrating the newer "windows into design" (Campbell et al, 2003) is central to my approach. Brainstorming and storyboarding are but two of the many methods for exploring the design space. Often a particular design space calls for new methods, specific to that domain (Campbell et al, 2003).

Good concluded the following from his research:

- Applications derived from a participatory design process can be applicable to others areas of work.
- Participatory design responds to its context, not a set of rules. Good found this surprising. Good reported that his design methodology still worked, "even though it did not take place in the five discrete steps [he] had initially anticipated." By responding to the context participatory design allows you to tighten your design specifications and make better use of the technology earlier in the design process. He also concluded that participatory design can be difficult both to initiate and challenging to sustain, and that finding participants can be a challenge.
- Participatory design can be a slow process, which should be appropriately accounted for.

Briefly, it was important for me to keep these considerations in mind when planning my own studies, as further expanded upon in the methodology chapter. Careful choice of activities and how to undertake them was central to effectively exploring the research space. I faced issues with dentists as participants, for reasons such as lack of time (given how valuable their time is), motivation (a lack of tangible benefits from involvement in a research project), and differing goals (a desire to find ways to improve their current work practice specific to their own needs). To accommodate these concerns, the designer must bring their skills to bear in improvisational ways to keep the process moving and keep the exploration continuing. The discussion chapter of this thesis further examines these considerations and their effects upon my research and efforts to build a useful and complete prototype.

In considering the deployment of ubiquitous computing in the more relevant field of health care, there have been only minor in-roads of ubiquitous computing (Sjöberg and Timpka, 1998); however there have been several attempts to create a usable computing platform for health care workers. One such study was conducted by Sjöberg and Timpka (ibid), which aimed to create an information system capable of handling computerised patient records, electronic messaging and web authorship in a hospital. A unique problem specifically identified by this study was the need to support different types of practitioners, specifically physicians and nurses. The prototype developed in their project used commercial products adapted with customised software developed for the project. Practitioners were utilised as informants of their work practice and problems with the interface. This project made good use of off-the-shelf software for quickly adapting to the practitioner's requirements.

Another important aspect of this project was its focus on engineers. Sjöberg and Timpka attempted to allow for equal participation from the practitioners, designers and engineers. However the conduit for this participation was the use of design meetings; the design and testing was divorced from the context of the workplace and the engineers were left unable to witness first-hand the requirements of the system or the results of their deployed software.

Another problem with the use of engineers in participatory design highlighted by this research is that of technical communication. Difficulties with bridging technical understanding to the designers (but not the practitioners) was explored, with mention made of the difficulty of explaining how a technical solution fitted into a particular context whilst being in a meeting room. This is a common difficulty of professional design situations and a necessary consideration for attempting more suitable approaches to design that suitably exercise all participants' knowledge and skill.

As highlighted in the introduction to this thesis, for me, as an engineer, it was worth reflecting on why 'traditional' design, which is still common, is inadequate for ubiquitous computing systems. Given my engineering background it was a bitter pill to swallow that techniques that I had been taught were unable to adequately address the complex design problems encountered in my research, particularly for dealing with tacit knowledge and social aspects of a work context. However, traditional design is not without merit, and there have been attempts to modify the way engineers both learn and design. Traditional design is effective as it cuts straight to the technical problem, however this may usually leave other concerns unconsidered. The next section briefly discusses and reflects upon the issues involved with a traditional (or engineering) design approach, and how it informed the approach for design employed for this thesis.

2.4 Integrating engineers into participatory design

> *"Sure enough, when we took it to the engineers, they said 'Oh.' And they came up with 38 reasons [why we couldn't do it]. And I said, 'No, no, we're doing this.' And they said, 'Well, why?' And I said, 'Because I'm the CEO, and I think it can be done.' And so they kind of begrudgingly did it. But then it was a big hit." (Steve Jobs from Grossman, 2005)*

One key reason there is a need for further engineer involvement in a participatory design process is the technical knowledge engineers bring to the process. Many engineers *are* engineers because they have a strong interest in their field. This means they have a strong awareness of competing technologies and technology development. In the field of technology development, where it is necessary to make use of existing hardware and software to help shorten design times and increase affordability, this is an extremely useful trait.

The benefit of a comprehensive knowledge of the field is represented by the example of the Independent Living Centre (ILC), located in Brisbane, Australia. The ILC is a centre that was set up in order to keep track of existing and upcoming technologies that allow for improved independence of persons with a disability. However, the focus is on technologies specifically designed for assisting with disabilities. While speaking with people who benefited from the centre of how they use technology in their lives, it was found many were limited to X10 devices[3] which did not adequately address their needs**,** and that they struggled with mundane things such as using a telephone. While members of the ILC were aware of new wireless phone technologies such as Bluetooth-enabled accessories, they were not aware of how they could be utilised to help further enable users of the centre with their tasks. It is such a gap in knowledge of technical capabilities that can be filled by an engineer. People may *know of* a technology but not realise its *potential*.

Because of these shortcomings, the need for participation in the design and implementation process has also been advocated by disability theorists (Oliver, 1993). It has been advocated that people with disabilities be in more of an "empowered

[3] X10 is a wireless standard that supports home automation, and X10 devices support this standard. Standalone boxes that facilitate the incorporation of these devices are called X10 controllers, and use power sockets located within the context of use for communication in order to control them.

consultative position in more aspects of their lives" (Luck, 2003). This process should involve both informing designers of what may satisfy a stakeholder's requirements, and learning of technical possibilities.

While practitioner education should be encouraged, particularly for realising how technical constraints may limit the design, Bucciarelli (1994) points out that you don't need to understand technology to use it and benefit from it. As an example, he questions whether the reader knows how their telephone works, beyond making a connection by dialling numbers. However, this conclusion should be carefully applied. If the practitioner understands the limits as well as the abilities of a particular technology, they are able to help guide the designer to a 'fit' in their work practice.

Members of the I3 group have also identified the importance of technical knowledge in the participatory design process (Agostini, 1998). This was concluded based on their work on several systems, primarily for local and virtual communities (De Michelis et al, 1997). De Michelis et al's research describes the general benefit of a "technology scientist" to provide up to date information and to help avoid technical redundancy.

What is not discussed by Agostini (ibid) is the need for an ability to impart technical knowledge to practitioners or how best to involve the engineer and the practitioner concurrently in the design process. Instead it is posited that parallel processes of the engineer and practitioner design contributions take place, with a designer acting as a mediator and defined user scenarios acting as a grounding point. This does not allow a relationship to form between the engineer and practitioner, and reduces the effectiveness of the communication and understanding.

To account for such a concern, Muller (2003) talks about using the "third space" as part of human-computer interaction focussed design. The third space is an area of design that combines the practitioner's and the engineer's work environment, and employs participatory design to facilitate this. Muller notes that within human-computer interaction research there have been many other projects that call for mutual or reciprocal learning, and he suggests that participatory design is the answer. He denotes the problem in design as relating to two worlds – that of end-users and that of software professionals.

Muller does much to help adapt participatory design techniques to traditional human-computer interaction methods. It is concluded by his research that by understanding and supporting the incorporation of sharing the practitioner and designer's work spaces that communication, innovation and quality of outcome may be facilitated.

It is through learning from the results of these studies and by recognising and reacting to how engineers may contribute to the design process that better informed and a more holistic approach to design can take place.

2.5 Conclusion

This chapter has discussed both the background and achievements of ubiquitous computing. It has examined research that has attempted to realise both a technical and philosophical perspective, why each has its own merits and how the field is progressing, in addition to how I believe it can continue to improve. Weiser's foundational work on ubiquitous computing (Want et al, 1999; Weiser, 1991; Weiser, 1993; Weiser, 1994; Weiser, 1994b; Weiser and Brown, 1995) work was examined, which described a pervasive and embedded method of computing. This computing was envisioned to allow the user to feel they personally are accomplishing the work, rather than using a computer as an intermediary – the invisible computer.

Researchers such as Suchman (1987) took ubiquitous computing a step further with a phenomenological view of design, while others such as Ishii (1997) examined alternative paradigms of computing. What emerged was the necessity to recognise the human aspect of computing, described in projects such as Good's (1992). Others such as Tolmie et al (2002) realised the importance of intense study and the need to fit technology to the practitioner, rather than emphasising the need for training. Instead, many of the ubiquitous computing projects focus exclusively on technical achievement and improvement. For example, there is an emphasis on smart displays and novel methods of embedding technology. Alternatively the emphasis could be placed on adopting both existing and new technologies to fit the user's work practice, revealing new design ideas and technical development paths, and to do so the need to use a participatory design methodology was discussed.

Participatory design provides both the framework and the methodologies to suitably address the philosophical requirements of ubiquitous computing and to support a human-centred approach to design. In order to effectively design for "real world" applications it should encompass concerns endemic to users in authentic work contexts, allowing for both commercially and technically feasible designs.

While there are many potential pitfalls to utilising participatory design, these caveats are not insurmountable, and there are potential benefits from carefully engaging in participatory work with practitioners. It was suggested that participatory design could be improved through further engineer involvement, which required special thought for how best to integrate them to an unfamiliar practice. The culture of engineering values and emphasises problem solving. However it was argued that there is a need to engage the engineers with users in order to propel designs towards better technology development paths and to consider complex social contexts of use.

It is through careful choice and application of methods that the integration of participatory design, ubiquitous computing and technically competent designers can be achieved. This chapter suggests that this is required to account for complex physical and social considerations in technically advanced systems. The next chapter describes the methods undertaken in this research to fulfil this.

3 Methods

This chapter deals with the methods used for my research. There were two primary methodological considerations for my research. The initial task for this research was to create a prototype multimodal ubiquitous computing system. Therefore the first consideration was of the design methods to use to create the system. As the research continued, it became necessary to reflect upon the design process and to consider the appropriateness of methods used to analyse and interpret what was happening. The design and research presented within this thesis are inextricably linked and it has been necessary to reflect and act upon what was learnt during design activities. The design research paradigm employed has allowed both the design of a new system for interaction while also reflecting and improving upon the design process and methodologies used.

In discussing the methodologies employed to complete this research, both methods used and the justification for these are explored. This extends from the comparison of different methods of design in the literature review and details the choices ultimately made and why. However, this discussion does not seek to assert how or why the methods used are 'better' than others, merely the benefits and shortfalls of using them. The reflection upon these methods and the resulting lessons for design are disseminated in the discussion chapter.

This chapter also lists and evaluates methods of data collection and analysis, and describes the idiosyncrasies that provide them with various advantages and disadvantages, and how they contributed to the outcome.

Finally, it should be noted that this chapter does not present an exhaustive list of methods used in this research. Instead, it represents the main methods and approaches consciously used for this research, which was a multi-layered and multi-threaded design investigation of dental practice. Other methods were emergent as research and design took place, and are described and explored in chapters 4, 5 and 6. This emergent nature of methods was influenced by the context of inquiry. The effect on the iterative process of participatory design depicted in Figure 2 is shown in Figure 7.

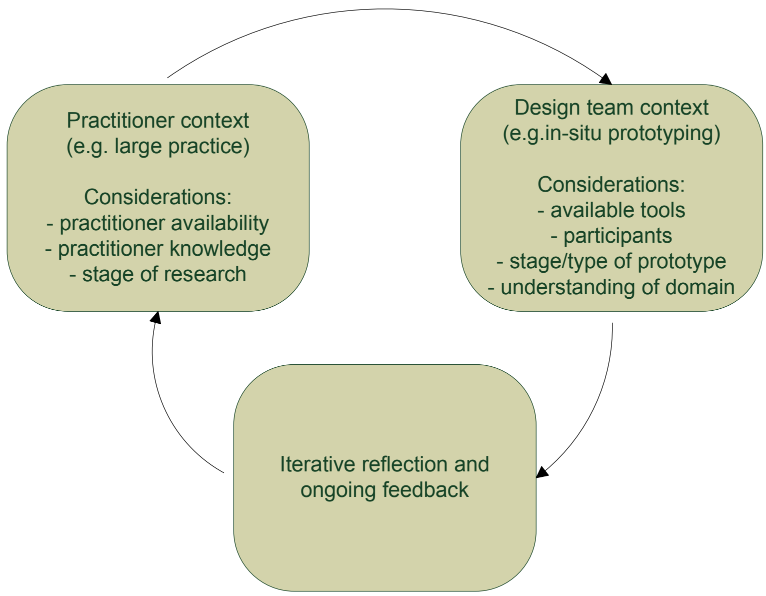


Figure 7: Influence of context on iterative design

3.1 Methods of design

Although it is not possible to make such a clear distinction, it can be generalised from the literature that there are two relatively common approaches to designing ubiquitous computing systems. The first is a technical approach. This is what I myself have encountered as a professional engineer: a new technology is being or has been developed, and the focus is to fit this new system to a useful application context. The problem space is therefore defined as needing to identify a possible use for the technology, and integrate it to existing work practice. While this approach is commonly employed within a commercial setting (as a means of rapidly appropriating nascent technologies), it is also an approach for developing interactive demonstrations that explores possible interaction (Greenberg, 2002).

The second (generalised) approach is user-centred: one where the researcher understands the benefits and applications of ubiquitous computing, identifies problematic work practices, and actively works to solve these with a novel system which respects the context of use.

There is arguably a third approach, whereby a designer simply imagines new products and systems, without necessarily explicitly involving users. This method is effective for talented designers who are able to envisage their product in everyday use contexts, however in specialised use contexts, or when products demand subtle understandings of use, this approach falls short. Moreover, engineering education does not generally develop these sensibilities.

There are many shades of grey for how both the main two approaches are employed – it could be argued (and has been) that by asking the user about how they would use the system, and indirectly involving them, the methodology could be termed user-centred (and by some, participatory) design. However, the approach utilised in this thesis is distinctly focussed on the user (or rather, practitioner) as a design partner within the process, with a commensurate amount of empowerment, differentiating it from other processes.

The approach to design utilised with my own research is heavily influenced by the philosophy of the field of Human-Computer Interaction (HCI). While the field of HCI is concerned generally with improving interaction between humans and computers, importantly the emphasis and central priority is focussed on the user of implemented systems. Technically superior systems may be achieved by focussing resources on technical development rather than accommodating the context of use, however it is of course the user who will use the system being designed and it should ultimately satisfy them to be successful. Although some systems designed with a technical bent may appear to have greater capabilities and more sophisticated, they can often fail to support or develop good work practice. Technical ability amounts to little if it is not able to be utilised due to issues of usability. In following HCI's philosophy it is necessary to consider the fundamentals of the field. Dix et al (2004) state that the golden rules are simply:

- Understand computers (limitations, capacities, tools, platforms)
- Understand people (psychological, social aspects, human error)

A participatory design approach should adopt these rules and interpret them in the context of the practitioner's domain and work practice to help design a system most beneficial to the practitioner.

The various methods that contribute to a participatory design process are cursorily discussed in the research review chapter. The requirements for effective participatory design are further considered in the discussion chapter and therefore will not be discussed here. However, methods appropriate for this research are more closely examined in the methodology chapter.

Participatory design mandates user participation in the design process as a means of creating a system that satisfies their needs while respecting a practitioner's tacit skills and knowledge. Participatory design also recognises that design activity involves more than just the designer and that design is a social process (Luck, 2003). There is no single unified theory of participatory design (Slater, 1998) and thus within this research, a variety of techniques that reflect the values and philosophies of participatory design have been drawn upon.

The process of design intervention used as part of the research presented by this dissertation is based upon action research (Lewin, 1946), which integrates theory and practice. Using ethnographically-inspired fieldwork to identify problematic areas of interaction, I then used participatory design techniques with the practitioner to create or propel prototypes. The analysis of what occurred during the design and trial of these prototypes then further informed the studies, resulting in an iterative cycle (see Figure 8).

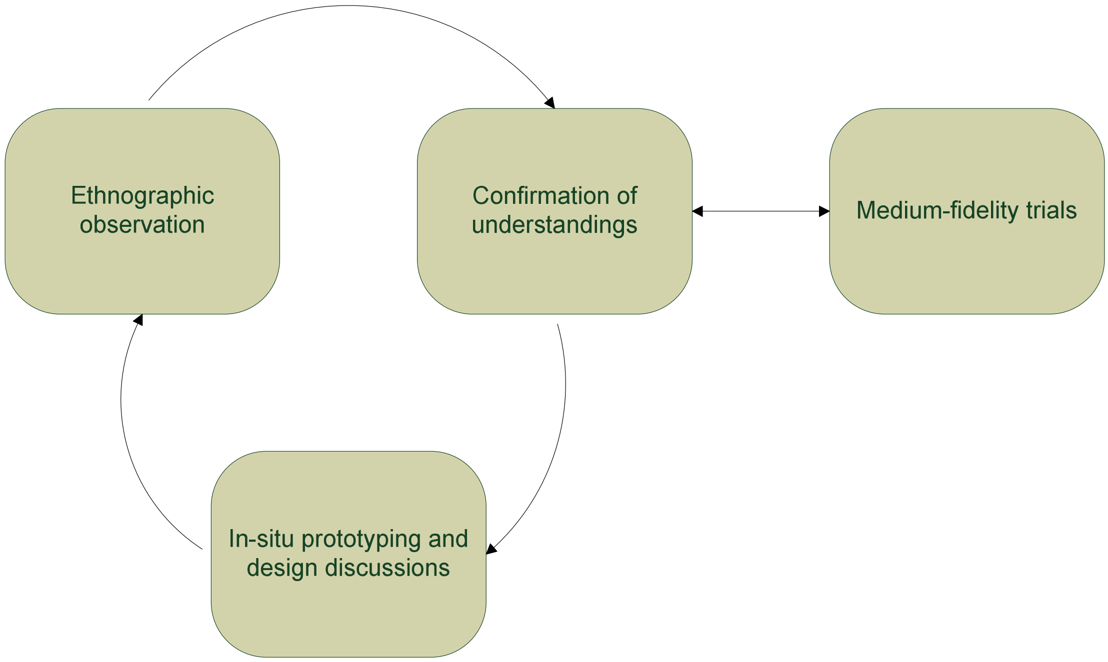


Figure 8: My iterative research process

The iterative nature of my design is particularly important. "One off" user participation can lead to the benefits of their participation decreasing over time (Macy et al, 1989).

In addition, the iterative process allows the accommodation of design adjustments swiftly and regularly. As Messeter (2004) points out, it is in recognising failure in existing designs that you may best improve the current system:

> *"The more reliable way to achieve success is to focus on failure, both retrospectively in existing things, and prospectively in the design of new things. Failures provide irrefutable evidence of what not to do the next time around." (Messeter, 2004)*

The iterative cycle used in this thesis has been referred to as event-driven design (Buur and Bødker, 2000). Using specific events to coordinate and meet with practitioners allows effective use of their time and ongoing collaboration. The importance of suitably respecting and utilising a busy professional's time in this manner is also further examined in the discussion chapter.

Participatory design is generally a qualitative process. Qualitative research characterises the space and lays the groundwork for quantitative research (Hammersley, 1992), and is also more likely than quantitative research to assist the researcher in creating meaningful and useful understandings of interactions (Minneman, 1991). Quantitative research tends to identify problems within a design, but not the complex causes behind them. Qualitative research affords a greater understanding of complex systems and allows for identification of useful intervention points and better informed designs.

The participatory design approach employed for this research included several different methods. Each has a strong emphasis on user involvement and was chosen from the wide range of participatory design techniques (Muller, 1992) available due to their suitability for use based on the following considerations:

- Work context
- Practitioner availability
- Timeline limitations for prototype development

However, as part of initial design considerations there is some debate in the field of participatory design over *where* to design (Muller, 2003) in addition to *how* to design. Generally this has been a simple dichotomy. Either designers place themselves in the user's workplace, or the user is brought to the design environment (Robins, 1999 from Muller, 2003). In practical application though, each has their own benefits depending on the greater context of the research. Buur and Pedersen (2000) found that when collaborating in the design environment, a general overview of the design space was obtainable and it demystifies the process to the users. In addition, collaborating in the user's work context allows conversations to be grounded in specific work experiences, and for the users to feel more at ease.

By taking design tools, such as laptops, prototypes and design representations to the workplace, a sense of demystifying is still achievable (Campbell et al, 2003). Indeed, this was the intent in my own design process, with a goal of intelligibly explaining technology to the users to assist their contributions to the design.

The complexity of the domain being explored and the work practice within, combined with the rich social and technical interactions that took place, meant design changes had to be carefully considered and grounded. To facilitate this, activities were completed mostly in-situ, as doing so can reveal how a participant interacts with devices within their actual work environment, and the designers can be informed of problems or potential in the design. Furthermore, with this approach the practitioners remain within their everyday domain, meaning they are familiar and comfortable with the design environment.

Finally, for this project, there were “real world” considerations to be made with regard to practitioner engagement, particularly for busy, active professionals. Access to the practitioners involved in my design studies was given freely of them, and they received no form of remuneration for their time apart from perhaps a satisfaction of interest in and contribution to the research. By centring activities at their workplace, maximum use can be made of a participant’s time, and inconvenience may be minimised. However, on-site design activity is not a replacement of the individual work of the designer (Brandt and Grunnet, 2000), and as such the design was propelled externally, with steps were taken to help continue practitioner involvement (such as wikis and emails, discussed further in section 3.1.6).

For clarification, throughout this chapter, prototypes are referred to as low, medium or high-fidelity. Usually prototyping refers to either low-fidelity or high-fidelity prototypes (Rudd et al, 1996; Walker et al, 2002). However, the use of medium-fidelity prototypes (Hakim and Spitzer, 2003; Pawlak, 2007) is a useful intermediate stage that provides enough functionality to communicate the design, while still being flexible enough to accommodate the participatory design process. As a rough definition, the prototypes are defined as such:

Low-fidelity: Mock ups, paper or foam prototypes, Wizard of Oz techniques.

Medium-fidelity: Limited functionality, but usable to a degree. It might still include Wizard of Oz techniques to show potential.

High-fidelity: Close to a final version, but still highly configurable. Demonstrates all of the final features and is highly functional. Can be used for extensive testing and ‘real’ work.

3.1.1 Contextual interviews

Contextual interviews are a primary source of information in participatory design, and in particular, unstructured interviews in context provide the most direct route to understanding the point of view of a participant (Matthews, 2004). During my research, interviews allowed deciphering of unexplained activity that took place during a procedure or allowed for emoting the problems (or benefits) of interaction techniques by the practitioner. Interviews are particularly important for understanding opinions, sensitivities, priorities and motivations (Campbell et al, 2003). Design discussions evolving from interviews were also found to be useful in identifying design intervention points, as they highlighted areas of concern from the practitioner. Interviews in this research took place both during ethnographic studies and collaborative design activities.

I found that it was important for the interviews to take place in context to create a common reference point for discussion. At one point I was writing to one of the practitioners involved in the studies regarding a request from him for change in the prototype. I realised I could not adequately respond to his email without opening the dental software application and my own code and referring to the patient notes from our previous session in order to recreate the context. Given the time constraints of working with busy professionals, it was advantageous to ground the interviews within the context to begin with, rather than artificially recreating scenarios for later discussion.

One difficulty I faced was ensuring that appropriate details were obtained in the limited time I had with participants. In order to augment data that could be obtained through interviewing, I used alternatives such as email that allowed participants to contribute in their own time with a suitable level of detail (section 3.1.6). While these methods had problems (such as unanswered emails), it was useful in assisting knowledge gathering, and any further gaps were covered with iterative design events.

3.1.2 Design discussions

Design discussions are similar to contextual interviews, but more focussed on prototype development. In m y research, there were first general design discussions that, for example, might stem from explaining what my research was about which could facilitate brainstorming with the practitioner. Later, technology demonstrations would further propel these discussions, and contribute at a greater level of detail to the design. By having these discussions in context, the practitioner could demonstrate procedures using the instruments and context at hand, while unambiguous references to any aspect of the work practice could be made.

3.1.3 Reciprocity

Reciprocity plays a major role in participatory design. Reciprocity as a general ideal can be achieved through contextual interviews (learning from the user), design activities (such as games and role-playing which allow joint learning) and discussions (collaborative design with the user with an emphasis on explanation and education throughout). Reciprocity and its benefits have long been recognised by the participatory design community. Floyd (1987) in her seminal paper on paradigm changes in software engineering methods concluded that mutual learning amongst users and designers was a mandatory aspect for participatory design while Bødker et al (1988) also discussed its need for mutual validation of diverse perspectives.

Much of the participatory design literature refers to the practitioner as a design partner (Pedersen and Buur, 2000), usually as someone brought into the design process, and to act as a resource. The benefits of reciprocity of the practitioner being informed by the designer are not often mentioned. Indeed, Reich et al (1996) refer to participatory design as “the antithesis of traditional design in which designers are expected to exhibit their expertise”, inferring that designers are not to exhibit any expertise to the practitioner whatsoever.

The benefit for the practitioner, who donates their time and creative energy to assisting the designer, is that this reciprocation can be gratifying for them by letting them see firsthand their influence on the design. It is important to demonstrate prototypes often, which also provides new opportunities for refinement. Furthermore it is often of interest to the user to learn about new and exciting technologies – this in turn then improves their ability to communicate effectively with the designers (since they learn the language and understanding required for open dialogue) and shapes their contributions to the design. With a proper mental model of how a particular technology works, new ways of adapting it can become clear, examples of which are shown in the fieldwork chapter.

3.1.4 Design games

Games have been used in participatory design since Habraken and Gross (1987) used 'concept design games' to explore interactions in the design process. Concept design games lack the element of competition found in everyday games, and when using games in the design process, the definition of a game is blurred further. The games used in my research had rules, a task to complete and multiple participants working together towards a common 'fun' goal. They did not make use of board game metaphors used by other designers but had more of a sense of 'play'. For example, students were asked to solve a particular problem of interaction in the surgery with one student role-playing as a dentist completing a check up, while the other acted as the new method of interaction for them.

Role-playing and the use of low-fidelity prototypes dates back to the UTOPIA project (Ehn, 1989). More recently, Binder (1999), used role-playing with low-fidelity prototypes to engage workers in an industrial setting to create a ubiquitous computing themed tool for monitoring an industrial plant. Buur and Pedersen (2000) used role-playing at a waste-water treatment centre as a method of evoking future scenarios. Brandt and Grunnet (2000) describe the usefulness of role-playing for evoking ideas and suggestions for design solutions. Finally, Buchenau and Fulton advocate the use of low-fi prototypes for "experience prototyping". They found that the use of low-fi prototypes during role-playing can provide inspiration, confirmation or rejection of ideas. Other researchers (Burns et al, 1994; Howard et al, 2002; Kuutti et al, 2002; Svanaes and Seland, 2004) have found similar benefits as those listed above.

Games and role-playing are vehicles for physical and visual interaction (rather than abstract discussions of design) while also provoking reflection and discussion of potential designs. Furthermore, practitioners often can offer only limited time to design, and games provide an organised framework for concentrated design sessions (Pedersen and Buur, 2000). Given the demanding schedule of dentists, it was found that short participatory activities, in particular games and role-playing, were useful for both increasing involvement and to structure our design activities for the short amount of time available. Finally, such activities were useful for when true work practice is not available, for example when there are ethical or availability issues for incorporating a patient (although it is important not to substitute this for real participation too often, as this can lead to stereotyping and distraction from the true work practice).

The basic concept behind the activities used was to allow practitioners to reveal details of their work practice in conjunction with the designers revealing technological potential. Low-fidelity prototypes allowed the practitioner to imagine possible uses. Instead of the technology 'declaring' how it should be used or what it is capable of, the practitioner is instead able to imagine ways to modify or adapt it. The ambiguity of mock ups, simple prototypes or "Wizard of Oz" techniques (Dahlback et al, 1993) was key to allowing this kind of flexibility.

3.1.5 Contextual prototyping

When I refer to contextual prototyping in this thesis, it should not be confused with the method of contextual prototyping used in software engineering. The software engineering method refers to an iterative process of software development with a focus on context for the design process (Stary, 2000).

An important aspect for engaging the practitioners and propelling design is the use of prototypes in context, allowing the 'realistic' visualisation and evaluation of prototypes (Ahmed et al, 2005). Activities initially used mock-ups, and then low, medium and high-fidelity prototypes. If a functional prototype was unavailable, Wizard of Oz techniques allowed for simulating system effects within the work context.

Contextual prototyping as used in this research was similar to experience prototyping (Buchenau and Suri, 2000), in that the designers investigated practitioner needs from their perspective. However, there are several key differences. While experience prototyping places emphasis on the designers acting as the practitioner - in essence, pretending to be the practitioner in an attempt to understand what they experience – the type of contextual prototyping used simply requires empathy for the practitioners. This empathy or understanding is gained through the other methods described in this chapter such as ethnographically-inspired fieldwork, design games and workshops, and contextual interviews. Another important difference is that in applying experience prototyping, it is usual to stage (create a simile of) the practitioner's environment. I believe this is inadequate due to the nuances of a real work practice that are impossible to capture through a recreation. As such, I took prototyping equipment (including hardware such as a custom-built gesture device and a Bluetooth headset) and a development laptop (with code ready to be modified, and a debug interface) into the surgery with me in order to effect in-situ modifications to the prototype (see section 4.1.4).

3.1.6 Persistent communication

A key aspect for the successful integration of a technical designer to the participatory design process is the ability to communicate efficiently and effectively with the practitioner. It is also necessary to support persistent and ongoing communication (Reich et al, 1996). When technical details of the prototype are being defined, it is often necessary to confirm an interpreted understanding of work practice or context with the practitioner. For my research, given the limited availability of dentists (particularly professionals), electronic forms of communication are ideal for facilitating this. For this purpose email and wikis were used. Wikis also allowed collaborative discussions when face to face meetings were not possible. Both were useful because they provided a non-real-time means of communication, while email was particularly useful for simple clarifications and because it is informal and widely accepted compared to wikis. In addition, a diverse range of methods for disseminating information provides asynchronous communication and a persistent record – both mandatory for long term projects (Subrahmanian et al, 1993).

Further to these participatory design techniques, I also used what may be said to be user-centred, rather than participatory, design techniques. These did not directly involve the practitioner, but did focus on them and their work practice. The methods used included a video mirror exercise, creating scale representations of the surgery, and reflections with other researchers. These techniques (discussed in greater detail in sections 3.1.8, 3.1.9 and 3.2.2) created representations (an account, likeness or reproduction that influences opinion, understanding or action (Campbell et al, 2003)) that allowed a 'window' into design, each providing a different perspective on the context, the practitioners and their interactions. These were undertaken with the spirit of participatory design and aimed to improve the work practice of the practitioner and facilitate empowerment in other stages of the design process.

3.1.7 Ethnographically-inspired field studies

> *"When chip maker Intel sent anthropologist John Sherry to Alaska last year to study the way commercial fishermen there use laptops, he found the machines shackled to the outside of the fishermen's trucks, where they were used to record the catch." (Knight, 2004)*

I used ethnographically-inspired field studies for informing my research. I needed a method of understanding the context of the design in the most comprehensive way possible. Field studies help to reveal an understanding of the context which helps identify problems and provide opportunities for envisioning solutions. This is also noted by Thomas:

> *"What you are really interested in within computing and software, is how can we as designers get to know more about the world that we are designing for, [such that] the systems we place in that world can better support the activities, [and] better support the work than they currently do." (Thomas, 2000)*

I refer to my studies as ethnographically-inspired, rather than actual ethnographic studies. The reasons for this are similar to those established by McGarry (2005).

While the principles of ethnography (Ball and Ormerod, 2000) are inspiration for the fieldwork taking place, since it fails to match the defining characteristics of true ethnography (as listed in Table 1) it cannot be termed ethnographic studies.

1. Situatedness – data collected from within the context of interest
2. Richness – wide range of data sources
3. Participant Autonomy – 'observees' have complete control over their participation (or not)
4. Openness – observer remains open to discovery of unexpected issues
5. Personalisation – observer notes their own feelings in relation to situations
6. Reflexivity – reflective and empathetic stance towards observees
7. Self-reflection – the acknowledgement that any interpretive act is influenced by background
8. Intensity – observations are long-term and intensive
9. Independence – the observer aims not to be constrained by a predetermined mindset
10. Historicism – the observer aims to connect observations to a historical/cultural backdrop

Table 1: Principles of ethnography (Ball and Ormerod, 2000 in McGarry, 2005)

In particular, the depth of the research was lacking in comparison to 'true' ethnography. While I had a diverse range of participants, and tried to understand the motivations of dentists, I do not feel I adequately fulfilled points 2 and 10 – richness and historicism, to a great enough level of detail. What makes ethnographically-inspired fieldwork important to participatory design is that good ethnography makes you care about the subject. For participatory design to work effectively, it is necessary for all participants to have a good 'stake' in the project in order to stay interested and make useful contributions, and ethnography assists in providing this.

3.1.8 Scale models

Scale models were used to help visualise the work environment and understand the spatial problems within. The primary motivation was to create a grounding point for future design discussions; however it also provided other researchers unfamiliar with the workplace with a reference point, and was useful for analysing and discussing video. Building a model (see Figure 9) was further beneficial in that it exposed what I was focussed on during fieldwork, what had been overlooked or wasn't understood.

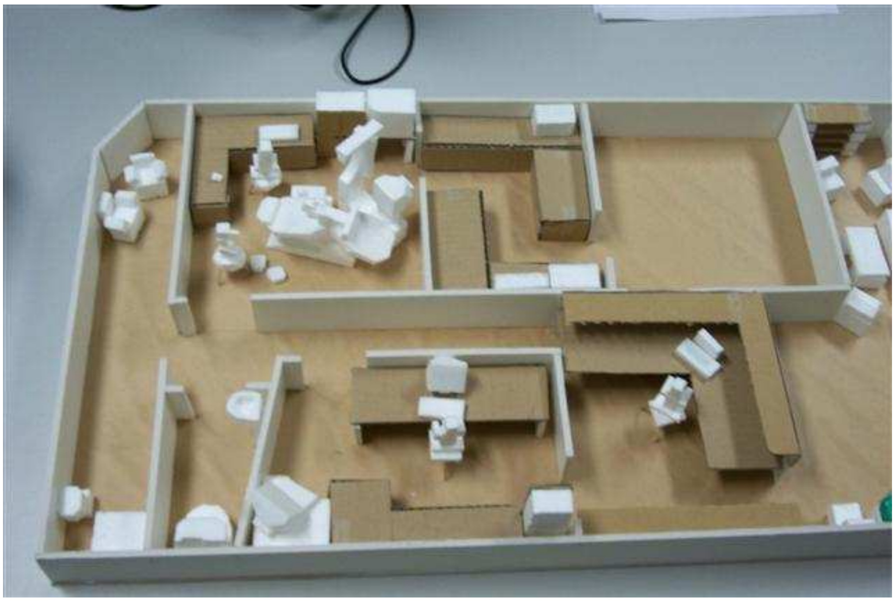


Figure 9: Scale model of a dental surgery

3.1.9 Video mirror exercise

When collaborating with other researchers who were not involved in fieldwork, I needed a method that compensated for the reduced understanding of the design context and the actions within. The video mirror exercise attempted to provide a shortcut to such understandings, and was utilised as an activity during a design event. To begin with, a short video clip was shown to other participants. While the clip played, participants of the activity tried to mimic the body movements within the video. Afterwards, discussing the experience and the video with researchers involved in the fieldwork provided at least a rudimentary understanding of the design context and the experience of the practitioner within it.

The video mirror exercise was used as part of this research in conjunction with themes of interaction (discussed in section 3.2.2.3). These themes had a single video clip that was representative of a recurring aspect of interaction within the design context. The video mirror exercise acts as an embodied extension of the theme, by giving participants a physical understanding. Enacting movements with a video gives a very different understanding than that gained by sound and vision alone.

3.2 Methods of data collection and analysis

As an engineer, my professional life revolved around being given a problem, and setting about solving it using any technique available to me. This would involve familiarising myself in the problem space using tools such as Google and maybe a reference book. I would then begin completing a design that most closely matched the specifications of the problem as I saw it, iteratively returning to external references for needed technical knowledge. What happened with the product after its completion was of little concern to me, and so beginning this thesis, I lacked the ability to properly reflect upon how these designs would affect others. In completing this thesis I am therefore indebted to techniques honed and perfected by Brereton (1998), Buur and Pedersen (2000), Binder (2002), Matthews (2004) and McGarry (2005).

It is worth mentioning this background, as trying to extract myself from within the design process and gain an external vantage point was something quite difficult. I can imagine why it is sometimes problematic to engage technically-oriented people in participatory or user-centred design processes, for example, acting or design games. To see the bigger picture was something never previously considered and simply added another layer of complexity to the problem at hand, something I will discuss in greater detail in the analysis chapter.

The data I collected was empirical, qualitative data: such is the nature of participatory design. Usually qualitative data is collected during the early, formulative stages of a project when it is too soon to know exactly which kind of data to collect and control for quantitative comparison. Instead, the focus in participatory design is on understanding the character of data, the possible areas of interest and issues. I determined the reliability of my results upon Minichiello's (1995) definition: the extent to which they are founded upon sound examples.

3.2.1 Data collection

For data collection, I drew upon the traditional methods of ethnography. Capture methods included video, audio (and associated transcriptions for both) and field notes.

The data was collected from interviews, passive and engaged participant observation, and design activities. The consideration of which method to use and when was important as it would influence the outcomes of the collection. The following are the methods I used and an examination of their relative strengths and weaknesses.

3.2.1.1 Video data

Video data is a medium that reliably and accurately captures a large amount of information which is then both re-observable and it can be used collaboratively. As Jordan and Henderson (1995) point out, “video records social events as they occur and with a level of detail that is unattainable for methods that rely on reconstruction”. For my research, I found that video review was also essential for familiarisation of a previous design event or study, further assisting analysis during repeated viewings. Video can also be used as a talking point (in methods such as in Video Interaction Analysis or for planning future events) and allows collaborative analysis. Video can be cut up and used as a design material (Buur et al, 2000), such as in the Video Card Game (Buur and Soendergaard, 2000) or in design activities.

While video has its benefits, there are some considerations to be aware of. Firstly, use of a video camera is highly conspicuous, which may affect the behaviour of the participants. Furthermore, depending on the setup for a particular study, the use of video can limit the researcher’s involvement, particular if they are required to operate the camera. Video is also selective – usually the camera will record what the operator thinks is important. For my own research, this last point was not as problematic in many of the videotaped events. This is because in the dental surgery all the action is enclosed in a constrained space (the dental chair and nearby workbench). Selectivity was still a consideration for more complicated procedures and general activity in the surgery (which required the use of other rooms for tasks such as taking x-rays). Finally, if video data is used without collaboration from the practitioner, false meaning may be drawn from the recorded events (Matthews, 2004), particularly if the greater context behind the captured situation is unknown.

3.2.1.2 Audio data

Audio is useful for more detailed analysis of what has been said, in particular, for conversation between the designer, engineer and practitioner. Using audio provides an avenue for interpreting motivations that are trying to be conveyed during discussion. This means however, that the analysis is limited to what is chosen to be externalised, but when used in conjunction with video data separately, it can provide a strong understanding of potential motivation that can then be discussed and verified with the participant later. If used for transcripts, descriptions and analysis can be far more complete if video data has also been observed, or the designer was in recent attendance of the event being analysed. In this case they can know the context of the situation, and remember actions that took place and concentrate on subtle meanings. Audio is also a useful medium for data capture when video is either too inconvenient or obtrusive. A small digital recorder can be discretely placed so as to allow recording while being less obtrusive and not interfering with the actions of the participant.

3.2.1.3 Transcripts

Transcribing audio provides reliable and accurate data, which allows closer analysis, and simplifies the task of extracting meaning from conversations. Transcripts are able to be easily shared with other researchers and are a quick and simple way to present a specific piece of data for discussion. Transcriptions are also useful for presenting data to support design decisions, and small dialogues are easily used in writing reflections on research. The limitations of transcripts are that they are simply a recording of exactly what was said; intonation, gestures and actions are lost when a conversation is transcribed. As such, when transcribing, it is important to pay careful attention to where descriptions of context, tone or action were necessary for complete understanding. However, the onus is on the researcher to decide what is and isn't important, which can bias results. Another difficulty with transcripts is the length of time taken to create them, particularly when analysing in conjunction with video data. Personally, I found that transcripts took at least an order of magnitude greater than the audio and/or video running time to accurately transcribe the information.

3.2.1.4 Field notes

Notes taken in the field are useful during stages where video is not available, such as when ethical clearance for such has not been granted. Taking notes as things happen is also useful for recording observations that may not be apparent in later reviews of other data sources. However, note-taking is hardly an exhaustive means of data collection and it is more than possible to develop large gaps in the data.

Notes were useful for me as a starting point for later analysis. They refreshed my memory of impressions at the time, and they were carefully chosen and presented chronologically.

One aspect of field notes that affects field research is the feeling it can convey to the subject that they are being studied and scrutinised. Having a person observe you and take notes can make the subject feel self-conscious and interrupt their work. A problem for me in later activities was that my own participation meant taking notes was not possible. In these cases reflective notes written immediately afterwards helped compensate.

3.2.2 Data analysis

3.2.2.1 Video Interaction Analysis

Video Interaction Analysis is "an interdisciplinary method for the empirical investigation of the interaction of human beings with each other" (Jordan and Henderson, 1995). It investigates human activity, particularly in complex environments involving many people and technology. The use of video, as already noted, allows close examination of gestures, actions, conversations and the domain. In Video Interaction Analysis, the primary investigator first identifies routine practices in the context. The other team members then view the tape and note their own interpretation. After this, the team as a whole attempts to come to a common qualitative understanding about what has occurred in the footage. I found this useful during early stages of my studies when trying to build my knowledge and understanding of the work practice and interactions of dentists.

3.2.2.2 Video Card Game

Initial analysis for my research used the Video Card Game technique devised by Buur and Soendergaard (2000). The Video Card game is a useful method of interpreting what video means to design by turning video into tangible arguments to support design work. The Video Card Game is based on a children's game from the United Kingdom called “Happy Families” where players collect families of cards. The video in question is split into sixty to seventy significant short (one to three minutes) sequences by the organisers of the game. These are digitised and a key-frame from each is used to create a card representing that clip (as shown in Figure 10). The game is then run in the following way:

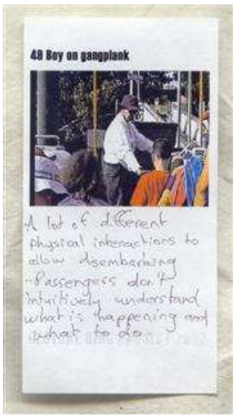


Figure 10: A card from the Video Card Game

Step 1: Dealing the cards. This takes about 30 minutes. Cards are divided into three stacks with duplicates of each. During this time the rules of the Video Card Game are explained and a video analysis training exercise can be run.

Step 2: The players now split into pairs to watch the video sequences. The players use the cards to take notes of what they saw. People are told to work individually and discouraged from discussing the clips with their colleagues. This takes about an hour.

Step 3: Arranging your hand. This next process takes about half an hour. During this time players are asked to group their cards openly in front of them on a table. Each player then briefly describes their structure.

Step 4: Collecting card families. Each person is now asked to choose a favourite family of cards. Each player then must describe in as much detail as possible their theme and invite other players to contribute cards to that theme. Completed families are then placed on a poster. This process takes about an hour.

Step 5: Discussing the card families. The players then spend time discussing each family trying to understand the meaning of the video clips and what each family means to the design. Since none of the players have seen all the clips, players show each other their clips and explain why they are relevant.

The primary benefit of the Video Card Game is that it acts as an enabler for those unfamiliar with video analysis. In this way it can provide a multi-disciplinary, collaborative analysis of the data with a wide variety of participants. While this was initially intended for involving practitioners, due to constraints on their time for involvement, my use of the game was to involve a wide variety of researchers to gain different perspectives of the data.

3.2.2.3 Interaction themes

Stemming from Video Card Game analysis of earlier studies (Brereton et al, 2003) were themes of interaction. By summarising these themes and pairing them with a key example and distributing these on a card, these provided a physical representation of themes of how people interacted with information in a variety of settings to assist brainstorming during design activities. Separating these themes onto physical cards allowed them to be used as physical reminders during collaborative discussion (for example, sharing them around a table) while also providing neat summaries that gave unfamiliar researchers a useful resource.

The theme cards were useful for directing design towards real interaction problems derived from observation and video analysis, rather than preconceived notions of how interaction could be improved in a dental surgery.

3.2.2.4 Interpretive understandings

Once a more complete understanding of the field was made and prototyping had begun, I started individual, rather than collaborative, analysis of my field data. This qualitative analysis was the process of reviewing what I had seen and making sense of it in relation to my increasing confidence in the field. Usually I would begin by reviewing video footage, and then transcribe the events exactly as they happened. I would then go back and add interpretations of what had happened or what someone might have been thinking. Finally I would try and draw themes from the data that helped me understand my overall understanding of what was taking place. These themes were partially biased – I was looking for evidence of events such as a demonstration of a shared understanding, but also new and relevant themes would reveal themselves in what occurred, such as the importance of patient education.

3.3 Conclusion

This chapter has presented a variety of methods I have used in order to best understand practitioners – both how they work and how they *want* to work. There is no completely right or wrong way of going about this – it is only possible to make the best of the techniques and resources available to the designer. Participatory and user-centred design provide a useful framework for approaching this, allowing 'cheap', intimate and efficient design methods.

This chapter presented two concerns for methods to consider. The first is the methods used for prototyping a new ubiquitous computing system, with the second being the methods needed for reflection and analysis of the design. In particular the need for participatory design and an iterative design process were addressed. By using a participatory process, it is possible to discern and directly address the practitioners' requirements, while an iterative process ensured mistakes and problems were addressed in a timely fashion, and stimulate further practitioner participation. Methods that form part of the participatory design methodology were chosen for their adaptive nature and the ability to have them at-hand for studies that were unpredictable in nature.

There is a need for qualitative research when employing these types of methods to help identify the causes behind complex problems in the design. The types of qualitative research methods employed were discussed, with special emphasis on the considerations for methodology choice particular to participatory design, including both how and even where to design. The methods used and described include ethnographically-inspired field studies, low/medium/high-fidelity prototyping, design discussion, games, role-playing, contextual prototyping, and persistent communication. These provided a rich variety of tools that afforded alternate views of the design space, allowing a more complete understanding for design. For collection and analysis of this information, I described the methods used such as video, audio, transcripts, field notes, Video Interaction Analysis, the Video Card Game and self-reflection.

A consideration unaddressed by this chapter is how the methods considered can be employed in a ‘real’ setting. The next chapter aims to discuss which methods I used in practice, and why and how they informed my studies, and to reflect upon their usefulness in real world application.

4 Early-stage Case Studies of Participatory Design

In this chapter I describe the fieldwork that I undertook in order to answer the question of how can participatory design inform the development of ubiquitous computing. Specifically, this chapter explores the fieldwork conducted with dentists for the majority of my research, and details design activities and their outcomes. The final studies, which involved a group of New Zealand dentists, are explored in chapter 5 as a case study of participatory design. How and why methods were applied and what their outcomes were will be further discussed in that chapter.

When performing research and attempting to understand practitioners, the first consideration was to consider a problem specific to a particular domain. Potential solutions to this problem benefit from developing an understanding of the work practice and context. This chapter describes how such an understanding was developed.

4.1 Exploring dentistry

Prior research I assisted with, by Brereton et al (2003), found that in a variety of contexts, it can be seen that the methods of interaction are nuanced to the particular context in which they are used and are mediated by social and physical cues. As part of this research, the context of work in a dental surgery offered compelling opportunities for design intervention. As part of this research, a theme was created using the Video Card Game (Buur and Soendergaard, 2000) (described in section 3.2.2.2) called “Barrier of Sterility”[4]. This theme represented the constraints for interacting with a computer faced by those in a profession that had mandatory restrictions on physical interactions with a computer. In the case of dentists, in their daily work practice, infection control constrains how practitioners interact with their environment. The dentist viewed had different ‘zones’ of cleanliness in his surgery, and he kept track of these zones to prevent cross-patient contamination. For example, instruments would start in the ‘sterile’ zone, and move to the ‘dirty’ zone after being

[4] Later corrected from ‘sterility’ to ‘cleanliness’, due to new understandings on how dentists view infection control and what is truly sterile versus what is only clean.

used in the patient mouth. This is shown in Figure 11, with red as the dirty zone and green as the clean zone. In addition, the keyboard and mouse needed to have protective covers on them which were changed between patients.

Figure 11: Dentist working with clean and dirty zones shown

With a domain with which to frame my research, I began a series of design studies with a diverse range of participants. These studies are represented in Figure 12. The same general approach to design was used with each group, although there were minor variations in activities. The diagram details how each group of participants informed studies with other groups.

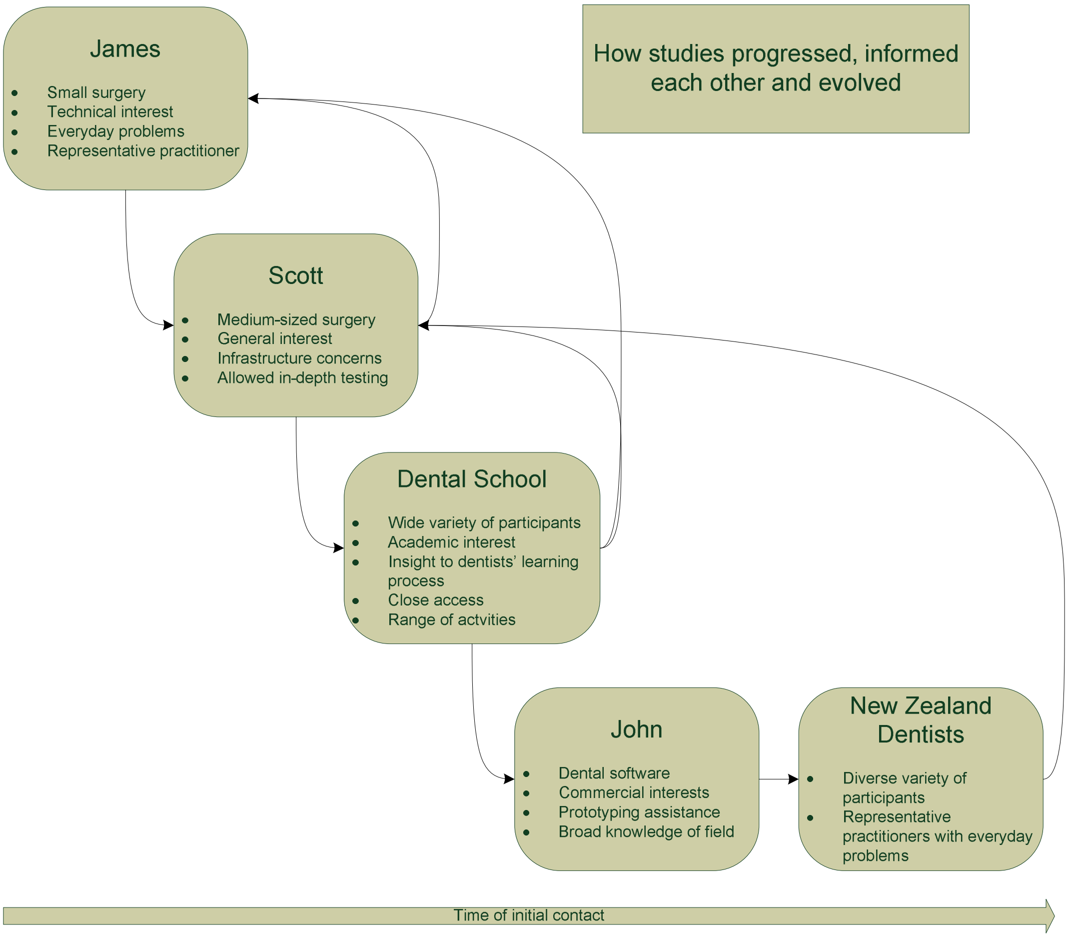


Figure 12: Diagrammatic description of studies

4.1.1 Initial contact

To explore this domain further, myself and two other researchers also interested in the problems presented in dentistry contacted the subject of the initial exploratory footage, James. James was our introduction into the field of dentistry and showed a personal interest in the research due to difficulties he experienced. Through early design activities, James showed he was open to new ideas and collaborative methods of design. However, it soon became apparent that James had limited availability. Planning for practitioner availability became a recurring theme in planning participatory design projects; the practitioner's availability and interest (or lack thereof) is critical to a project's progress.

It became apparent that to further explore the design space, it would be necessary to extend participation to multiple parties. As discussed in the literature review, sufficient involvement is a sometimes overlooked aspect of participatory design since realising participation from practitioners can initially be quite difficult. The first opportunity to expand the number of participants involved in the research to do this came by fortuitously[5] when a dentist, Scott, working at my personal dentist's practice expressed interest in the research.

Scott was part of quite a large practice and being one of the junior staff with a computing background, also handled their IT requirements such as integrating new software and hardware. He noted difficulty in adopting electronic records and computer-supported dentistry techniques into the surgery and so had an interest in exploring computing potential and assisting with brainstorming ideas and testing prototypes.

However, with a private surgery I was faced with difficulties regarding ethical clearance associated with long term observation of a professional dentist and his patients. Therefore I approached a local dental school for an opportunity to observe their students. Dental school patients were familiar with observation and interruption, and being part of a research focussed university, the dental school was receptive to design studies located in their surgeries.

Working with a dental school provided other benefits: the students had good availability for design events, and were available for longer interviews and activities than those from a private dental surgery. The field studies at the dental school therefore provided a rich resource of information for design and facilitated the depth of involvement necessary to help develop the understanding of dentistry required for future design collaboration with dentists.

4.1.2 Commercial participation

[5] Early in this research I felt I was taking too much of an "ad-hoc" approach, by involving participants who were not specifically sought for their involvement. Later in my studies I came to realise that this was a necessary part of participatory design, given the potential limited availability of participants.

For realising a prototype, I explored the possibility of interfacing with an existing dental software system to support it. It was not the aim of this research to develop a new system of record keeping for dentists, but rather a means of interacting with those records. I explored common software applications used by dentists for tracking patients and procedures. Contact was made to explore support opportunities with several companies that provided software used by a significant number of dentists. Ultimately interest was expressed by John, the CEO of a dental software company based in New Zealand. DentalSoft is a software company providing a patient record system used internationally, and is the de facto standard for dental patient records in several countries. DentalSoft provided software and resources for prototyping, with no requirement for reciprocation other than a collaborative process. John's connections to the dental industry also meant he was able to secure extensive access to dentists for me, allowing design activities involving medium-fidelity prototypes to be explored in greater depth.

4.1.3 Research in the field

During the research all design activities were situated at the practitioner's domain. The benefits of doing so are discussed in greater detail in the literature review of this thesis. In the same vein as Buur and Pedersen's research (2000) and as discussed by Campbell et al (2003), in order to demystify the design process, we took design tools, such as laptops, prototypes and design representations to the workplace. For this research, this also assisted with intelligibly explaining technology to the users to assist their contributions to the design (Cederman-Haysom and Brereton, 2004). By understanding the designer's limitations and expertise, the user is able to contribute in more meaningful ways.

Prototypes were designed to reveal the internal functionality of the system with debugging modes used for all prototypes. For example, the speech recognition prototype allowed for dynamic changes to the grammar and dictionary (Figure 13), while the gesture recognition system clearly showed the actual system input to the user as a means of highlighting the difficulties faced in recognising input (the output is displayed on the laptop in the background as seen in Figure 14).

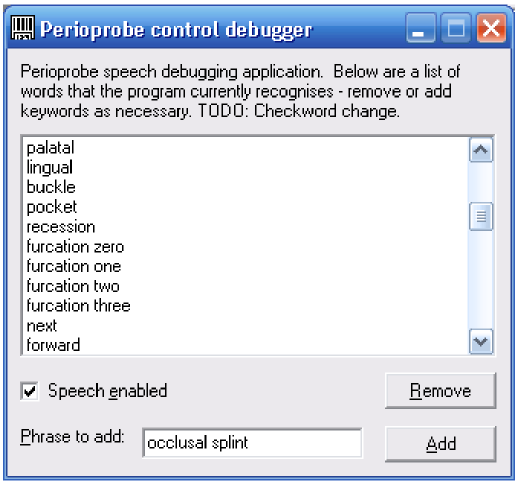


Figure 13: Speech recognition debugger

Figure 14: Gesture recognition system (Donovan and Brereton, 2004)

Furthermore, design changes had to be carefully considered and grounded within the practitioner's environment, due to the complex interweaving of social interactions with information work and dental work. There are many actors who coordinate their actions in a dental surgery, from the receptionist, to the nurse and the dentist. In addition, there are many different stages of a dental visit, from arriving and preparing the equipment, to the procedure itself, finishing with explaining any follow up requirements and billing.

Making a change could affect any of these and in-situ activities revealed how the participant interacted with devices in their actual work environment, along with follow-on effects, providing immediate feedback about problems or potential in the design. On one occasion during a contextual interview we[6] had been informed that dentists performed charting around the teeth in a particular order. Once adopted as the understood technique for charting by the prototype, several dentists realised that although they had been taught to chart a particular way, in practice they used a more ad-hoc means of recording information.

Specifically, the dentists described charting around the teeth starting with the palatal right third molar (the upper right wisdom tooth), moving around the roof of the mouth, and then starting again with the buccal right third molar (lower right wisdom tooth), and continuing around the jaw. As such, automatic tooth selection was supported by the prototype that followed this pattern. When testing this prototype with one of the dentists (Jason), he found that the rigid charting procedure did not support how he charted periodontal information in practice (periocharting).

Periocharting refers to the dentist recording information about the gums, specifically periodontal disease. The periodontal chart is used to both identify and track significant signs of disease, which is manifested in deeper than usual “pocket depths” (anything greater than 2 or 3mm). The pockets refer to the spaces between the teeth and the gums, and there are six measureable pockets per tooth. The large amount of data that needs to be recorded means that unless the dentist only remembers significant measurements it is very difficult to record all the data necessary. The procedure itself is also slow and painful for the patient. Charting in general had previously been recognised by James (discussed with transcript in section 6.2) as requiring design intervention, and several dentists referred specifically to periocharting as a difficult procedure to complete that would benefit from new methods of patient charting (such as by Scott in section 4.3.2)

For Jason’s procedures, periodontal charting was usually started where periodontal disease was suspected from visual inspection and, depending on the measured pocket depths, charting either continued in that area or moved to other areas that may be problematic. When questioned, other dentists who participated in the studies also stated they followed the same procedure; however they made it clear that other

[6] When I refer to ‘us’ or ‘we’, and do not explicitly state who is involved, I refer to my colleagues from the Phenomenal Interaction Group at the University of Queensland.

dentists familiar to them did follow strict charting throughout the entire mouth. By identifying this difference early in the process, it allowed for rapid changes that supported actual work practice.

4.1.4 Design activities

Choosing appropriate design activities was an important consideration. As discussed, the core concern was that I needed a way to maximise the effectiveness of the time spent with the practitioners – both reducing the amount of time I needed from them (given how valuable it was) while allowing time to gain sufficient understanding about their work practice and their response to design intervention.

For choosing these activities, I drew from a variety of sources, primarily from the field of participatory and user-centred design. The core of each activity was the use of ethnographically-inspired field studies, which provided non-invasive and non-time-consuming (for the practitioner) methods of observing the dentists' work practice and context. For the student participants, for whom observation can be intimidating, design games were used to provide an interactive way of becoming involved in design activities.

My points of interest however were to get to the root cause of usability concerns, to understand interaction and to develop more elegant means of interaction. In order to explore these I found contextual interviews could be used to very quickly get to the crux of why and how things were done and potential problems. Testing of resulting prototypes was done with contextual prototyping and further design activities. I made a point of adapting the methods used according to the interest and availability of individual practitioners. The activities are explored at a finer level of granularity in the discussion chapter.

The rest of this chapter discusses the fieldwork with the practitioners who participated in the research and their contributions to this thesis.

4.2 James

4.2.1 A small professional dental surgery

The initial contact for research with professional dentists was with James. James was a member of a small local practice with a second dentist, who owned the surgery. We were introduced to James through personal contact with a fellow researcher who knew he had an interest in new technology. Studying James was a good starting point, as a small practice allowed detailed studies. This was due to the personal connection to James as well as the lack of a corporate restriction on access and availability.

James had an interest in the nature of the research (particularly the potential of ubiquitous computing) and of exploring potential technologies for improving his dental practice. In addition, the surgery James worked at was dealing with its transition from paper to digital records, a problem reported by several other participants as typical of many dental surgeries. Given this background, James was able to contribute to the design sessions both abstractly (considering the problems faced by the typical dentist), and grounded in real issues faced by the surgery. An example of both these types of contributions is presented in the following transcript. We were able to present issues seen in another context (the dental school) in addition to exploring at-hand considerations.

> *Researcher: "Was I right in saying these are typically the tools… I mean, we see the mirror a lot, and…"*
>
> *James: "The mirror's used for virtually everything. You can use the sickle probe with the mirror just before starting the filling, just to check "ok, oh this is the area where the decay is" or "do we need to go to the back part of the tooth or only on the front part of the tooth?" But we wouldn't necessarily be doing a full, I mean, we wouldn't need to open up an exam for that one, even though we picked up those instruments there."*
>
> *Researcher: "Yeah, I think there'd be instances where you picked up the instruments but didn't necessarily want to see what was [in the patient chart]... But yeah that's something we're interested in, and I'm not sure."*
>
> *James: "Yeah the mirror and probe are used for virtually every procedure that we do, even if it's just for a bit of torture."*

[laughter]

Researcher: "Yeah that's right, so it's up and down a lot and I suppose if it's not on here then it might be still being used. Well, we noticed in the dental school they often keep their instruments on the bench as well, so I mean, it might not be being used, but it could be put somewhere else."

James: "Yeah. I don't really have room to put it anywhere else, so if it's not being used, it's on the bracket table[7], but on the odd occasion I've found I've put it in the dirty area."

During previous ethnographic studies we had observed the frequent use of the mirror and probe during procedures. The dental mirror is a small, circular mirror attached to a metal stem which allows the dentist to observe all parts of the mouth. The probe is a sickle shaped instrument used to enhance tactile sensation for the dentists. From what we had observed, it appeared that the mirror specifically indicated the dentist was checking the teeth for charting purposes, and would therefore want the patient record available. From the conversation with the dentist it became clear that the mirror and probe are very general tools for observing the teeth, and this information is used to support a variety of procedures, and not just to record information about what was observed. By relating how we planned to incorporate the tools as a contextual cue to the design, James was able to specifically give us several examples of situations where the mirror might be used otherwise. This provided confirmation of the use of the artefact in general practice while further exposing other at-hand considerations, such as the varying location of the instruments during procedures.

4.2.2 Scale models and prototyping

An initial study was conducted with James during which general routines were videotaped. The resulting data was explored using the Video Card Game, and themes of interaction were drawn from this data. These themes provided reflection and focus points for considering interaction difficulties faced by dentists. Based upon the problems we had seen with social and physical interaction within the surgery, a second study was organised that consisted of an unstructured interview to explore the

[7] A bracket table is the small table attached to the dentist's chair where the dentist keeps their instruments.

design space. This study also incorporated further data gathering through the videotaping of more procedures (such as a patient's general check-up). These studies helped introduce new observations of the nature of dentists' work. These included the importance of maintaining infection control, the complex arrangement of workspace, the large amounts of data generated by procedures and the importance of the dentist-patient relationship.

Specifically, it was observed during the studies with James that maintaining infection control was paramount. Before a procedure, the dentist creates a clean environment for the patient. This includes the sterilization of surfaces (whether through disinfecting of a permanent surface using chemicals such as bleach, or through the use of a temporary cover), the sterilization of instruments (with an autoclave, then kept in a sealed wrapper that the instruments are dispensed from) and the dentist themselves (through hand washing). Through contact with the patient, these clean zones become 'dirty', and as such if a clean instrument is required, it is removed from a clean zone and never returned there. It is instead moved to a different area where dirty instruments are kept, usually the bracket table. The dentist keeps track of these zones throughout procedures and must remain vigilant to prevent contamination.

In addition, all observations of the patient's dental health must be recorded, both normal and abnormal. The state of the patient's teeth is noted as well as observations which may affect future work (such as minor abnormalities in the teeth and self-reported data). All pertinent aspects of the procedure are also recorded, including such things as the materials used, the work performed and likely future work to be completed.

During the procedure, the patient's reaction to the dentist affects the work, and the information provided from him or her is vital to deciding the work to be completed. As such the patient must be kept physically comfortable and encouraged to build a good rapport with the dentist.

The follow-up session with James was useful for extending the knowledge of how dentists worked, with first-hand observation that also underscored the interaction problems observed from the first session. In addition to interaction difficulties, the importance of interaction between practitioners became clear. For example, James would wait until he heard his assistant typing to continue a procedure and make further observations. His assistant, upon hearing James talk about x-rays with the patient, would pick up a lead apron, only to put it down when she saw him putting on gloves (revealing his actual actions).

To conclude the second study, a tour of the surgery in its entirety was organised, which was used by myself and fellow researchers involved in the study to develop a complete physical understanding of the surgery. This understanding was translated to a foam-core model of the surgery (Figure 15). This provided a focal point for discussion with James whereby it was possible to explore work practice abstractly and gain a holistic understanding of the surgery to aid design activities.

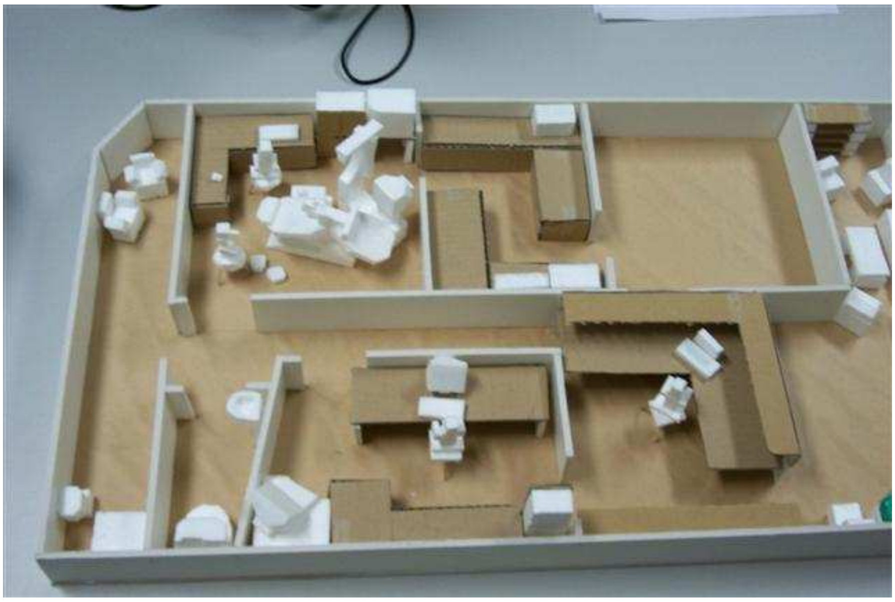


Figure 15: Scale model of the dental surgery

A third visit to James centred upon validating the model of his surgery in order to obtain this understanding. Discussions centred on the physical model allowed brainstorming of further design ideas. We were able to question things such as the placement of instruments and workbenches in the surgery, and have a way of physically identifying locations of difficulties for interaction. The close proximity of the equipment in the surgery, the required layout of the computer and the difficulties of accessing it while performing a procedure on a patient were made clear. The flow of activity and the flow of documents throughout the surgery (for example, the patient record when it moves from reception to the surgery, or the x-ray from the camera to development to display on a light board in front of the patient) were also considered. The need to access the workbench while seated and performing a procedure, and the layout of ‘clean’ and ‘dirty’ areas was also elicited from this discussion.

A final activity with James was conducted after further reflection and design work was completed. An in-situ design discussion was organised where medium-fidelity prototypes were presented to James as potential design artefacts and as a discussion point in the design process. One of the researchers demonstrated a bracket table that had load sensors embedded within it. The idea for a context sensitive bracket table had evolved from previous discussions about observations made in the surgery. In particular, the bracket table had been identified as being a necessary part of almost all procedures in the surgery.

Much like self-checkout systems utilised by supermarkets, the prototype bracket table recognised different weights on the bracket table to identify the item placed or removed from it. The microchip embedded in the system communicated with dental software used in the surgery if a particular instrument had been picked up. It was hypothesised that different instruments indicated different activities and in particular they represented different types of information that needed to be recorded or viewed in the patient’s record. By sensing the type of instrument in use, the information represented or recorded by the software could be adjusted accordingly.

After spending time brainstorming the uses for the augmented bracket table in this final design session, a medium-fidelity prototype was discussed and tested with James. This was a digital pen based prototype, with an idea of incorporating it within a larger system to allow hygienic recording of patient data. This prototype had previously been discussed with Alison, a lecturer from the local dental school (see section 4.4). There had been positive feedback towards this prototype from Alison and it was felt that it would be a good fit for most dentists’ work practice, given the remaining prevalence of paper records, even in surgeries with computer-based records.

Figure 16: The digital pen (bottom left)

The prototype as it was shown to James was similar to that shown to Alison. Some paper printouts of a dental chart were made when used in combination with a digital pen could recognise and record the pen strokes, which would then be synchronised with a computer maintaining the main record of the data. The paper printouts had a lightly coloured cross-hatching pattern which represented positional data for any mark made on the page. These pages were created by combining the Anoto pattern provided for working with the pen with scanned representations of the patient record.

The digital pen had a built-in camera which could analyse the Anoto pattern printed on the paper, and determine when and where pen strokes were being made and store them in internal memory. The physical paper also afforded extra functionality in that some areas could be programmable beyond recording raw data. For example, a checkbox drawn on the page would have data encoded to record a boolean value as to whether a pen stroke had been made in that area. The pen could also provide physical (vibration) feedback when checking the box.

However, after being shown the digital pen (see Figure 16) and discussing its functionality, James felt the use of a digital pen did not suit his surgery. James did not feel that writing notes would be useful for his patient record, given the automated patient monitoring and payment system in place that would not benefit from a digital copy of handwriting. While a digital pen would support existing work practice and constraints of the context, it did not adequately incorporate other benefits of switching to a digital record keeping system, limiting its usefulness.

This highlights two potential difficulties with participatory design. Firstly, if a group of stakeholders involved with the design is too small or specialised, the resulting design is usually closely linked to the work practice of the practitioners participating. This can hamper attempts to find a good design for a sufficiently broad range of practitioners to make its production and development cost-effective. Secondly, a limited series of design activities may not highlight potential problems with the resulting design; an appropriate number of iterations are required to address this.

4.2.3 Accountability in design

In addition to developing and helping constrain new designs, James allowed a level of access to the dental surgery that afforded a much closer insight to the vagaries of the design space. These included:

- Empirical data which showed the complex flow of information within the dental surgery.
- How small surgeries were coping with transition from physical to digital information.
- Difficulties faced by dental surgeries in managing and recording patient information while constrained by hygienic requirements.
- An ethnographic survey of how dentists in a small surgery work while performing a variety of procedures.
- The need for accountability in the design process.

Accountability in design has traditionally been defined in two different ways (Eriksén, 2002). In software engineering practices, accountability is a goal for the quality of design processes. Accountability in this case is about making design and development processes open and understandable to all stakeholders. It focuses on the *methods* of design. In ethnomethodology, accountability refers to understanding how people organise their interactions and actions, making them visible and accountable, with emphasis on local co-construction of meaning by the participants. In human-computer interaction and computer-supported co-operative work, accountability takes on a hybrid meaning with alternative interpretations, with Eriksén (ibid) suggesting it means a holistic view of visibility of the design itself and considerations for its context of use. The effects of actions must be considered across a broader context than just the at-hand practice (for instance, how does the dentist updating the patient record affect administrative staff members?), and the design itself should be accountable, with the system and its outcomes having a common understanding.

The importance of these became clear as the studies progressed. I was able to see firsthand the complex negotiation of patient information between long-term records and administration and making relevant information ready-at-hand. Difficulties such as the transition between paper and digital records were identified, and the increasing use of digital information was seen to be a key consideration for design in his surgery. The combination of off-the-shelf computers and custom dental equipment was shown to be a necessary design consideration (including such concerns as how to physically adapt a computer to be usable during procedures). James also showed how different instruments were used during everyday work practice.

However, it was during the final design session at the surgery with James, I realised that the more I understood the surgery, and the more familiar he became with the technology, the more interesting and productive (for design) our discussions became. In reviewing some of my design specification notes derived from a later study with James I noticed the following requirement for the interface:

> *Furcation: If on the palatal side, then must listen for mesial or distal. For example, if the user says "furcation mesial <grade>" it adds it appropriately. If mesial or distal is missing it ignores it. Opposite for buccal where there is no mesial or distal. For the lower teeth there are no mesial or distal measurements. A shortcut to each of the furcation gradings would make this a lot easier (is possible by moving the mouse to click on a shortcut at the moment).*

In laymen’s terms, the first part of this explanation means:

> *For grading the amount of the tooth’s roots that is exposed from the gums: If on the side of the tooth facing inwards (ie towards the tongue), then must listen for the terms “mesial” (meaning towards the front) or “distal” (towards the back – this is due to the fact tooth*

> *branching only occurs on the inside and so can go either forwards or backwards). If the direction is not specified, then do not record a value as it is invalid. If on the side facing towards the cheek, then ignore mesial or distal because branching does not occur. For the lower teeth, no branching teeth values are recorded.*

Without the in-depth knowledge I had gained from previous studies, it would not have been possible to write such specifications about how to use speech recognition to navigate through the tooth chart and to understand the terminology and processes. Throughout the studies, I felt that not only were the practitioners gaining a better understanding of the technology and how it affected them, but all researchers involved were learning the practice of dentistry. By better understanding the practitioners' work, it was possible to become a better informed and more effective designer.

This requires sufficient information of how the practitioner works, and how existing technology affects and influences their work practice, such as why they need a particular information representation (such as an x-ray) displayed at a particular time, how it is provided in the existing work practice, and the reasons for this. For example, x-rays for James were physically displayed on a light board. While assumptions could be made that it was chosen (instead of digital x-rays) because it affords a greater level of detail, or a more tangible means of interaction, in James' surgery his choice was driven by cost issues, and to a lesser extent, difficulty of integration (due to a paper to digital transition). In terms of design, the information must be made clear to the dentist, but the requirements for this should in turn be revealed by an accountable design process to the researchers.

4.3 Scott

4.3.1 A large private surgery

I was introduced to Scott through the surgery I attended personally for dental care. Scott was a new dentist at the practice and through discussions I had with him during normal check-ups he became aware of the research presented in this thesis and expressed interest in contributing and offered to provide his expertise and time for design activities. His motivation for doing so seemed one of personal interest, given a hobby of computing. Initial involvement was established as ethnographically-inspired fieldwork, whereby a fellow researcher and I would observe and videotape Scott during commonplace procedures in order to further our understanding of dental practice and working environment. At a later stage in the research Scott made himself available for design discussions and prototype tests, becoming a resource both for testing design at later stages in the research and for reflecting upon the design.

Scott was part of a large practice consisting of twelve dentists in a surgery located in a central business district. The practice was modern, with electronic patient records combined with technically advanced equipment for dental procedures. Scott's additional responsibilities as a member of the practice included computer support, and as such he handled the infrastructure for the dental software. He had been instrumental in customising the software for the surgery and handled its maintenance.

4.3.2 Managing expectations – a perspective on integration and configuration

Through the design studies with Scott the following lessons were drawn:

- Researcher motivations should be properly explained to the practitioner.
- A shared technical understanding is needed early in the design process.
- Design choices cannot take place in isolation – seemingly unrelated systems can be affected.
- Periocharting was one of the most difficult procedures for charting based on interaction difficulties.

After establishing a relationship with Scott, I organised for an initial session to make contact and learn more about his work practice. We were given a tour of his surgery, but when we began an interview to discuss the use of computing for completing his work in dentistry, Scott focussed almost entirely on technical aspects – how many computers they had, what sort they were, how they used them, how the network was set up, and so on. Reflecting upon this, I realised this was an interesting example of the need for managing expectations of what is involved in design research. The practitioner should be informed of how the design process may affect their work practice, and an initial briefing session also helps to frame discussions.

From this interview it became apparent that Scott had assumed that any prototype system would work neatly with their existing setup. Initially I dismissed this as naivety. However it soon occurred to me that I had assumed that it would be obvious to all that a technically complex system would not be 'plug and play'. Ubiquitous computing literature had influenced how I saw ubiquitous computing system design. Much of the existing research focuses on ubiquitous computing systems that are wholly contained – existing systems are unconsidered and work practice is supported with infrastructure developed from the ground up. In reality, people update their systems incrementally – it is rare for a small to medium business (or even enterprise level companies, although they are more likely to have the budget and motivation to do so) to replace a system completely.

Scott's practice had already been struggling with these incremental updates. In particular, members of the practice were investigating methods for integrating x-rays to be a part of their digital records. Digital x-rays, on paper, offer many benefits over traditional x-rays. They consume far less power while in operation, which in turn means they emit less radiation which may detrimentally affect the patient. Without the need for processing and development, digital x-rays provide immediate results and allow for computer-based manipulation, facilitating patient education (an important aspect of dentistry which I will discuss further later) and faster diagnosis.

Without delving too deeply into the concerns of a dental practice, there are several issues when considering new technology such as this. First is cost – it cost roughly $10,000 (as at 2005) for the necessary sensor plate that is used inside the patient's mouth. The second consideration is size – the plates are not as small as regular film based plates, and may be uncomfortable for some patients. Third, there is the difficulty of integration with existing infrastructure. Most digital x-rays require specialised software and hardware to capture and process the image. These three difficulties, I would later come to realise, in fact represent exactly the problems of deploying ubiquitous or multimodal computing systems to dentistry: cost, fit and integration. The issue of digital x-rays is represents both real considerations, previously unforeseen by the researchers involved, and a grounded lesson for business considerations in adopting new technologies.

Scott was also a source for observational studies. He provided a striking comparison to how James used the computer to support his practice, through his greater reliance on technology for both data gathering and performing his dental procedures. These differences made me reflect on whether it is possible to employ participatory design to create a system that can be generalised to a broader group of practitioners. However, observational studies of Scott identified similarities between dentists; for example, the use of patient records during procedures or how data entry is handled while not ‘clean’. Below are some notes made from reviewing video of Scott, which is representative of the role of hygiene and how notes are used during a procedure:

> *The patient is now seated in the chair and ready to go. However the assistant returns with some x-rays, so Scott leaves to go look at them to. As he interprets them, he continues putting on his gloves without looking. Apparently these are old x-rays (2001) and the 2003 x-rays cannot be found. He brings up the tooth history chart again and checks the exact date and compares it to the scanned record. He finds that he actually does have the most recent record scanned but it is hard to tell as there is no communication as to what has happened (that we can hear anyway). The procedure now begins.*
>
> *[There is no further updates of the patient record throughout the procedure. Scott periodically reviews the information on the screen, and is in a position so that he can easily see it but the patient can’t.]*
>
> *Upon concluding the check up, as the patient rinses, Scott brings up the patient chart again. He then selects (after scrolling through the list for a while, moving both up then down again) glass ionomer and applies it to the graphical representation of the teeth.*
>
> *He then places a “watch” label on the bottom right tooth which had some sign of decay and cracking showing. Scott then ticks off the fact that the check up has been done and updates the recall (by pressing a large button on the bottom right of the patient appointment plan). Scott removes his glasses and throws away his gloves, and washes his hands again.*
>
> *When questioned at the end of the procedure, Scott indicates that he must memorise all the updates he wishes to make. As such the notes are short and to the point:*
>
> *“monitor 8s, and reassess next recall, stay or remove”*
>
> *[8s refers to one of the wisdom teeth]*

Scott also uses the x-ray and existing notes to help provide a reference point for the updates he must make to the record.

During the same session, Scott made an interesting observation that became the germination point for the final prototype:

Researcher: "Do you ever use [the periochart]?"

Scott: "Not all that regularly – it's a bit cumbersome. It's a situation where you need to go from the patient to the computer on a repeated basis so when you have to keep coming back and doing a lot of data entry, it gets too difficult. You've still got the issue of dirty hands operating the computer, and even though we've got barrier techniques we still try to minimise interaction with the computer."

Researcher: "So the periochart would be somewhere where you'd…"

Scott: "…definitely have voice recognition. Maybe gesture and voice. It's underutilised for those reasons. Having some sort of voice or gesture activation to use the charting would be the biggest benefit I think."

The periochart is generally an invasive, slow procedure that ties up both the dentist and the attending nurse who must record a large amount of information (the measured depths). Given its difficulties that touched on many areas of interaction difficulties in a dental surgery (complex social interactions, computer use, large amounts of information to be recorded) it seemed a good activity to centre prototype development around.

In addition to numerous observational studies, Scott was engaged for several design activities over a period of two years, culminating in a final test of a high-fidelity prototype. The prototype testing and design discussions that followed are of great importance to the conclusions of this thesis. The transcripts of these are located in the appendices of this thesis while the reflections are discussed in greater detail in the discussion chapter.

4.4 *Alison*

4.4.1 A dental school

The limited availabilities of professional dentists and the ethical difficulties of involving patients paying for privately funded sessions with their dentist were a cause of concern for furthering the research in the private sector. The University of Queensland's dental school was therefore investigated as a possible source for both extending my and other researchers' knowledge of dental practice and to provide access to a larger pool of potential members for design activities. We contacted a lecturer at the school, Alison, for a meeting to discuss our research, potential involvement, and what would be required for the school's design activities. At this meeting, we explained our background and motivation, and our desire to observe students and potentially involve them as participants in the design process through structured activities. The dental school provided the following insights:

- Understandings derived from long-term field studies.
- The benefits of design games and role-playing.
- An exploration of alternative methods for soliciting practitioner feedback
- How student dentists responded to augmented equipment (using a digital pen).
- The ability to better understand dentistry by designing within a learning environment.

4.4.2 Design discussions and games

Alison was interested in our research and gave her approval for the dental school's involvement. Once appropriate ethical clearance was given we began by running an ethnographically-inspired study that consisted of six visits over two months. These visits allowed close observation of students already familiar with dentistry, but still learning. This gave a unique perspective – it was possible to learn of procedures with the students, as well as observe what aspects of dental work practice were problematic for inexperienced dentists.

Following observations made during the visits, we would discuss both the work the students were completing during procedures, and how the school functioned as a whole. Towards the end of the study we also began discussing potential designs and involvement in design activities.

From the observations made and the discussions conducted with members of staff and students, I developed the idea of using a digital pen to replace the existing record infrastructure, which I prototyped and presented to participants from the dental school. A fellow researcher presented a modified version of the bracket table (as demonstrated with James). The patient record software used for testing the bracket table was the same as implemented in James' surgery, and was a fairly common program for patient record keeping.

I organised a design demonstration with Alison after building a suitable medium-fidelity prototype of the digital pen system using off-the-shelf parts and some customised software. The digital patient record used was modelled after the physical records already used by the dentists. I scanned and edited the most relevant pages as described to me by the students, and combined them with the pattern necessary for converting the pen strokes to digital data and made up a usable booklet, similar in nature to that already used by the students for their normal patient records. The following discussion took place during the demonstration:

> *Researcher: "So I've been having a look at… when I was talking with Jennifer, she was telling me about how many times the records are transcribed once the person has written down. So if the student marks it down on the throw-away bit of paper and in the end transcribes it to their record book, and then it goes out to reception and gets transcribed again, is that right?"*
>
> *Alison: "Yes, yes…"*
>
> *Researcher: "And so we were talking about the idea that you could just write things down once and what you wrote down was recorded digitally then it'd certainly make things a lot easier. So what I've done is converted part of the record onto digital paper. It's just like regular paper, except it has these dots on it, which tell the pen where it is… So you can actually just write wherever and it just comes up on the computer afterwards."*
>
> *[long silence while Alison fills out the form]*
>
> *Alison: "Is that cleanable or sterilisable or what?"*

Researcher: "Well yeah, that's one thing I wanted to talk to you about. Because when they use pens in the surgery, don't they just wrap them in glad wrap? "

Alison: "Yes, they do."

Researcher: "So would that be alright for that?"

Alison: "Yes, that could be alright because they wouldn't be touching… touching the tool. So that could be wrapped in glad wrap, and probably wiped down with disinfectant afterwards, would that affect anything?"

Researcher: "No, it's sufficiently packaged so you can wipe it down."

Alison: "I think it's an interesting concept actually, it's very neat. Very impressive. Very impressive. How much does that cost?"

Researcher: "I think it was $150."

Alison: "Really? Then you've got to have the program obviously…"

Researcher: "The program came with it…"

Alison: "I think it's very neat – I love it. That's very neat. Yes, no I can see that could have some… and once you've actually got it onto there you can change it? I mean really, once you've actually got it into typed words, you can then modify and change it or correct any mistakes. So really very interesting legal point actually about records – because records you're not meant to change and that's one of the concerns about digital stuff and things – x-rays can be doctored and all sorts of things can happen to them."

While Alison expressed interest in the pen, she could not see the benefit of using the bracket table prototype. This is not to say the pen was intrinsically better than the bracket table, but rather it reflected that while Alison could envision the pen being adopted, she could not understand why you would want a context sensitive bracket table, when you could simply use buttons instead of instrument detection.

Another avenue for prototype development was the use of medium-fidelity gesture recognition prototypes which offered a limited degree of functionality which served as discussion points for future development and refinement. Specifically, some basic forms of gesture recognition were demonstrated to students, and they then participated in activities to explore the possibilities for recognition. The prototype tested used the previously discussed gesture ring prototype (section 1.2) which made use of two accelerometer chipsets to record accelerations in three dimensions. It then displayed the data that the system was receiving in real time on screen and allowed for recording video of the motions along side of graphs of the data being received. The neural network and learning process for the gestures was explained to the students, and in turn this visualisation meant that gesture could be evaluated in real time for how distinguishable they were. It was interesting to see that after just a few sessions, students would explain to other students and staff at the school how the system functioned and described its potential.

In addition to prototype testing, I used design games to explore new means of interaction with the students. Some of the games helped me understand more abstractly how dentists like to work. For instance, having dentists attempt to complete their tasks using a single interaction modality (such as only speech or only gesture) exposed tacit knowledge held by the dentists (such as what information needed to be recorded during a particular routine) by constraining their normal methods of interaction.

In other activities I used role-playing and Wizard of Oz techniques to explore how modality changes affected work practice. Asking one dental student to act as a ‘gestural and speech interface’ for the other dentist helped with understanding what was required in such an interface. I used A2 printouts based on the dental students’ normal charting sheets, such as that shown in Figure 17. For the task, the students were asked to complete a regular patient check-up. Other tasks took advantage of the procedures already taking place, for example putting in a filling.

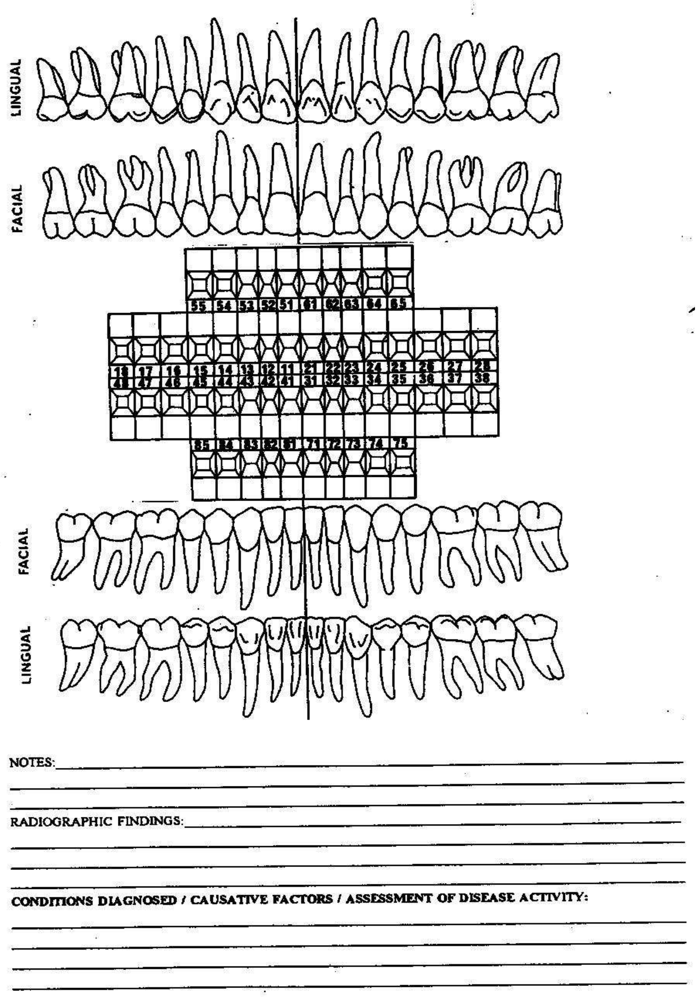


Figure 17: Dental interfaced used for Wizard of Oz activity

The following conversation took place with the students during this role-playing exercise:

> *Student 1: "One more question – is she meant to be telling me where she wants me to write? Usually we just listen to them talk and write."*
>
> *Student 2: "It's easier for me to just say… 'Medical history – nil sig' so the heading, where I want to write it, and what I want written I suppose."*
>
> *Student 1: "Cause see how she's talking to him, saying do you use fluoride toothpaste, do you do this, do you do that, and then turning to me and going 'fluoride toothpaste, this' [Student 1 gestures while she's saying this]. Usually while she's saying that I'd be doing that anyway."*
>
> *Researcher: "Okay, so have you guys done that before, where you're filling out the patient record for someone else?"*

Student 2: "Yeah, yeah, if we've got a spare session then we always do it for someone else. The only difference is if someone like a dental assistant or someone is assisting you, like I said, they sort of automatically know where to put it approximately, so there's no repeating any information or anything like that."

Student 1: "Say [Student 2] will be looking the mouth, she'll go through and say 'Yep, quadrant 1 is fine, there's this here', and she'll just say it as she's going and I'll just write it wherever it should go."

The students were not observed dictating to each other during ethnographic studies, and so without having them trial this interaction technique through role-playing I would otherwise have not accounted for the fact they are accustomed to dictation for their records. Furthermore it highlighted an existing efficient method in their current work practice for collecting the data: they know the structure of the patient record and the required order for tasks within the procedure. With this contextual information it could be concluded that a potentially sufficient design may be the use of speech recognition and minor contextual clues from the dentist's speech or activities to confirm where the information is placed in the record. However, having a human interpret another human as opposed to a computer interpreting a human is a complex issue that would require a separate inquiry. Humans are much better at repairing conversations and have a much better understanding of context than a computer.

In considering the activities at the dental school, I found that in comparison to professionals, students were more likely to be engaged by role-playing and design games. In part, this is due to the students having more time, but in addition it is likely that the learning environment assisted in contributing to the fostering of an exploratory nature. A further consideration for interpreting the data was that students have a greater deal of assistance, both from nurses and lecturers in completing their procedures. This assistance is seen to a lesser degree in professional practice, and by observing how students adapt technology to compensate when this assistance is removed identified design intervention points within procedures.

4.4.3 Perspectives of a dental school

The dental school was a useful environment as it gave me the rudimentary knowledge of dentistry required for complex discussions centred on more finished prototypes. By studying dentists who were in a learning environment, I myself was able to learn more about dentistry as a profession firsthand from both the dentists and their teachers.

The activities also provided an understanding of *how* dentists learn their craft which provided a unique perspective on what aspects of their work practice are most important and where hidden meaning may lie. These aspects include infection control, patient communication, record keeping, focus of attention and managing the equipment required. Understanding dentistry from a student's perspective also contributed to a greater understanding for how professional dentists approach their work practice. Some notes taken during studies with the dental students highlight some of the issues also seen in professional dentistry.

> *9:10am New patient. "So what brings you here today?" Patient describes problem and student checks against record to confirm tooth being discussed. Trying to visualise problem? Checks medical record for long term problems. Closely examines x-ray before beginning any work. Puts mask on and adds some details to the patient record.*
>
> *9:15am Student initially grabs light directly rather than the controls covered by a clean wrapper. Corrects himself and uses handle instead.*
>
> *9:20am Patient/dentist interaction seems very similar to that seen with Scott and James. Patient's head is in dentist's lap – intimate access. Very focussed work, requires patient's trust. Long periods of still work – patient must remain motionless for long periods.*
>
> *9:25am Student moves chair away from patient, conspicuously holds hands high in the air. Tool selection is important but still being learned – "touch, touch, touch, grab".*
>
> *9:45am Lecturer comes to assist. Patient controls the suction and performs assistance work. Patient looks uncomfortable and flinches a lot.*
>
> *9:53am Student uses clean tweezers to interact with instruments and workspace. Spare hand is kept behind back.*

10:00am Patient records updated. Great deal of time spent recalling procedure and recording all notes. Team of assistants clean patient area.

This session is representative of many of the procedures observed at the dental school. Specifically, the main concerns of a dental surgery are all represented in this brief glimpse into a student procedure. This includes the necessary arranging of instruments, infection control, patient interaction, record keeping and the need for a keen focus on the task at hand. Instruments were carefully chosen and arranged according to the procedure. The tools most used were laid out closer to the dentist, and like the clean and dirty areas in James' surgery, some areas of the students' workspace was clean (for example, drawers containing materials required) while others were dirty (such as the benchtops, where discarded material was placed). A separate area for record keeping was maintained, and again, both a clean and a dirty space used. Rough notes would be recorded to be later transcribed carefully by the dentist so as not to contaminate their patient records.

Observing a student dentist provided a unique insight into dentistry as taught rather than dentistry as evolved in practice. Each of these considerations had an impact on the design process, and ethnographic sessions such as this allowed a close view of how they affect the dentist's work at hand.

The dental school was also useful for my research due to the level of access available. It was possible to visit every week, sometimes several times, depending on design needs. This allowed greater depth of the activities compared to the lengthy gaps between activities with professional dentists. The amount of time we were able to spend with the students was also generous in comparison and this allowed for extended discussions and extended activities such as the games.

Games were not as well received by professional dentists. Attempts to engage Scott with design games were of limited success. In addition, when discussing their use with John, the CEO for DentalSoft, he recommended against their employing them. As such games were kept as an optional part of the design studies with the New Zealand dentists.

When trying to engage with the first dentist, Peter, he remained unenthused during role-playing (which we felt was a simple precursor for design games), and so we discontinued their use. The reason behind the lack of success of design games with professional dentists is not explored by this thesis, but is most likely due to the highly technical and expensive nature of their work and the dentists' perceived usefulness of the activity. However, design games were still useful for allowing alternate windows into the design process with students.

As part of the design activities with the dental school, I was able to explore the use of electronic resources such as wikis and email to facilitate knowledge sharing. Email was useful for all participants given its familiarity and asynchronous means of interaction. An example of its use was for clarifying observations and understandings:

> -----Original Message-----
> From: Alison
> Sent: Thursday, 15 January 2004 12:32 PM
> To: tch@itee.uq.edu.au
> Subject: Re: Question about procedures in the clinic
>
>
> Tim, depends whether you are talking about dental assistants in Clinic 2 or
> in general practice. In clinic 2 dental assistants are mainly involved in
> mixing and passing over the filling materials and cleaning the chairs. They
> may also assist in charting the teeth at the first appointment, putting on
> rubber dam (the sheet of rubber the students use) and also in assisting
> the student during cavity preparation by using suction to remove saliva.
> In general practice the are usually at the chairside all the time (called
> 4 handed dentistry). Hope that helps Alison

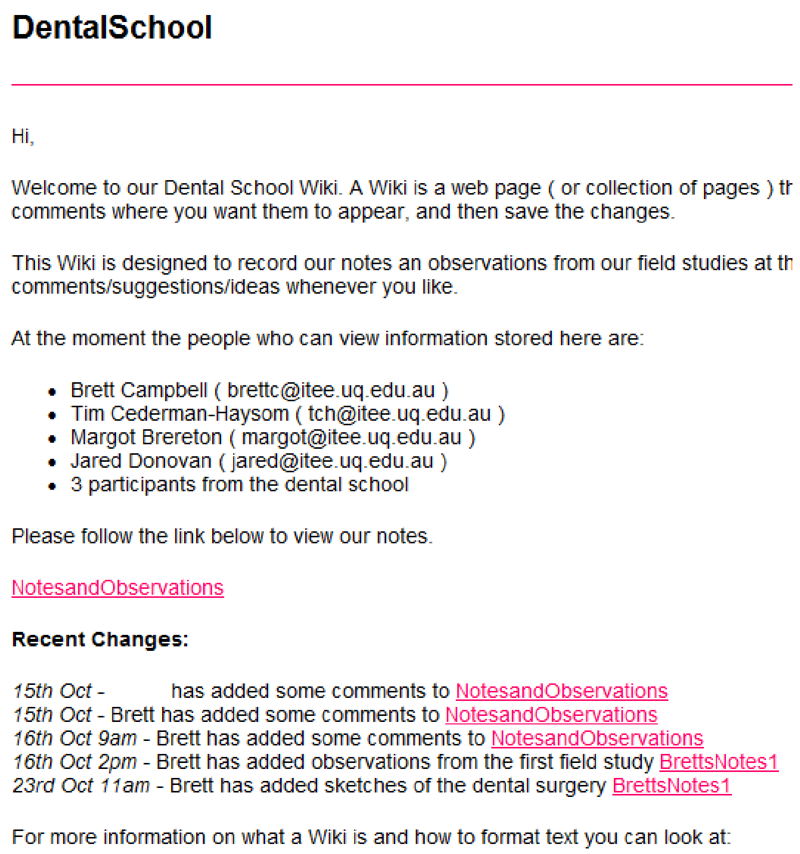
That's extremely helpful thanks Alison. I was asking in particular about clinic
2 as I am trying to recreate a possible scenario for use in our design event.
Am I right in assuming that for charting the teeth, they are filling out the
patient record for the dental student as they examine the patient?

Thanks again.

Cheers,
Tim

Email afforded an expedient means of validating understandings, and removed the need to make assumptions of the practitioner's behaviour.

A dental school wiki allowed me to show the participants the results of activities (an example of which is shown in Figure 18 with the participant's name redacted), while they in turn were able to use it to explain procedures or correct misunderstandings. While trying to engage professional dentists to participate in this way, their lack of free time seemed to reduce the amount they contributed or reflected upon the information presented in the wiki. However, the use of these techniques was shown to be useful for student practitioners, most probably due to a combination of familiarity with the technology, being in a learning environment, and the time available to them.



DentalSchool

Hi,

Welcome to our Dental School Wiki. A Wiki is a web page (or collection of pages) tr
comments where you want them to appear, and then save the changes.

This Wiki is designed to record our notes an observations from our field studies at th
comments/suggestions/ideas whenever you like.

At the moment the people who can view information stored here are:

- Brett Campbell (brettc@itee.uq.edu.au)
- Tim Cederman-Haysom (tch@itee.uq.edu.au)
- Margot Brereton (margot@itee.uq.edu.au)
- Jared Donovan (jared@itee.uq.edu.au)
- 3 participants from the dental school

Please follow the link below to view our notes.

NotesandObservations

Recent Changes:

15th Oct - has added some comments to NotesandObservations
15th Oct - Brett has added some comments to NotesandObservations
16th Oct 9am - Brett has added some comments to NotesandObservations
16th Oct 2pm - Brett has added observations from the first field study BrettsNotes1
23rd Oct 11am - Brett has added sketches of the dental surgery BrettsNotes1

For more information on what a Wiki is and how to format text you can look at:

Figure 18: Dental school wiki

The wiki facilitated conversations around the outcomes of the studies, and allowed us to be transparent with our motivations and understandings with the participants. An example of this is taken from the wiki:

> So far we have conducted three field studies. Our aim was to familiarise ourselves with dental practice, particularly with information handling apsects of the work (how the patient record is updated). The understanding gained from the field studies will inform the design of technology to aid in updating the patient record.
>
> At the moment our notes are organised by date.

- 5th August - FieldStudy1
- 12th August - Field Study 2
- 26th August - Field Study 3

Comments

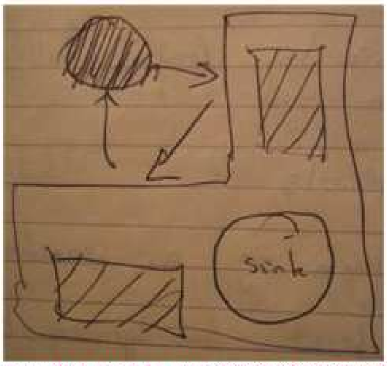
Field Study 1 You have a good grasp of what goes on congratulations. You need to clarify your terminology of student , dentist, supervisor as they are a bit confusing at times. Disoposables such as saliva ejectors etc are discarded. Sickle Probe. Students shouldn't need to change gloves that often if they are organised. Alison

Thanks for your input Alison. As we put up new notes we'll use:
Dentist A = workspace #1
Dentist B = workspace #2
Demonstrator
Assistant
in order to avoid any confusion and we'll go back and adjust field study 1 accordingly. **Brett**

The wiki provided a means of both providing a long-term and shared record of understandings, but importantly it also allowed a historical view of how the negotiated understandings were built up over time. The flexibility of the wiki system also allowed the sharing of notes and drawings, as seen in Figure 19.

Foci of Attention:

The work observed was very focussed. Several occasions were observed where finding the right instrument or necessary piece of equipment disrupted the work. The proximity of the patient to the dentist is extremely close and is well within the personal space of both the patient and the dentist.



www.itee.uq.edu.au/~pig/dentist/attention1.jpg

There are very long periods of still work. Fine focus and fine motor control are required for a dentist to perform a procedure well. However, at the same time, the patient must also remain very still with their mouth open for extremely long periods - upto 45 minutes. One of the attention breaks noticed was the need for obtaining instruments. The dentist (both students and the instructor) would "touch, touch, touch, grab" to find the correct instrument. The instruments look very similar and there are a lot of them. Many procedures have a limited time period due to setting amalgam and the like which causes the dentist to be quick with picking up and putting down tools.

Figure 19: Example of notes from wiki

Such a system created greater visibility in the design process, specifically, allowing the practitioner to see what is important to the designer and how they interpreted the data. Further, the wiki facilitated feedback on this and for corrections in understandings, as seen in the previous extract.

4.4.4 Innovation versus Expectation

When considering the outcomes of the activities that took place with practitioners at the dental school, the reception to the dental pen (as explored in section 4.4.2) compared to the 'smart' bracket table, the motivations of the participants need to be carefully considered. The different reaction (of Alison's enthusiasm for the pen compared to relative indifference to an enhanced bracket table) showed that the bracket table may not be as compelling or able to be immediately appropriated to use, or perhaps that participants in a participatory design process are more likely to respond favourably to something they are more used to. While a tenet of usability is to provide interfaces that allow for expectations of how the interaction takes place, innovation may require a break in expected methods of interaction. This is an example of the type of concession needed in participatory design (as discussed in section 2.3.3) in order to continue to innovate. It became clear from the design activities at the dental school that it is necessary for the designer to incorporate both their design expertise and the participant's perspective of what is important to their work practice in order to design a new system that is both usable and useful for new means of interaction and appropriation.

4.5 John

4.5.1 A dental software company

My initial contact with John was when I contacted his company to ask for a trial copy of their software. Dentistry software is quite expensive, running to the thousands of dollars per copy. I had contact with another company who also provided popular dental software within Australia, which initially seemed to be quite useful but they lacked interest in setting up long-term relations. After explaining my research to John, he provided me with a copy of DentalSoft's dental software called Chartware and we set up a meeting. John's company was based in New Zealand which added some difficulties in continued contact; however we were able to maintain an effective relationship through electronic methods such as email and by utilising local employees and travelling as necessary. The first contact for the design process was established when my thesis advisor and some research colleagues met with John during a business visit to Australia. Local relationships were also was established with DentalSoft's Brisbane-based software representative, Marissa.

John was interested in adapting Chartware to support alternative interaction methods, such as gesture, as a way of improving its marketability to dentists. He also had an interest in new modalities and had experimented with speech recognition in his software in the past. However, it should be noted that apart from the provision of dental software for prototyping purpose, there was no remuneration for either party's involvement, and John did not attempt to influence or direct the studies for business purposes.

4.5.2 Collaborative design

The initial meeting was used to familiarise each other with our work and our motivations. We explained our method of design, interests in interaction and work to date. Likewise John described to us how his software was developed, where they were interested in improving it and the type of support he could offer. Of particular interest was when John described how they tried to make their software usable by managing context. John stated that a primary consideration already identified was the need to appropriately manage the workflow and information organisation (something any good information architect should know). However what was interesting was the degree of importance this held to dental practice. As such, the actual interaction with the software had not been a primary concern during development by DentalSoft, but rather emphasis was placed on workflow and features requested by dentists using the software.

This contact was followed up with design discussions with Marissa. Marissa was primarily a support contact for dentists in the area and assisted in both practitioner training and localisation for practices. The discussions with Marissa helped further our knowledge of what was required in accommodating new information systems in dental surgeries. A great deal of training and customisation was required which we were previously unaware of. However it should be noted that this customisation and training is a common approach for enterprise software, yet the limitations of software for work practice persist, so should not be seen as a replacement of the participatory design process.

After the first design discussions with John and Marissa, John's involvement with the research became more of a support-role for Chartware. I was developing a prototype in conjunction with dentists in Brisbane and kept in contact to let John know of progress and for help with any difficulties I was encountering. These difficulties included limitations of the software (such as keyboard shortcuts or workflow within the application) or how completing my understanding of how dentists integrated the software to their work practice. John provided me with updates to the software and provided insights into its use in dental practice. However this involvement changed once more after the prototyped matured to a level of medium-fidelity and became usable during actual procedures in a dental surgery.

We had discussions on the available functionality of the prototypes that myself and another researcher were working on (which were speech and gesture based). Based on these discussions John expressed interest in setting up contact for us with a variety of dentists that he knew used his software and would be both willing and interested to donate time to the project to help improve and validate the prototypes. His personal interest stemmed from an attempt by the UK branch of his company to develop speech recognition that was cancelled during the testing phase due to a poor reception from dentists. He arranged for three dentists, Peter, David and Jason, who all had availabilities at close to the same time to accommodate us for design activities. This allowed access to participants with a broad range of capabilities and approaches to dentistry, with each practitioner having different work practices. The outcomes of these sessions are disseminated in the discussion chapter of this thesis; however a brief description of what transpired is as follows.

We met with Peter first. Peter ran a practice by himself and although he used a computer for his record keeping, he did not show interest in alternative methods of interaction. During the design activities with Peter, he dismissed speech recognition as being a potential method of interaction based on his past experience. However he showed some interest in gestural interaction, particularly simple pointing for interaction with information. With Peter we demonstrated medium-fidelity prototypes (such as the digital pen and the bracket table) and had him perform a procedure on a fellow researcher to explore the prototypes. After completing these activities, we then reflected with Peter on his interaction with the prototype and future possibilities for new interaction modalities. We had a conversation with him about integrating new devices to his surgery:

Researcher #2: *Is there anything like an electronic mirror?*

Peter: *Well, there's the intra-oral camera.*

Researcher #2: *That's not really a mirror is it...*

Peter: *Yes, I use it like mirror.*

John: *Would you ever use it in your left hand, like a mirror?*

Peter: *No. You could, but I wouldn't.*

John: *We have a tab called video, so you can do freeze frame images and link them with the patient. You can use a foot switch also.*

Researcher #3: *Do many people use that?*

John: *30 or 40 percent*

Peter: *The main benefit from the dentist point of view... it's patient education and also having things at 5 times magnification you can see things that you wouldn't usually see. Plus we use it for before and after images in cosmetic dentistry.*

This conversation highlights several outcomes of the study. The first was the benefit of having a technical consultant on hand. By having John with us, he could act as a resource for technical explorations and understandings. He could tell us about existing technologies, and also tell us how well-received it was (through an admittedly rough quantitative figure). The second was the consistent new understanding gained of work practice for dentists. As external researchers, the use of a mirror and the use of an intra-oral camera seemed completely unrelated (as shown by Researcher #2's reaction). Design discussions with dentists exposed these biases and corrected them. Finally, this was the first time the importance of patient education was discussed by the dentist, a previously unconsidered requirement of the design.

Next we met with David. David was an endodontist[8] who used a microscope the majority of the time to assist his work. He made extensive use of new technology, such as tablet PCs and pen based interfaces for his record system, but had little computer interaction during a procedure, instead relying on his memory for recording charting information. With David we were unable to go through a scenario with him due to time constraints, so we instead spent our time demonstrating and discussing prototypes as well as being shown his equipment and how he used it. Of particular interest was the technicality of his work, requiring fine motor control for measurements, and bulky equipment. While demonstrating the prototypes, there were difficulties in having the prototype function as expected, with the Bluetooth microphone malfunctioning and preventing the demonstration from proceeding. David made clear to us the importance of robust equipment in the surgery:

> *David: See, in a surgery environment, you don't want that sort of thing to happen. You want things to…*
>
> *John: … work. Yeah, absolutely.*
>
> *David: Yeah, work every time. They have to be rock solid, and the first time it doesn't work in a dental surgery, most dentists will give it one more crack and next time it doesn't work, it's going to go in the top drawer and it's never going to get used again. So…*
>
> *Researcher: Yeah, I don't think you'd ever use a Bluetooth headset, you'd use a dedicated*
>
> *[simultaneously]*
> *Researcher: wireless*

[8] Endodontists are concerned with tooth pulp or dentine complex. The most common procedure performed by them is a root-canal.

David: wired

Researcher: microphone.

David: Well, or one that won't give you problems.

In addition to hardware problems, David shed light on the importance of software robustness. Specifically, he indicated that robustness wasn't an absolute quality – rather that its function should be predictable.

David: Yeah I like the idea of speech recognition, it's just how reliable it is. I used Dragon for a while.

John: Mm-hmm. Yep.

David: I trained it pretty well and had it to within about 90% when I was writing assignments, but then sometimes it was making too many…

John: This is the continuous stuff?

David: Yeah. Sometimes it'd make too many errors and you'd just get annoyed with it and go back to typing. I'm not a very fast typer so I could get most of it in there and then go back and fix the problems. It's pretty straightforward – it's how you get it to work really… consistently. Consistency is the thing. If you can get it to be 95% consistent and only have to make a couple of changes then that'd be great. If it's not consistent and it just keeps breaking down it'll just end up in the top drawer.

Finally we met with Jason, a general dentist with a large practice. In addition to owning and running two practices, he also maintained the new equipment and IT setup, and so knew a great deal about cutting edge equipment in dentistry as well as being very open-minded as to new interaction possibilities. Jason first showed us around his entire practice, and then we showed him the prototypes we brought with us. We ran through a scenario of a periodontal exam with a gestural prototype, which we videotaped. Finally, we showed Jason the videotape and used it as a discussion point on the gestures he was using and future interaction possibilities. We brainstormed with him how gesture could support interaction with the patient chart and incorporated ideas into our session with Jason:

John: If you were trying to enter, like, going back to this gesturing. Like, if you're probing, you could probably do things with the probe to

> *navigate or whatever as well, couldn't you? It'd be quite easy, same as when we were doing charting, and you could do sort of...*
>
> *Jason: Yeah, that's right. Yeah it's quite easy, going around the spreadsheet, probing and writing a number in. It's actually quite easy then because that way you're specifically working on smooth surfaces, so you'll be working on stuff to write on.*
>
> *Researcher: What if you tap the tooth you're working on and then said a number – would that feel less natural than writing it?*
>
> *Jason: Tap the tooth and what?*
>
> *John: If you were saying the number. If you said the number instead of writing it.*
>
> *Jason: Oh that'd be alright.*

Grounding such discussions in Jason's work context facilitated "quick and dirty" evaluations of new ideas and access to immediate feedback in order to validate or dismiss such explorations.

We had planned to conduct each field study in the same manner; Jason's study was the closest to the one envisaged. However, constraints such as time, interest and surgery space meant that each time we had to adapt to make the best use of the situation. This is yet another aspect of participatory design that is important to manage and account for, however it is this flexibility that is sometimes very useful for adapting to the unforeseen, and allowing both collaborative design and collaborative design methods.

4.5.3 Perspective from an engineer and CEO

The outcomes of the field studies undertaken with John, Peter, David and Jason are examined in closer detail in the discussion chapter. It is worth discussing the involvement of John as a practitioner and a participant in this process to provide further insight into the outcome of these design studies. Through the contact with John, I was able to collaborate with a company that produced commercial dentistry software, and to ground my own prototypes to something that was utilised and required in the "real world". While non-commercial design activities will provide useful information, by basing the studies in existing work practice it was possible to derive more tangible and immediately useful information about dental work practice.

John was also able to give me an engineer's perspective of existing dental software and the design decisions behind it. Finally the access John enabled to professional dentists allowed me to evaluate what I had determined from a small subset of practitioners against a larger one. This contributed to the completion of a prototype and a point of reflection of the design process, and how the participants influenced it.

4.6 Fieldwork conclusions

This chapter has reflected upon the domain researched and reasons for examining the field of dentistry. From my own broad computer engineering background, with an interest in human-computer interaction and embedded computing, I was attracted to the field of ubiquitous computing. To this end, I compared multiple domains of interest for possible intervention points for design to help improve interaction using ubiquitous computing technology.

Through the use of techniques such as the Video Card Game (Buur and Soendergaard, 2000), I was able to compare large amounts of video footage obtained from these ethnographic studies of different domains. This provided a starting point by highlighting difficulties in traditional computer interaction methods. The domain of dentistry provided the most potential for deploying a ubiquitous computing system, given its difficult requirements of patient privacy, cleanliness and exact record taking.

This chapter discussed the participants who helped me explore this domain and test new methods of deploying innovative interactive systems to their everyday work practice. The aim of this close examination of the actors involved was to provide further insight and explanation to my research conclusions and to complete the 'story' of my research. Each participant had their own unique personality and background which guided the design process. I provided details of how the participants were approached and incorporated into the study, as well as their responses and interactions with both the researchers and technology involved. Below is a table summarising the highlights of the fieldwork:

Method	Design outcome
In-situ design (p. 103).	• Facilitated demystification of the work process to the designers, and the technology and design process to the practitioners.
Open prototypes (p. 103).	• Internal functionality and limits were made clear to the user (for example, using debugging windows or exposing sensor data), which allowed them to explore ways to adapt their work practice in response.
In-situ design (p.104, p. 114).	• Effects of design changes could be realised immediately, which was useful given large number of actors affected in a dental surgery. • Allowed designers to learn a practitioner's work practice which allowed for a more informed design (evidence of a true understanding of work practice from use of dental jargon).
Design conversations (p. 107, p. 134, p. 135).	• Determined from James that previous observed behaviour was not comprehensive (the mirror and probe were used far more often than thought). • Involving John, with his dental software engineering background, helped designers understand existing systems to support work practice. • Revealment of further design requirements (such as robustness of hardware and software from David).
Ethnographic studies (p. 109, p. 118, p. 126).	• Revealment of detailed, previously unconsidered aspects of work practice. • By observing practice across different dentists, similarities were identified, supporting the idea that findings were generalisable. • Understanding of how dentists learn their craft, giving insight into what parts of work practice are most important.
Scale model of work context (p. 109).	• Revealment of flow of data and activity in the work context.
Early-stage prototype demonstration (p. 111, p. 121).	• Fast evaluation of feasibility and application of prototype. • Revealment of further design requirements (such as sterilization of a digital pen). • How dentists responded to augmented equipment.

Manage expectations of design research (p. 116).	• Facilitates engagement from the practitioner appropriate to the level of prototype. • Conversation that sets expectations also helps engineer realise how far from "ideal case" the actual design will be. People update systems incrementally, leading to system messiness in practice.
Design games (pp. 122-126)	• Isolation of different modalities in work practice, which shows tacit knowledge which can be utilised in the prototype. • Highlighted differences between students and professionals, and the need for alternative approaches between different types of practitioners.

Table 2: Summary of fieldwork

This chapter examined dentistry as it is taught, and as it is performed in varying private practices. In doing so, a view of dentistry has been discussed from how dentistry as a profession is learnt, to its commercial considerations. In engaging professionals, the design became grounded in specific prototypes, contexts and social considerations, providing a more commercial view of design requirements. There are many different ways to approach the design problem, with most participatory design approaches focussing on a specific group of practitioners. The fieldwork presented in this chapter instead reveals a path of understanding from the basics and key concepts of a profession to everyday commercially-grounded considerations. As opposed to traditional participatory design, the methods employed for this research utilised a multi-layered and multi-threaded design investigation of dental practice, and explored the design space with starkly different participants who each provided their own unique insights into dental practice.

Unlike user-testing, the fieldwork for this thesis was always in-situ, providing a realistic depth of understanding of how the design will be received and appropriated. The design activities involved the following participants:

- A dental school involving students and lecturers.
- Small private practice incorporating just two dentists and their support staff
- Large private practice, including multiple dentists, nurses and administrative staff, with more equipment.
- A dental software company CEO.

- Several dentists with varying types of practices, all of which were known "power users" of a popular dental software suite.

The participatory design methods used for each varied according to their varying motivations and availabilities. Such methods included:

- Ethnographically inspired field studies and observation.
- Design games and roleplaying.
- In-situ prototyping and design (participatory bootstrapping).
- Contextual interviews.
- Scale models of the domain.
- Design discussions.
- Wikis and email for continued external discussion.

The prototyping of varying design encompassed several different alternatives for improved interaction. This included embedding computing in:

- The bracket table used by the dentists for placing their instruments.
- The pen and paper recording used for patient records.
- Common dental software used by a number of participants.

Ultimately, it was seen that the following aspects of the resulting design were of the greatest importance to the dentists:

- A robust system, both technically (long battery life, low failure rate) and in terms of usability (simple to use, not prone to errors in their application).
- A system that is respectful of the domain of dentistry, in supporting the context of use (a noisy, busy dental surgery), how the dentist works, and commercial considerations (the cost and availability of such a system).

This fieldwork in this chapter serves as a background to the further discussion of my research and the conclusions made through the design process. The next chapter discusses design events with a group of dentists in New Zealand in detail in order to explore design lessons for the process of participatory design for ubiquitous computing.

5 A Late-stage Participatory Design Case Study

5.1 Introduction

This chapter presents fieldwork from the more detailed design and implementation stage of the project as a case study. Using data from fieldwork that took place with three dentists in New Zealand, this chapter draws lessons for participatory design of ubiquitous computing systems through the development a detailed prototype, and is a case study of how the participatory design approach evolved during the process. It grounds the conclusion of the research as a whole with specific example from a series of design events held with professional dentists based in New Zealand.

In detailed design, the designer should address the finer points of work practice. Coupled with the notion of ubiquitous computing as a means of supporting innovative interaction comes the realisation that if any new form of interface or computational appliance is to fit 'invisibly' into a work practice, it must fit with the work and rely upon the skill of the practitioner to adapt and appropriate it into their existing material environment and set of practices. This often unacknowledged form of work in adapting and appropriating tools and methods is referred to as articulation work (Suchman, 2002). The designer then finds ways to work closely with the practitioner in order to understand their practice, and to find ways together with the practitioner to design. Suchman (2002) points out that design does not finish, but that practitioners continually design as they adapt and develop their work practice with new devices. The activities with the New Zealand dentists aimed to continue detailed design work to address these issues.

Design or systems development should be seen as an "entry into the networks of relations – including both contests and alliances – that make technical systems possible" (Suchman, 2002). This is currently not satisfied with the use of traditional design methodologies which see the designer and user as opposites, wherein designers design and users use, test, or are probed. This necessitates replacing the "designer/user opposition" (as identified by Suchman) with a different kind of designer/practitioner relationship which embraces more mutual learning and richer layers of engagement in the traditions of participatory design. Such a relationship was sought with a variety of practitioners and the outcomes are detailed in this chapter.

In my research activities with dentists I have sought to satisfy the difficult requirements for usable ubiquitous computing using participatory design methodologies. In doing so, I have drawn lessons from reflection on what happened, and what did and did not work (and why) in a project that spanned technical research interests, commercial objectives and placing demands upon the time of skilled professionals. This chapter details the studies that took place and reflects upon the outcomes.

5.2 Case study of detailed design and implementation

While there were several groups of dentists involved in the design process, the activities with the final group of practitioners, individual dentists based in New Zealand, provided a case study of how methods devised to support participatory design were received by a variety of stakeholders of the process. The activities were the culmination of the design and development of a prototype ubiquitous computing and multimodal system for interaction. The background of these previous studies and prototypes, and also how the studies with the New Zealand dentists came to be are discussed extensively in Chapter 4. This section describes the background and motivation of the study, the participants involved and the outcomes of the activities. The resulting prototype and its evaluation with Scott, another participant of the studies, are described.

This research differs in the approach to participatory design compared to that taken during the 1970s and 1980s (section 2.3.1). Traditional methods of participatory design focus on a specific group of practitioners and their collective views. The domain for design was usually constrained to a single workplace and participatory design was a means for workers to become more empowered in a design process that would directly affect them. Alternatively, I have pursued a multi-stage, multi-participant approach to participatory design.

5.2.1 Studying dentists in New Zealand

For this study, the most advanced of my low-fidelity prototypes developed at this stage of the research was a speech recognition engine coupled to a common dental application package for recording patient data.

The prototype used basic grammar-based recognition (provided by an implementation of the Microsoft Speech API) to provide input to the multipurpose dental software from DentalSoft that most of the dentists studied used. A more complete description of the final prototype, and the choice for its application, is in section 5.2.11.

While I had recognised (and adapted to) the technical problems encountered in speech recognition, I chose to explore it further as it was one of the best received prototypes and it showed the potential to be testable during a procedure. However, adding contextual triggers to the dental application required the assistance of the company who developed the software, and John, as the CEO (and former software engineer) became closely involved with the prototype development. The relationship with John led to access to a wide variety of dentists who used the software and were interested in testing new versions.

As part of John's new role within his company he was interested in exploring new design ideas for his software. By setting up access with three separate "technology-interested" dentists to help provide feedback on the prototypes it would also allow John to see what software features dentists would be interested in, while for me, one problem for employing participatory design was identifying practitioners willing to participate. Good (1992) spent five months finding interested practitioners within a company that had *requested* the design work.

While I was based in Australia, the dentists' practices were located throughout several New Zealand cities. I was able to organise a timetable whereby both John and the dentists were available for a period of two days, allowing myself and a colleague to organise design activities that involved them.

5.2.2 Planning for activities with the three dentists

My first impression from John was that the three dentists held quite different attitudes to new technology. The first dentist disliked using new technology (such as speech recognition) and did not believe it would be useful in a dental surgery. The second dentist had transitioned to a completely paperless office and had up-to-date, practical equipment. The third dentist was an early adopter who used new equipment both to improve his work practice and to appeal to patients as having a cutting-edge practice.

As an example of this contrast, while one dentist used tablet PCs for the patient to fill out their record, and a high degree of automation for charting, another dentist had the patient fill out their personal information with his secretary on a piece of paper, before transferring it to a digital form later on.

All that was really known of the practitioners before the activities was that they had an interest in new versions of the dental software. Our team wanted to make our limited time with them as productive as possible by getting feedback on designs generated from discussions and ethnographic studies with other dentists, while also finding out about their practice, particular ways of working and design ideas. Therefore, we decided to plan fairly general activities that introduced different ways of interacting with the dental software. We sent a list of the activities to John so he could pass it on to the dentists, and so we could gain any feedback from him regarding our proposed approach.

What was also difficult in this scenario was although we had managed to gain access to a number of dentists who were open to donating their time to our project, it concerned us that we did not have the time to establish working relationships with them. While I had plenty of prior experience in dental surgeries, and thus was able to participate in an informed way (as participatory design “power user” (Sperschneider and Bagger, 2003)), it was critical that the practitioner had a level of trust and openness in order to foster good communication and exchange of ideas.

5.2.3 Planned outcomes

As a result of the design sessions, I had planned to progress to a speech technology based interface that a dentist could use during a patient consultation. Specifically, the interface was to support periodontal examinations. The previously mentioned dentist, Scott, had been closely involved throughout almost the entire design and had given comprehensive constructive feedback on past occasions and so after a period for development and refinement, it was planned to test with him.

5.2.4 Activity considerations

The methods used were influenced by several factors. We used our experience in participatory design, particularly with dentists (Campbell et al, 2003; Cederman-Haysom and Brereton, 2004; Cederman-Haysom and Brereton, 2004b), to inform the choice of activities that would be effective. While we had previously found activities such as games and role-playing useful for ourselves as researchers, we decided that these were not appropriate intervention methods, since these shift the power in the relationship to the facilitator who decides the ground rules and frames the debate. The feedback and degree of participation previously received from professional dentists also did not favour these methods.

We also felt that it was important to ground our design activities and discussions in their work practice. Furthermore, we had to design the activities based on the fact that the dentists were not familiar with our work, and also probably unfamiliar with participatory design. The final consideration was the limited time that we could expect from our professional dentist volunteers. We had short windows of opportunity that represented lost revenue for the parties involved. The activities we planned were therefore kept relatively unambiguous and constrained. We first wanted to show prototypes we had been working on, and also have the dentist show us their surgery and equipment. We also planned to explore how gestures and speech are used by the dentists and to discuss how multimodal interaction might be used with their dental software for charting or a periodontal exam. Finally, we wanted to brainstorm different approaches to implementing gesture interfaces and to explore the distinctiveness of different gestures. Table 3 illustrates this planned timeline.

Time	Activities
1 hour	Introductions and technology demonstration - we show prototypes we have been working on and the dentist shows us their surgery and equipment. **Activities**: Introduction, demonstration of gesture device, demonstration of speech device, "Show us your surgery".
1 hour	Multimodal interaction - exploration of how gestures and speech are used by the dentists and a discussion on how multimodal interaction might be used with their dental software for charting or a periodontal exam. **Activities**: Design problem explained – "How could speech and gesture be used together for charting?", Situated Scenario – videotaping how the dentist uses speech and gesture during a periodontal exam
1 hour	Explore movements with technology - Brainstorming different approaches to implementing gesture interface and exploring the distinctiveness of different gestures. **Activities**: Video review of movements used, establish key movements they could be used for the design, act out future-use scenario.

Table 3: Timeline and descriptions of activities

We carefully considered the order in which we would run the activities and took the view that we would rely on improvisation in order to maintain a good discussion, rather than steadfastly following the original plan. Our main concern was to understand the practitioners' work and concerns and to give them a voice, while garnering realistic feedback on our prototypes.

While showing them prototypes first could have potentially biased their feedback, or moved their focus away from their work practice and concerns, we felt it was necessary to show what we had already done in order to explain why we were there. Our original inclination was to ask for a tour, and to have a general discussion, before explaining the design work to date. This was largely so as not to seem self-focussed and so as not to show naïve designs to someone whose work practice might have no call for such designs. However, by way of politeness it seemed we should explain ourselves and why we were there, and the best way to do this was through the artefacts of the design endeavours to date. Ultimately we decided to offer to demonstrate first, but also to offer the choice to the hosting practitioner.

Such were our musings in order to plan for the most revealing design conversation that we could have. As mentioned, in the first activity with Scott, when asked to explain how he used technology in his surgery, he talked about his Linux server and the hardware configuration of the individual machines. This was seemingly because he was talking with someone who was interested in the 'nuts and bolts' of the technology. Conversations during design activities sometimes took us deep into interests and into issues of configuration as well as into immediate use. This indicated that if technical questions are asked of a participant, you are likely to get technical answers. This indicated the importance of framing questions appropriately as to the desired outcomes of the study (i.e., providing accountability to the practitioner of what the designer's motivations are).

5.2.5 Activity planning

The activities were based on the broad aims of our research (to understand how to develop speech and gesture prototypes that fit with work practice), and on our design environment (an unknown dental surgery, with the only certainty being that they used the dental software John sold). We took laptops with the dental software installed, and the necessary equipment with us to demonstrate prototypes, knowing that the dentists would be familiar with the software interface.

We were concerned to manage expectations. We did not want the practitioners to think they were testing complete systems, or to assume we were developing from scratch. This was addressed by demonstrating our technology and setting the tone for the follow up activities from the outset. This is not to say we did not have open ended discussions regarding technology, or explicitly stated that they were to only keep the demonstrated prototypes in mind. Our aim was simply to frame and contextualise the interaction. If you ask about technology (that is, what the designer shows interest in), you will get answers about technology. These answers may not be particularly insightful for the design, as the practitioner is concerned with their work practice rather than technology itself.

Finally, there was the issue of practitioner availability. Although our ideal plan was for three hours (as mapped out in Table 3), John advised that we would only be able to realistically get about two hours with each dentist. To adjust for this we considerably shortened our time spent demonstrating the prototypes and viewing their surgeries, instead choosing to concentrate on exploring the design problem. Our new timetable we used is shown in Table 4.

Time	Activities
30 minutes	Demonstrations and "show us your surgery"
30 minutes	Design problem explained and situated scenario acted out.
30 minutes	Video analysis of the situated scenario – drawing out movements and actions useful for the interface
30 minutes	Explore movements with technology

Table 4: Revised timeline for activities

5.2.6 The reality of situated design

Given that participatory design is about building trust and relationships leading to fruitful collaboration, there can be no set of procedures that will be followed to the letter. However, it is important to have a plan as a guiding point and to help keep the activities focussed. Knowing that the situated action would be different to what we had planned, we tried to keep in mind our three main objectives:

1. To improve our understanding of the dentists' instruments and technologies (particularly those new and unknown), in addition to sufficiently informing the dentists of our work to date, especially existing prototypes (and the underlying technical understanding).

2. To examine the methods of interaction used by the dentists, and explore ways of incorporating these or intervening to improve human-computer interaction.
3. To develop concrete design ideas for our prototype to move it from low-fidelity prototype to a usable and testable device.

It was important to us that the dentists were engaged and able to work with us the best way they could. To do this we had to adapt our plan to each dentist during the activities. In doing so our three design sessions were quite different from each other due to individual improvisation. The next sections will recap and expand upon previous discussions regarding the activities with the dentists in New Zealand.

5.2.7 Activities with Peter

The first dentist, Peter, ran his own practice and as previously discussed did not have a strong interest in new interaction methods for his surgery. We began by demonstrating medium-fidelity prototypes, which he was not very enthusiastic about. At this point John interrupted and attempted to explain our work in a way that was compelling to Peter. In particular John highlighted how our work would fit in with his existing methods while improving efficiency – grounding the research to specific concerns he had and how it would benefit him. After piquing his interest in this way, Peter began brainstorming new methods for interaction that suited his work practice.

> *John: Let's go back to the charting again. If you were using that wooden thing, could you detect a tap with the instrument?*
>
> *Peter: Yes, you could do that.*
>
> *John: If you had an accelerometer and you recorded an entire charting session, could you figure out which tooth was used?*
>
> *[extended discussion on this point]*
>
> *Researcher #2: What about if you were holding the probe and you were doing that thing you were talking about?*
>
> *[Peter picks up a wooden probe being used as a low-fidelity prototype and points to the screen.]*

Peter: Well the other thing is, with the screen in that position it's ideal. But if the screen was behind you might have some problems

John: You could just use it like a 3D mouse. What sort of gestures would… [observes Peter turning the probe over in his hand and examining the ends] How important is it being double-ended?

Peter: Very important. That's the other problem: you're going to be swapping the instrument from end to end.

John: Could you use the mirror... it means that you're going to be controlling it with the left hand.

Peter: I'm a little bit ambidextrous.

Researcher #2: Should we try it with this as if it was the mirror then.

John: Pretend that's the mirror, see what that's like...

Peter: You're limited in the movements you can do because you've got a finger rest, see.

John: What if you banged it on the tooth?

Peter: Well, whatever happens, there isn't going to be much movement.

Researcher #2: If you're rolling it perhaps? [demonstrates movement]

Peter: Tapping?

John: Like that Maori game with sticks.

Peter: Yeah, that would be something. Next tooth. Because, doing this I don't see that there would be enough movement.

This spontaneous brainstorming was interesting, but used up half our time with him. We decided at this point to shorten the remaining activities. We asked him to run through the basic steps of a periodontal procedure on one of the researchers while attempting to integrate the gesture prototype. It was obvious to us by this stage that Peter was most interested in concrete examples that could relate to him, so we continued to brainstorm with him in the vein of 'realistic' product ideas (i.e., ones he felt he could purchase and begin using immediately), which helped us understand what was important to him.

With Peter we were able to learn what is important to dentists who want to complete procedures using the skills they already know without disrupting their work practice. What was important was that the changes offered obvious benefit without too much disruption (such as learning difficulties, new demands on the patient or price). In addition to the insight of the requirements of the dentist, we learned from a first person perspective of the need to consider the patient’s requirements. One idea that emerged from the above discussion was being able to tap a tooth to select it for charting information about it. We ran through a quick scenario in the chair using Wizard of Oz techniques, and found that no matter how gentle the tapping was, it caused undue discomfort and annoyance to the patient.

5.2.8 Activities with David

David was an endodontist who relied on a lot of dental technology to support his practice. Given his exposure to a variety of technical systems, he also made use of a lot of new technology for administration work as well, using devices such as tablet PCs and pen based interfaces. During an actual procedure, he found that he was unable to find a computer interface that suited his requirements for data entry and relied on manual methods for patient charting.

We found that once we met with David, he was running late and so we were unable to run through a scenario with him. Instead, we spent our time demonstrating and discussing prototypes as well as being shown his equipment and how he used it. David impressed upon us the need for robust technology in addition to other requirements (see transcript in 4.5.2).

David also presented interesting examples of articulation work for integrating his equipment to his work practice. His primary concerns were of infection control and spatial requirements. For example, when interacting with a touch screen, he would use a cotton bud which he could throw away afterwards. Large equipment required appropriate positioning in relation to other supporting technologies (such as the computer interface to the patient record, and the dental chair itself) to accommodate how he worked during procedures.

Discussions with David showed the benefit of including an engineer for propelling outcomes. The prototype demonstration included explorations of technical limitations of speech and gesture recognition and their supporting hardware and the technical conversation meant a quick “ramp up” to engaged design discussions. David also related the need for the technology to be accountability to his patients. The technology needed to be explained in its use to the patient to facilitate its proper use. In this practice, patients would enter their personal details directly into the computer (rather than writing it on a piece of paper). To help them do this, he would help them understand the limitations of the pen interface by explaining “treat it like a Magna Doodle” (a toy that lets children draw on a small screen with a magnetic pen). There was a noticeable delay for writing and by explaining this it allowed patients to use the pen without making mistakes when they first used it.

5.2.9 Activities with Jason

Jason was not a specialist dentist and ran a large general practice which employed several other dentists. Jason had a personal interest in IT, and therefore vetted new purchases and was the primary source for purchasing and adopting new infrastructure for the surgery. There were many examples within the surgery of old equipment that he had tried to appropriate for the surgery, but for various reasons were no longer in use. From speaking with Jason, he informed us that a lot of equipment had been a “great demo” but not as useful in practice.

Jason had more time than planned and so we were able to complete our timeline of activities in full with him. With the amount of time available, it was possible to elicit the benefits and shortcomings of existing prototypes, possible future prototypes and extensive details about his work practice. Below is a transcript that is representative of the session with Jason:

John: And do you do… the other thing we talked about, this goes along the palatal surface duh duh duh, would you ever do, like palatal and buccal? Around the tooth effectively?

Jason: I would like to!

John: You'd like to, yeah, that's what we thought.

Jason: Yeah but it doesn't allow that, because it only goes that way.

John: Because with the voice you could, because with the voice navigation we made it so you can, you know, put the measurements 3, 4, 5, and then you say "buccal" and it just switches over here.

Jason: Yeah, that'd be great.

In this way, Jason validated design potential and provided new avenues for realistic development and prototyping that informed both my final prototype and other researchers' (also involved with the studies) prototypes.

5.2.10 Results of the activities

These sessions enabled me to modify and extend my speech based prototype for interaction with a patient record while undertaking a periodontal procedure in a dental surgery. The use of participatory bootstrapping, of revealing the technology in intelligible ways and designing in-situ, facilitated rapid design iterations and new understandings of work practice. The activities also provided new insights into design techniques. These lessons for design are discussed in chapter 6.

The activities confirmed what appeared to be generalisable problems within the domain, which together with knowledge of the domain, provided me with all the information required to complete a prototype that could be trialled in a procedure. By later observing Scott using the prototype and discussing its benefits and shortfalls, I was able to identify where the design process was successful and where it was problematic, allowing me to reflect upon the benefits and shortfalls of methods used, further informing my lessons for design.

5.2.11 Prototype development

The finalised prototype consisted of a speech engine that used grammar-based speech recognition[9], which then provided navigation and data input for a periodontal charting application. The application used as a basis for the prototype was the existing periodontal recording section of the Chartware software, shown in Figure 20.

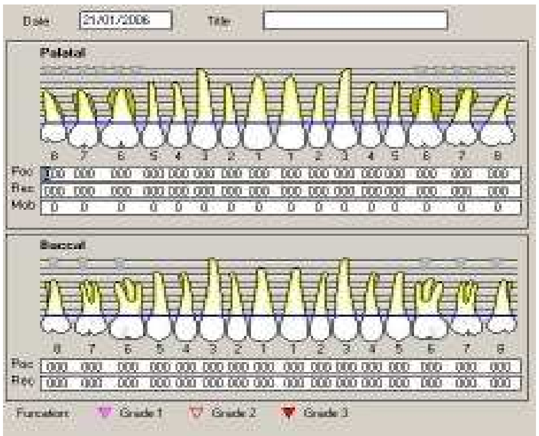


Figure 20: The periodontal charting interface

The speech engine had been specifically developed for use in noisy environments. To achieve this, the Microsoft Speech Software Development Kit 5.1 was utilised, which provided built in functionality for cancelling noisy backgrounds from the speech. As part of the software development kit, speech profiles could be trained and exported for modular use, negating the need for individual training across machines. Such a system was also chosen since Windows XP and Windows Vista allowed for speech recognition out-of-the-box, and could utilise these profiles specifically.

Time was spent training and refining a profile that accommodated a noisy environment and Australian and New Zealand accents. To do this, it was required to read passages of training text using the accent required and with the expected background noise. Prior to final testing, the speech recognition was tested by Scott and other dentists in his surgery several times as problems in the recognition were identified. Development stopped once an acceptable level of recognition was reached. This was decided by subjective feedback from the dentists as to when they

[9] Constrained grammar speech recognition can be configured for a general group of speakers rather than requiring individual training. Usually it is for a particular region, but with a small dictionary space, is generally successful in providing recognition without training.

no longer felt frustrated using the interface (which coincided with a recognition rate of approximately 90%, as shown in the appendix by notation of speech errors). The source code for the finalised prototype is included in the appendices (Section E).

The speech recognition used for the prototype was deliberately and specifically contextualised to be used in a dental surgery by an Australian (for accent purposes) dentist. The training for this was done using the Microsoft Speech SDK training tool. The vocabulary used, and the timing and context of the speech were well known for the environment, as was the type of data to be interpreted (such as the noise from the surgery and the quality of the recording). By customising the speech recognition to the context of use, a much better fit for the ubiquitous computing was obtained. This is a tension in creating a ubiquitous computing system, of usability in contrast with adaptability.

Several methods for speech capture were investigated and trialled throughout the research, including ambient microphones (Figure 21), throat microphones (Figure 22) and both wired and wireless headsets.

Figure 21: Ambient microphone

Figure 22: Throat microphone (Planet Airsoft, 2006)

It was important to balance the practical needs of the practitioner (accommodating cleanliness, a device that is simple to use, robust and with a long battery life) with that of the technology (clear audio would help recognition, the computer needed a microphone that worked with its sound card). The final choice was to use an off-the-shelf Bluetooth wireless microphone (as seen in Figure 23). This provided several benefits, such as a long battery life (8 hours or more), good compatibility (based on the Bluetooth standard, which comes built-in to many laptops) and it was unobtrusive. The headset could be attached to the dentist's glasses, or kept clipped to their chest as the ear-hook could be removed. The headset could also be used whether the dentist was or wasn't wearing a mask, as it did not significantly affect speech recognition rates even though it muffled the audio.

Figure 23: Sony Ericsson Bluetooth headset

The prototype software kept track of how the dentist was working (for example, if they were looking at x-rays, or the patient's chart), and the location in the mouth for data entry when using the periodontal application. It accepted both direct tooth selection (by using dental references such as 'occlusal', which means the biting surface of teeth towards the back of the mouth, or 'distal', which refers to teeth towards the back of the mouth in general, and tooth numbers), or if a tooth had finished having data entered it would automatically move to the next most convenient data entry point that the dentist would be likely to use. The speech interface allowed the dentist to customise the order that data was recorded around the tooth. The default was to go from tooth 1 to 32, as learnt by the dentists, but if a section of teeth needed to be skipped, the dentist could announce which tooth to jump to. Previously, the next entry point would need to be selected manually by the dentist after each entry was made (Figure 20), and the automatic selection in the existing software did not follow traditional means of charting around the mouth. All aspects of periodontal charting were supported using the speech interface, including furcation grading[10] and pocket depth measurements, as well as incidental requirements such as bringing up x-rays to assist diagnosis and evaluating prognosis.

Efforts were made towards developing a gesture prototype for navigation control, but the hardware was not sufficiently mature for use during a complete procedure. While gesture recognition technology had been trialled during the studies at the dental school, going as far as a medium-fidelity prototype and a list of gestures identified for navigation. What was important for testing the design was that it needed to be usable and robust enough in actual work practice to exercise all possibilities of how it would affect the practitioner and their domain.

One of the most important aspects of the design was the need for appropriate error correction and avoidance mechanisms. This was closely studied in order to provide the most suitable system for practitioners. There were several mechanisms to best account for errors. The first was by providing the practitioner with multiple selections for word choice. For example, they could say either 'select' or 'set' to specify a value, or 'back' or 'move left' to control the cursor. To further assist the modification

[10] Furcation grading is the level of a gap created by the branches of the tooth roots.

and extension of speech recognition, a debug mode was included which would run in the background during testing (Figure 13).

The other consideration for error correction was how the practitioner could know input (erroneous or otherwise) had been accepted. To support this detection, tones generated by the PC's internal speaker were used to signify which value had been entered into the system for the periodontal charting application. A specific low tone signified recognition of navigation within the application, while a flat, low tone signified an error. Tones along an increasing scale represented each of the possible values that could be entered into the application when using general data recognition. It was interesting to see how quickly the practitioner learned to differentiate tones and notice when they had made a mistake from this feedback. During initial studies on how to recognise errors, it was requested that the application read out the exact value entered via text-to-speech. A quick mock-up was created and the practitioner realised that the repetition was distracting. Using my knowledge as a designer and engineer I created a prototype with the tones, which I had personally trialled and found useful. When testing this with an actual practitioner it was well-received and remained a part of the prototype.

The software was reprogrammed to be adaptable to any type of modality input. It relied on action commands to control the interface, rather than hard-coded interaction with the particular modality. The emphasis remained on adapting the technology available to ourselves and the dentist into a usable system that supported new means of interaction, fulfilling the philosophical prerequisites of ubiquitous computing. The source code for the prototype is included in Section E of the appendix.

5.2.12 Final prototype testing with Scott

The prototype developed from the activities in New Zealand was tested by Scott during an actual periodontal procedure, but without a nursing assistant, under an approved ethical clearance protocol. It was partly because of the difficulties of using real patients while designing prototypes that much of my research to this point had involved scenarios and having the dentists "act out" how they work. What was important to me in the design process was that the practitioner used the prototype (once sufficiently mature) on real patients. Subtle nuances in the way people work in an authentic situation can have significant effects how they perceive and react to the prototype.

The test for the prototype was straightforward. Scott was asked to undertake a periodontal examination with a research colleague volunteer as the patient, and a researcher on hand for any questions or problems with the speech prototype. After a quick run through of the navigational commands and a description of how the software worked, Scott attached a wireless microphone to his protective glasses and began the procedure. The charting was completed in approximately 15 minutes. Time was then spent discussing the prototype with the dentist and acquiring feedback. Below is an example of the trial with Scott. Bold type indicates a speech recognition error.

> *Scott: "'set one' 'set seven' 'set one' 'go to recession' 'go to last tooth'"*
>
> *[Pauses to check location because of lack of feedback]*
>
> *Scott: "**'set one'** 'set one' 'set two' 'set three' 'set speech off'"*
>
> *Researcher: "It's kind of annoying with the recognition rates sometimes…"*
>
> *Scott: "But not too bad. I think I need feedback for when I'm going to recession and when I'm going to pocketing, so I know I've switched between them."*
>
> *Researcher: "Yeah I noticed that yeah."*
>
> *Scott: "That's probably the biggest thing. And it feels a little bit strange sometimes if you go through a series of determining pocket depths for a tooth and it jumps to the next tooth [computer beeps to say speech is back on] and you want to go back and record the recession. 'Wasn't talking to you' …and you want to record recession for the same tooth."*

My main concern was the problem of error correction. In particular, I aimed to avoid errors that cascade into other errors and disrupt the flow of work. As identified by Karat et al (2000), cascade errors account for the majority of time spent correcting misinterpreted speech recognition, particularly for novices. One method identified for reducing errors is the use of multimodal input (Karat et al, 2000). However, this was not a possibility for me, given the problems involved in using a keyboard and mouse and lack of a mature gesture interface as planned. It can be seen in the example transcript that while there were recognition errors, the system did not create cascade errors.

I was also concerned that the reduced accuracy of a prototype might be sufficient to disrupt the workflow and irritate the dentist. However, as exemplified in the transcript, the errors that occurred were tolerable, at least for a prototype. The dentist could identify errors in recognition easily and fix them simply. There was unintended triggering of the speech system during conversation with the researcher, but the dentist was unmoved, quipped back to the speech engine and then continued in conversation. While these errors would be annoying in practice, they did not noticeably disturb the procedure or the participatory design conversation. The dentist became comfortable with the speech interface in a short amount of time and soon began charting at his normal work pace.

There were issues with regard to feedback and contextual navigation, which are also seen in the transcript. Some of the audio feedback, having been deemed too distracting during previous design discussions, had been removed from the prototype. Because Scott was unable to see the screen, on occasion he was unsure of whether the computer had heard his command. Furthermore, automatic navigation driven by the context of the procedure (as requested by several dentists) interfered with the way Scott worked, and became a nuisance when an error was made.

In my case, I realised that with the context-dependent navigation I had overlooked a possibility about how dentists chart around the tooth. My design was based on the explanations of practice by Scott and Jason and limited ethnographic observation. In the course of the procedure I found that the dentist did not always want to chart all points of a tooth, leading to a subsequent prototype modification before the final prototype trial (as described in section 4.1.3). Although I tried to eke out all possible variations in our discussions with the dentists, later trials in authentic contexts naturally found things I had overlooked.

There were some potential problems in the prototype that I simply dealt with up front. Using an off-the-shelf speech recognition engine from the United States meant that some Australian pronunciations weren't recognised regardless of the training used. Accuracy reduction due to accents is a recognised problem in speech recognition research (Pedersen and Diederich, 2007) and there is not yet a satisfactory solution beyond specific localisation of a particular speech engine.

When a speech interface doesn't respond, the natural tendency of the user is to hyper-articulate (Kraal, 2003). This does not help the speech engine decode the speech. For certain words, 'eight' in particular, we had to point out to the dentists that it was necessary to pronounce 'ayyt', instead of 'aayt' as it might be pronounced in Australia or New Zealand. There are occasions in design where it is necessary to adapt the user to the system provided – the most effective approach is not always to completely accommodate the practitioner. An example of this can be seen with the development of the Graffiti interface for Palm personal digital assistants. While Graffiti provided a simple and mostly natural interface to handwriting recognition, it required the user to adapt to specific requirements for interaction. For example, the letter 'e' need to be entered as a backward three. This is a relatively minor adjustment in use of existing skills, and as witnessed by the success of the Graffiti system, one easily accommodated. Thus I needed the dentists to slightly modify their speech for the prototype, just as handwriting must be slightly modified for accurate detection on some handwriting recognition based interfaces.

> *[Scott is trying out the speech interface to test for accuracy before beginning the procedure] "go 5". [computer beeps and inputs 5]. [changes tone here] "go 8". [computer beeps and inputs 8]. Alright.*
>
> *Researcher #2: Just try "6".*
>
> *Scott: "go 6". [computer beeps and inputs 6]. "go 6". [computer does nothing]. "go 6". [computer beeps and inputs 6].*
>
> *Researcher #2: "6" has been a really tricky one, I have no idea why. I think it's because we've had to work with a free speech recognition app - it's for Americans,*
>
> *Scott: Okay.*

Researcher #2: so I've been trying to train it for the Aussie accent. But it's still...

Scott: "go 6". [computer beeps halfway through from recognizing part of the conversation and inputs 7].

Researcher #2: So just...

Scott: [with American accent] "go 6". [computer beeps and inputs 6]. [with American accent] "go 7". [computer beeps and inputs 7]. [Scott laughs]

By making such technical problems or quirks transparent prior to the prototype use, the dentist readily accepted the modified way of accenting some words. Plainly stating the problem and giving an example (such as the ‘eight’ above) to illustrate gave the dentist insight into the technology and its limitations, and this seemed to be an effective way of bringing an early prototype into a professional use situation in order to have a participatory design conversation.

The trial also demonstrated that it is important to have a technical team member who is able to ground technical discussions, provide layperson explanations and fix problems in the prototype. This was particularly true during the trial itself, where there were issues with wireless connections, and minor bugs in the code. Involvement of an engineer also allowed for in-situ technical development with the three dentists during the New Zealand design activities, allowing a shorter development period before trialling in another authentic scenario.

5.3 Conclusion

As discussed in (Cederman-Haysom and Brereton, 2004), it is not possible to understand shifts in work practice that result from technology until technology is fully implemented and used in every day work contexts; such is the contingent nature of work. However, the process of participatory design employed in the manner described in this thesis allows for iterative development of a new design which attempts to allow for this shortcoming by collaborating with practitioners in real work contexts.

This chapter has described how a participatory design approach was used for engaging dentists with varying backgrounds to help develop a ubiquitous computing prototype. A group of dentists from New Zealand were identified by the CEO of a dental software company as "power users", and as such were approached to take part in a series of design studies to further refine and develop a speech-based ubiquitous computing system that aimed to improve patient charting and record keeping.

The activities with the New Zealand dentists were carefully chosen using the researchers' experience and the literature, and aimed to make the best use of time for busy professionals. It was found that during the activities they had to be adapted to make best use of the time and involvement of the dentists. The activities included demonstrations and walk-throughs by the dentists, situated scenarios, brainstorming, on-site video analysis and technical explorations. While no quantitative measures were made of how the practitioners perceived the methods and outcomes, their reception was evaluated qualitatively by the character of engaged discussion and the extent to which the dentists contributed and built upon ideas, and offered examples of use.

The following table summarises the contributions from different participants, as a way of illustrating how participatory design affected the synthesis process:

Contributor	Design consideration
Peter	• Screen visibility during procedure (p. 151). • Instrument orientation and effect on sensors (p.151). • Movements to use during gestural interaction (p. 151).
John	• Technical feasibility of accelerometer embedded in probe (p. 150). • Probe augmented to act as 3D mouse (p. 151). • Movements to use during gestural interaction (p. 151). • Contextual movement around the tooth when charting (p. 154).
David	• Possibility of workarounds for 'clean' interaction within the surgery with technical equipment, such as using a cotton bud for interacting with a touch screen (p. 152). • Consideration of technical limitations, such as delay in converting

	tablet input to screen display (p. 153).
Jason	• Useful voice recognition commands (p. 154).
Scott	• Suggestions of microphone alternatives. • Attachment of microphone to protective glasses. • Text-to-speech confirmation of speech input. • Exact tooth location control for data entry rather than contextually moving between teeth automatically.
Author	• Extended redundant command set for speech recognition. • Use of tones for confirmation of speech input.

Table 5: Contributions from different practitioners

Ultimately, the completed activities provided enough insight to complete a prototype ubiquitous computing system that was then trialled with one of the dentists, Scott, who completed a procedure that was videotaped and evaluated. The outcomes of the activities and prototype trial were the basis for lessons for design, which are discussed in the next chapter.

6 Lessons for design

The outcomes of the research led to the conclusion of several lessons for design. These lessons are distilled from reflecting on the multiple interactions that took place, the forces at play and the ways in which design choices revealed themselves. Given the importance of their contribution, the design activities that took place with the New Zealand dentists are used as a case study for these lessons. These lessons are an attempt to generalise the research findings in the context of a broader sense of design studies.

6.1 Designing for busy professionals

Overwhelmingly, one of the most interesting challenges was finding means for encouraging effective contributions to the design process with busy professionals. Specifically, methods were required that provided detailed insights into how they interpreted and understood new technology, existing technology and their work practice. Practitioners such as dentists have busy schedules which do not afford much time for extracurricular participation, and donating their time effectively means lost revenue for their business. Therefore, finding ways to compensate for short access periods, long gaps between availability and a dearth of willing participants becomes a primary concern. These included staging events, making use of industry contacts, and finding ways to more efficiently make use of time with the practitioners.

Staging events was found to be an efficient means for propelling the design. Events encompassed methods including design discussions, design games, contextual prototyping, and participatory bootstrapping. Events are an effective way of concentrating activity and focussing the design process (Binder et al, 1998). Like Binder et al, the methods used favoured conversational design, for the reason Schön (1987) noted that "development work is propelled by the dialogic engagement of stakeholders and object worlds". Staging events allowed concentrated access to the dentists and provided the dentists ownership of the research through their participation. It was found that events provided a good framework for participatory design methods (particularly by locating events in context), and also allowed for effective use of time with practitioners by concentrating activities and engagement to a single period of time. This contrasts with traditional methods of participatory design, such as those used at the dental school, which include repeated visits over extended periods of time.

By staging events that made use of the dentists' work context, prototypes could be explored with dentists in a realistic setting. By grounding the design in the use context, when practitioners are in their everyday domain, they are familiar and comfortable with the design environment, helping to place all parties on a level playing field. A familiar environment helps the practitioner feel more comfortable, and staging events in their work environment improves their ability to contribute their domain ability and knowledge.

There are also practical considerations in choosing the sites of inquiry. Access to the practitioners was given freely by them, and they received no form of remuneration for their time. By centring activities at their workplace, maximum use could be made of their time, and inconvenience was minimised.

One benefit of contextual prototyping as posited in the methodology chapter is it both encourages mutual learning between the practitioner and designer, and it also prompts the practitioner to work as normal rather than in a contrived fashion. In addition to validating design, this can also prompt the designer with avenues of design to pursue, providing a nucleation point for the design process. As an example of validating the design (after a similar nucleation from Scott as discussed in section 4.3.2), after discussing his use of a wireless keyboard and mouse wrapped in plastic in the surgery, James (from 4.2) reported:

> *James: "Charting is the most important procedure, and the one that requires the most improvement for how it's done on a computer. But the problem is you can never really get rid of a keyboard, you can only cut back on its use."*

This was a difficulty both observed and reported by other dentists. James' comment was illuminating because it showed that dentists recognised the difficulties, but felt unable to overcome the limitations of the methods of interaction, seeming to confirm that aiding charting with new technology was a suitable intervention point for the design.

James was intrigued by the idea of co-opting normal use of the bracket table as a means of controlling how information was entered into the patient record. He could think of several scenarios where such a sensing system would be useful in his everyday work practice, such as bringing up a patient chart while performing a procedure. James highlighted unconsidered difficulties such as how the potentially unstructured nature of his work could make context detection using instrument weight difficult. This conversation chronologically follows the previous one:

> *Researcher: "Ok. So we're just using a Lego Mindstorms kit, just with three touch sensors and just an infrared connection. So it's something, you could have this wired into, cause you already have this table wired up to do various things."*
>
> *James: "Yeah it wouldn't be too much to wire that and add a few sensors or something like that. So that was purely by feel that it recognised you lifted up the mirror and probe… just a touch sensor was it?"*
>
> *Researcher: "Yeah, the weight in the table just drops – it doesn't actually know that I've picked up the mirror in this case, we're just picking up 20g or whatever it might be. Yeah that's the way it's set up at the moment, but the problem I suppose with trying to detect which instrument is that they're not always laid out nice and pretty, they can be mixed up and that might even change the weight of the table."*
>
> *James: "Unless they were all encoded with some identifier that told the computer what the instrument was, that'd be very difficult."*

This design session is an example of successfully engaging a practitioner as a member of the design process. In particular, this dialogue shows that James could understand the technology of the prototype at a sufficient level to engage with it to question it, talking about 'sensors' and 'identifiers'. By reaching this understanding, it was possible to validate a concrete design with the practitioner, and reconsider it according to their needs before the prototype became too formalised. It is an example of where both the practitioner and the designer are able to technically bridge the design discussions.

The research outcomes were also benefitted by involving DentalSoft CEO John, particularly given his status as a skilled practitioner and the connections he held within the industry. Access to a professional network, normally not possible for a short research project, provided a range of much needed participants to further develop, finalise and test a prototype. John was instrumental in contributing to the activities, facilitating effective design sessions without the prior involvement normally required. John was initially to be only an observer, but from the outset was extremely helpful in garnering trust with the dentists and assisted in making efficient use of the time. Recognising and supporting John's ability to assist in studies was in hindsight a key part of completing the design with professional dentists. Having a mediator such as John created a bridge between unfamiliar groups and assisted in ensuring effective communication between them. In this case, such benefits were not planned, but instead simply fortuitous, and his involvement in the sessions ultimately made them a success.

Finally, during events and activities it was necessary to improvise effectively to make most efficient use of the time. Unexpected time constraints or reactions from the dentists forced in-situ adaptation so that time and access to participants was not wasted. As such, while activities were planned, "fall back" plans were also made, and schedules and activities were not rigidly maintained. In particular, emphasis was placed on attempting to generate and maintain a fruitful design discussion and to ensure the practitioners had the ability to communicate effectively, even if the time available was curtailed (such as cutting short a role-playing activity, or taking an unplanned extended tour of the surgery). This could be seen when working with the dentist Peter (section 5.2.7) when the planned strategy of performing activities with Peter was not received with much enthusiasm. John was able to adapt how he presented the research to Peter so that it appealed to his immediate work concerns and we began brainstorming design ideas instead of completing the video analysis of a situated scenario.

6.2 Creating communication in design

Effective participatory design rests upon appropriate communication between all participants. Effective communication can be seen when both designers and practitioners are able to frame and shift the debate, contribute without fear of embarrassment, take initiative in offering examples, ask rudimentary questions, seek to fully understand and clarify and remain engaged. The benefit of such communication is something that became apparent in early studies and as such methods were adapted during each design activity and sessions to support it. This is not a new methodological finding by any means. During her design of a multimedia educational application, Robertson noted that:

> *"Cooperative design of the product was enabled and achieved by the work that the designers did communicating with each other." (Robertson, 1996)*

What is interesting is the types of participants that help this communication, and the ways of improving it. For example, involving a software engineer of the dental software company (the CEO for the company involved in the studies had worked on the project as a developer) in our activities allowed for explanations of the underlying structure of the code. When we were discussing with David how a new prototype system for interaction may work, Scott explained how the Chartware code currently worked for moving around the chart and how the software logic worked internally. This in turn provided realistic avenues for brainstorming based on existing constraints and more efficient decisions for generating deployable prototypes.

This thesis also builds upon other early attempts to improve technical understanding during participatory design of ubiquitous computing, such as Good's (1992) work with a portable torque feedback device. While technical expertise is necessary, but not sufficient for design on their own (the practitioner's perspective and other design skills are also needed), one important challenge is how to represent technical knowledge in design conversations. It should be done in such a way that it educates and informs practitioners and gives them access to the nature of technical decisions involved. Examples in this research include explaining accent difficulties with speech recognition (section 5.2.12), and how item recognition took place using weight sensors (section 4.2.2). Below is a further example of a technical discussion, which regards the use of accelerometers before the dentist trialled the prototype:

> *Researcher #3: It's the type of sensor that is used in airbags and they just detect changes in acceleration. So they're mass produced and therefore pretty cheap and they're quite small, just sort of silicon chip type things.*
>
> *John: What accelerometers can do is measure when you move, like you could swing the end of a circle, or tap it, it can detect the movement because of the…*
>
> *David: So you could have a whole range of movements to mean a whole lot of different things.*
>
> *John: Yeah, yeah you could. It's a recognition process of recognizing the movement, but the accelerometers let you measure things, what type of movement's going on, very specifically, so it's quite easy to determine a circle versus a square versus a tap, or I think what [Researcher #2] is working on, is what sort of movements are kind of natural for people holding their instruments.*
>
> *Researcher #2: So you can sort of see there it picks up the tilt quite well, so usually I have this on my hand so it's a bit easier to understand but you can sort of see it as I rotate the thing it's changing the tilt – so if you sort of smooth the data coming in, there's a bit of jitter in that, and that's just a part of the sensors, but if you smooth the data, it is possible to have quite fine changes in the movement. So there is this kind of continuous control, but then also this thing…*
>
> *John: Basically when you're holding it still, it's detecting gravity.*
>
> *David: Oh okay.*

In another example, John uses a common New Zealand children's game to help explain movements he is imagining to the dentist, Peter. Relating complex ideas to a shared simpler one ensures mutual understanding, and facilitates the flow of conversation.

> *Researcher #2: If you're rolling it perhaps? [demonstrates movement]*
>
> *Peter: Tapping?*
>
> *John: Like that Maori game with sticks.*

Peter: Yeah, that would be something. Next tooth. Because, doing this I don't see that there would be enough movement.

In addition to relating technical *understandings*, it was also necessary to communicate technical *knowledge*. What may seem obvious to an engineer is not to someone who is not immersed within a particular field. For example, even though David was very familiar with speech recognition interfaces, this did not translate to a close familiarity of technical problems:

Researcher: Yeah, I don't think you'd ever use a Bluetooth headset, you'd use a dedicated

[simultaneously]
Researcher: wireless
David: wired

Researcher: microphone.

In this case the unreliability was due to the fact the wireless microphone was an 'ad-hoc' system, and there were driver and pairing issues hampering its use. The researcher knew this was the case and that a wireless microphone design specifically for everyday use would solve this problem and be just as reliable as a wired microphone. The dentist was unaware of this knowledge, and so while David understood the technology, with his knowledge he concluded that the wireless nature of the interface was the cause of the problem.

By bringing a technical nature to the discussion, biases in how participants view technology become clear in the study. Attempts were made to keep the discussions open-minded and to encourage participants to brainstorm without restriction: it was explained to practitioners that the purpose of the research was to develop *new* methods for interaction that facilitated naturalistic human-computer interaction. In addition, questions were asked about their work practice rather than their computer interaction, and early prototype demonstrations took place without using dental software to avoid biasing the design. Nevertheless, when considering how it might be used, supporting existing interaction paradigms became the concern:

David: It's just while I'm doing any physical work. So when I'm actually doing work, there's some areas in there that I need to enter data like lengths, reference points, there's a few other things like curvatures, file types, file diameters, things like that, the nurse sometimes enters or writes down and we enter at the end of treatment but there's a treatment page that stays open while I'm working that's got the ability to be able, you know you could pocket down and just enter lengths and things as you go along because again it's all point and click so nothing needs to actually be physically typed in, you can actually just…

John: Do it all.

David: ...click a box, move to the right spot, click the right spot and then close it out again. So it's quite mouse driven.

John: Yep.

David: So if you had something that was able to control your mouse sort of thing, like you know, you could have some movements to say you know, right click, left click or double click.

John: And sort of next.

David: Yeah, like "tab", next.

In this conversation, John and David indicate their familiarity with the use of a keyboard and mouse for interaction, and translate the work practice through this paradigm. While every effort should be made to support existing understandings, the focus should remain on supporting the work practice itself, and not accommodations for technical limitations. Identifying and accounting for these biases is facilitated through the technical nature of the discussion.

An important consideration within the design process is how to ensure effective communication is taking place within a design activity. To do this, it is first required to *recognise* that appropriate communication is taking place. Researchers may have a "gut feeling" that a discussion or activity is proceeding smoothly, but through examining videotape after-the-fact it is possible to identify what contributed to creating communication and what indicated it was or was not happening. One sign of useful communication is obvious attempts at sharing understandings, such as offering clarifying information or finishing a statement. This indicates an interest and confirms to the other party that there is common ground. In doing so, it may also expose new opportunities in the design.

While John and David were discussing the use of accelerometers in a gesture recognition device, David was able to suggest new gestures based on his new shared understanding of the technical details.

> *David: Yeah so again, movements of a mirror, you don't, your elbows stays in about the same position, for me anyway, and then there's fine motor movement. So big circles and things means you're probably going to get fatigued, going to get forearm fatigue. So it'd be fine movement like rotation, tapping's good. You could easily have something to tap, like one or two, or a button, like a mouse button, but even that movement there you…*
>
> *Research #2: Yeah.*
>
> *David: Just banging it.*
>
> *John: Yeah. We thought, when Peter was doing an oral exam, he just went around with a mirror and he was scratching the teeth, and we thought we could bang the tooth even with the mirror, just like next tooth, you could kind of track, you wouldn't have to… The idea was not to have to move your hand very far, you know…*
>
> *David: Or if you have another thing you could tap it couldn't you?*
>
> *John: Or bang it with the other instrument even.*
>
> *David: And it registers a tap like that.*
>
> *John: Yeah*
>
> *David: It's a very clear, bang, there's a tap, bang bang.*
>
> *Researcher #2: Mmm.*
>
> *David: You don't want to get into, you don't want us stuck thinking, you know you have to do a circle or make an A, that's going to be far too arduous and fatiguing, so it's got to be fine movements and subtle movements as well, particularly if you're working with patients.*
>
> *David: The tapping's good though, I like the tapping. [taps the device]. Yeah, tapping or just like little flicking, flicking up or flicking sideways.*

One of the researchers had previously explained to David that accelerometers were like “jelly on a plate” and the jelly sagging affected the voltage, which in turn allowed measurement of acceleration. With this knowledge, David was able to vet gestures being supposed by the dentist, supposing when one would provide appropriate means of detection. In addition, he related the problem of particular gestures fatiguing the dentist during their work.

Further evidence of effective communication comes when the practitioner moves from thinking about how they work, to how similar practitioners might work. For example, Jason began describing problems with a potential interaction technique because “from dentist to dentist, it’s going to vary again”, and proceeded to demonstrate the different ways other practitioners worked in the same situation.

> *Jason: A lot of it’s going to depend on what they’re using their mirror… how they’re holding it. What sort of manner they’re using. I can retract your cheek in two ways, with that mirror I can pull it back that way or I can actually go in that way and look at the reflective surface [Jason retracts the cheek, and moves the mirror around to illustrate this]. So there're variations in the actual use of that mirror, and that then affects how I use the other instruments.*

Such spontaneous examples of practice and explanation also indicate that practitioners are engaged in the process. Spontaneous brainstorming indicates a level of comprehension that acts as a platform for new ideas. This is assisted by designing in the practitioner’s domain. Doing so allows the practitioner to posit new ideas for interaction within their domain and to draw inspiration from their existing work practice.

Another consideration for promoting a level playing field is how the design team reacts to new ideas from the practitioner. While respect for ideas is expected during brainstorming activities, new ideas may occur at any point of the interaction between the participants. When spontaneous brainstorming occurs, ideas should be met openly by the designer during all stages of the design process. When this is reciprocated by the practitioner, it is also an indication of a level playing field and the level of trust.

The following example shows how in the process of suggesting a new interaction technique, the practitioner gives an example of how the technique might be helpful in practice, which in turn leads to further brainstorming and realisations about why the interaction may be useful.

Researcher: "What if you tap the tooth you're working on and then said a number – would that feel less natural than writing it?"

Jason: "Oh that'd be alright."

Engineer: "So you might be able to use the probe for navigation, like what surface you're on and then entry say…"

Jason: "…and then say four…"

Engineer: "Four, two, three…"

Jason: "I do that with the nurse already."

Researcher: "So it'd definitely be more natural?"

Jason: "Yeah, yeah, that would. Speaking would be more natural, also from a communication point of view, because what I normally tell the patient is that twos to threes are quite normal, when I start getting to fours, fives and more, we're in real trouble then. So what happens is the patient is there going 'oh I hope it's not a four, oh great it's a two, it's a three'. We're going along well, and then all of a sudden, 'Oh no, it's a six'. So it's driving home the point that gum disease is there, and then if you get a whole range of issues, that are there, you can tell them well look you have a whole range across here, the disease is quite general. If you only call out those numbers a few times, you can say it's localised at a few areas, and they've got their communication by the fact you've talked about those numbers."

Engineer: "And when you're saying it, you're just reinforcing…"

Jason: "Reinforcing, that's right. So you're plying them with education."

Engineer: "So saying it out loud is quite an advantage."

Jason: "Yeah, a big advantage than being silent. Because quite often we've been silent and they're going, 'oh I wonder what he thinks.'"

Initially Jason is not that interested – "Oh that'd be alright" – when asked about using speech instead of writing information on the teeth (another interaction possibility).

However, once he begins thinking about it and drawing an example from experience, he relays that saying numbers out loud would help educate the patient, and becomes quite interested in this method of interaction. It can also been seen here that all participants now understand each other, with the rejoin from Jason of "reinforcing, that's right."

Just as communicative resources are important in design, they are important in dental practice. Practitioners recognise a need to communicate to their patients and to educate their patients in dental care. One of the best ways to do this is during the conduct of the visit itself. Dentists also recognise that service sells and justifies the bill.

6.3 Creating and supporting social relationships in participatory design

> *"Design or systems development should be seen as an "entry into the networks of relations – including both contests and alliances – that make technical systems possible" (Suchman, 2002)*

One consideration for employing participatory design is the value of being a part of the process to the practitioners themselves. In traditional participatory design practices, such as the founding practices from the 1970s and 1980s (Ehn, 1992), it was clear that the union workers worked with the designer in order to gain technical benefit for their cause (of improving work practice), but it was clear that the designer worked specifically for a single stakeholder (the unions) whom directly benefited from participating. In engaging practitioners today, there are different motivations for contributing (particularly for design research) as there is often no product or outcome that directly benefits them. Not only are practitioners who contribute busy, but their altruistic contribution directly affects the nature of participatory design.

The benefit derived from becoming part of the process is both personal and social in nature. Personally, the practitioners are better informed, and gain an understanding as to possibilities for improving their work practice. Socially, networks are formed and they gain social currency. For example, activities with the dental school were probably helped by a feeling of mutual learning goals across departments. There was also a feeling of camaraderie of being fellow students when working with practitioners at the dental school, which appeared to assist in fostering a fruitful collaborative environment. As another example, the New Zealand dentists benefitted from participating in the activities by realising the state of technology and different ways they could approach their work. They may have derived personal satisfaction from reflecting upon their work practice, contributing to a learning experience and assisting someone else. Furthermore, the New Zealand dentists specifically were asked to help by the CEO of an important software company that directly affected their work practice. By assisting John in design activities, they may have encouraged him to assist them in the future.

Ultimately, by creating and supporting these relationships in participatory design, a more complete approach to design is possible, by motivating the practitioners to participate. It is important to find ways to encourage practitioners to continue to contribute by creating sufficient value in the participatory design process. This includes fostering existing social networks, creating new ones, and by encouraging the mutual learning process to increase the likelihood of further participation.

6.4 Fostering technical understandings in participatory design

Designers with a strong technical competence facilitate the mapping of technology to practice. A dictionary of technical abilities allows such a designer to help find suitable intervention points and technical solutions. The constraint of the design from the engineer's knowledge may also be constrained by workplace practice by the user. In developing a new concept mapping tool, Gomez (2005) was attempting to transition from Tangible User Interfaces to a Flash based system of control that required a physical input mechanism. Gomez attempted to build a wireless system that tracked individual objects from scratch, but an engineering friend who heard about the system showed her instead how to incorporate off-the-shelf RFID tags to achieve the necessary functionality. Without this extensive knowledge of what already has been developed, time may be spent "reinventing the wheel".

There were also several examples of the benefits of technical competence seen within the design activities in New Zealand. John's detailed knowledge of Chartware provided pertinent and timely information for prototype choices, such as what was technically feasible to adjust within the application, during in-situ design. In turn, an engineer was able to explain to David about problems of wireless systems and why the prototype seemed unreliable at times. While testing, there were issues with out-of-date drivers on the machine we were testing with, causing problems with the microphone, as mentioned in section 4.5.2. By explaining that the headset was going into battery-saving mode unnecessarily, it was possible to discuss alternative and more reliable means of wireless speech transmission.

Explaining the limitations of speech recognition and the reasons for them rekindled interest in a technical option with both Peter and David. Describing how accelerometers function and their technical capabilities allowed Peter to contribute more feasible options for design while brainstorming. When questioned about his knowledge and experience with speech recognition applications, David responded "Oh, they're all rubbish." Exploring the difficulties he had previously faced with the software and how the technology had since improved prompted a new level of interest from him and enthusiasm to try the prototypes to experience potential improvements (as described in section 4.5.2).

This type of communication is reciprocated by the dentists with their existing technical equipment, for example, with the functionality of a tablet input device explained by David as acting like a Magna Doodle (a child's drawing toy). In this way, quirks and limitations can be accounted and adjusted for in the design process.

By engaging in design with different practitioners in different contexts, an engineer can explore the prototype and its limitations more comprehensively, but still in the spirit of participatory design (which often focuses on a single set of participants and context). As such, it is suggested that as part of a participatory bootstrapping approach to design (as described in section 2.2.2), engineers might opt to set up conversations around prototypes in context in order to receive timely and effective feedback in a participatory manner.

6.5 Accountability and design

The interaction between Jason and the researchers in section 6.2 of recording measurements via voice recognition was what led to the development of an interaction method which made the dental procedure understandable and transparent to the patient and dental nurse, and the design process accountable to the dental practitioner and designer. It emerged through the process of participatory design in which both practitioner and engineering designer sought to understand each other's work.

This research suggests the importance of accountability in design, which is achieved by being cognizant of and supporting communication between all participants in the design process. Accountability from an ethnomethodological perspective refers to the fact that parties to an interaction have access to and can report on the action taking place. Eriksén (2002) discusses accountability in design from an ethnomethodological perspective (how to assist practitioners to make sense of the design in the context of their work practice), from a political perspective (from the point of view of adequately considering issues important to all stakeholders) and from a technical perspective (in terms of transparency of the workings of the technology underlying the interface). Eriksén (ibid) shows that accountability in design provides a richer understanding of design choices which may need to be considered. The transcript in section 6.2 is a demonstration of how in seeking to make the interaction intelligible in the natural course of conversation (accountability in the ethnomethodological sense), the interaction leads to a design that at least partially addresses issues important to stakeholders in the political sense – knowledge of how the procedure is going is made available to the patient. Both patient and dentist have access to and can report on the action taking place.

One example of bringing accountability to the design process was in the development of the scale model of the dental surgery (see section 4.3.2). This revealed to the dentist what we noticed and what we may have missed, providing several important contributions to the design. First and foremost, its creation made us carefully consider the design space. Details such as equipment location, information flow and the how much physical space was available became clear. Secondly, through its validation with James, it provided a means for discussing the surgery as a whole and for completing our understanding of the work space. Finally, during design discussions it was used as a reference point for the broader design space, and created a tangible approach to discussing the complexities of the surgery.

The transcript segment below highlights the benefits of accountability in the resulting design itself (its provision of accountability of the dentist's actions through its use): the dentist reflects on speaking the procedure out loud to the patient and the importance of patient education:

> *Jason: "So yeah, calling out numbers is a big advantage, because just from treatment wise, periodontal disease is hard to sell to clients, because they have no pain, there's issues going on, so what if the gum's bleeding? It's no biggie. They stop. And it's one of those things where you've really got to get on top of it, and if you can use those numbers and that's one of the reasons I like the lines on that, is that it really starts to point out things…"*
>
> *"What I say to them is that, okay, these lines represent the level of bone and you've only got two spaces left, there ain't much there, and they can relate to that because they can see it on the computer. The computer doesn't lie."*
>
> *"Graphing is actually really important, charting is really important to reinforce it. The voice side of it is good, if the dentist uses it in the correct manner. We've got to start educating them why we're charting and what we're looking for and then it actually works in their favour in getting that treatment accepted."*

The existing periocharting application for dentists was criticised by the dentists for having a poor interface for data entry. However, as data is entered into the application, it draws a corresponding graph of the patient's gum-line and the bone structure beneath (referred to as "the lines" in the transcript). Due to the assistance to patient education (and the associated benefits of this, such as improving dental care and the patient accepting treatment suggestions), one dentist (Jason) reported that many other dentists had found a work-around for entering the data just so that part of the application can be used[11].

[11] In light of this example, it is worth mentioning the comparison of "usability" and "usefulness". If, given the constraints of the interface, a function isn't "usable" (in the sense it takes time to learn, or isn't intuitive), but is in fact useful (in that it provides an important ability), then it has value and will be used regardless of its problems

While the dentist suggests what they are willing to share with the patient, it is often not practical for dentists to share everything. Billing information, past history and minutiae of the patient chart are either inappropriate for sharing, or distract from the work at hand. Nonetheless, this kind of interaction serves as a promising start for exploring what could be shared, and under what circumstances, leading to more possibility for opening up the medical (and perhaps billing) view to the patient (where the patient so desires).

During the research, it became clear that accountability is an important aspect of design. Accountability is important ethnomethodologically, politically, and technically. Politically, it reveals both the designers' intentions, methods and design components, and the participants' work context and motivations. In the technical sense, it allows all stakeholders to participate equally. Because technical decisions and understanding of use are so intertwined, both practitioners and designers need to ensure they are fully communicating in light of everything that they know. A clear understanding of the constraints and workings of the work space needs to be balanced with the understandings of the limitations of the technology in order to design a system that satisfactorily improved work practice. As such, to provide accountability, the designer has to continually keep clear the brief and motivations of the design work and provide views onto the technology that the participant can understand, while the participant reciprocates.

6.6 The nature of participatory design with busy professionals

This thesis has explored how designing multimodal interfaces and ubiquitous computing could be done differently by collaborating with practitioners in authentic work domains through participatory design. In contrast to traditional participatory design approaches, design activity has engaged with different practitioners at different stages of the research as design interests progressed from early explorations with general dental practitioners, to meeting the CEO of a dental software company, to meeting dentists who were interested in the development of dental software. It is reasonable to question whether such an approach is actually user testing rather than participatory design.

Rather than engaging dentists as users in order to test ideas, research was conducted in the spirit of understanding the dentist, giving them as full access as possible to technical knowledge and choices, and giving the dentist a voice. Emphasis was made on developing relationships of trust where research findings were reported to the dentists and further input invited. While struggling with the need to fit within the limited time and availability of busy professionals means methods require ad-hoc approaches to design, the endeavour is no less participatory. While the methods used are described as participatory design to collaborating practitioners, it cannot be assumed that participants adopt the view that they too are participatory designers. Nonetheless, the planning and execution of the design activities have always endeavoured to *design with* dentists, rather than *design for* dentists or *test designs on* dentists.

In considering the nature of participatory design, it is worth considering researchers spontaneously suggesting and creating a prototype digital pen for the dental school (section 4.4.2). Given this method of interaction was not collaboratively developed during a design activity with the practitioners, it is questionable as to whether this method of design was participatory. However, by that stage of the research the designers had all formed a strong understanding of the tacit knowledge held by the practitioners and what was required of them in their work practice. The design had been developed in the spirit of participatory design, and worthy for practitioner evaluation.

This research project had no guaranteed outcomes for the participants, for example, changes to instruments and software in their work environment, unlike other participatory design projects such as UTOPIA (Ehn, 1983). Dentists have a wide choice of software and instruments they may purchase and use in their surgeries, and in turn the design process has less of a stake for the participants, and there is little in the way of organisational politics. Instead, the politics are much more characterised by those of personal negotiation, and the benefit of dentist engagement, insights, and time were requested for the research.

Ultimately, by consulting different people at different stages of the design to understand different things, given the current era and design context, a more pragmatic approach to the design process was employed. This was achieved by using existing social connections (such as with the dental software CEO and the New Zealand dentists), carefully planning design activities based on the type of participant (including their location and the methods employed), and by being able to readily evolve and adapt the design process to best facilitate discussion and engagement.

6.7 Adapting technology for participatory design

Based on early ethnographic studies and problems seen in the literature of ubiquitous computing for achieving usable systems, the aim for a tangible prototype was to make incremental adjustments to work practice by limiting prototype development to the most effective areas of change. By keeping development scope realistic, it was found that in addition to wanting mature, usable technology, a constant concern from dentists was price. This was interesting because even though many of the design sessions were unsolicited by the dentists, they still contributed to them in the same manner as if the participatory design outcome would actually affect their work practice. Such reactions indicate engagement by the dentists in the design process and a sense of ownership and interest in the design.

While the prototype was not to develop new technological breakthroughs per se (rather, it was to enhance technical integration), it was important to be aware of what was technically possible in the future, so as not to limit design potential. For example, for prototyping a 'clean' speech recognition interface, a somewhat clumsy (in its transmission quality and size) Bluetooth headset was used. However it was known that research into the field would produce more elegant and useful replacements in the future. These potential improvements ranged from something relatively simple, such as a throat microphone with improved noise cancellation or to the more advanced realms of research, such as DARPA's Advanced Speech Encoding, which replaces microphones with non-acoustic sensors that use feedback from nerve and muscle activity to generate the digital encoding of the speech

(Hambling, 2005). Examples such as DARPA's prototype offer future technical replacements for integration. Ultimately, the design activities were to explore technical possibilities in work practice, not to find the best technical solution as at the time of the design work.

Early studies indicated, in some ways contrary to expectations[12], that speech based interfaces could be effective in some dental procedures. Therefore a speech based prototype was devised to allow multimodal interaction for dentists. Focussing on speech allowed for the development of a single technology to a satisfactory level of maturity for trialling in patient examinations.

Configuring and applying the speech recognition engine was problematic. As noted by Kraal, speech recognition is not a "one-size fits all solution to any problem" (Kraal, 2003). While speech is a modality that is both natural and frequently used for communication, this does not mean it automatically lends itself to human-computer interfaces. Although the input of speech is relatively simple, editing and correcting errors is difficult and can in turn produce more errors that need to be fixed, leading to error cascading. Errors occur because there is more variation in tone, inflection, speed and intonation in human speech than the acoustic computer model can accommodate (Karat et al, 2000). The tendency of people to hyper-articulate words that have been misunderstood can lead to further recognition difficulties. Thus when speech technology is used it tends to require a lot of appropriation and articulation work on the part of practitioners.

Many of the successful applications of speech recognition occur where it is deemed clunky or inappropriate (Kraal, 2003). It is often simply a more efficient method for entering text than other alternatives despite its shortcomings.

In designing for speech applications it is critical to understand the context in which speech recognition is to be used, what kinds of things are to be said, and how they might be said. Each application will be unique, even though, as Kraal (2003) points

[12] Research into multimodal interfaces (Billinghurst, 1998) claims that speech recognition is too cumbersome for use as a navigation technology. Therefore the initial research focus was the investigation of the use of gesture for navigation and speech for data entry. It was to surprising then that the dentists found speech useful for navigation as well as entry.

out, much of the research into speech recognition usability overlooks this. It is suggested then that the route to successfully incorporating speech driven interfaces into practice is through participatory design work with practitioners in order to understand the context of use and to cooperatively design aspects of editing, choice of commands, error correction and so on.

Given that there is a broad corpus of research in speech recognition, the aim of the prototype was not to improve the technology behind speech recognition, but rather to use participatory design to more effectively design or customise speech recognition applications to suit the context of use.

6.8 Concluding statements

A participatory design approach was brought to the design of multimodal interaction and ubiquitous computing. Such an approach recognises the articulation work (Suchman, 2002) done by the practitioner in adapting and appropriating ubiquitous computing technologies into their cultural practices and material environments and seeks to engage the practitioner in design by building relationships of trust and mutual exchange. The participatory design methods related the following design outcomes:

Method	Design outcome
Discussion of work practice during contextual prototyping (by James, pp. 166-167).	• Identification and confirmation of importance of prototyping a periodontal application (role of charting in dentistry established). • Validation of prototype implementation of bracket table (difficulty in using technology paradigm for desired use based on real-world consideration of instrument-weight differentiation)
Involvement of trusted and domain-knowledgeable participant in design process (pp. 168-169).	• Design conversation facilitation (John describing how Chartware code could support a potential design) and spontaneous activity improvisation (brainstorming with Peter).
Engineer on-hand to validate technical understandings (p. 171).	• Continued use of a wireless microphone in the prototype after reliability issues cropped up, but were determined by the engineer not to be due to the wireless nature of the equipment.

Recognition of bias from existing system paradigms (pp. 171-172).	• Recognition that practitioners are used to a keyboard paradigm and understanding that workflow is not contingent on supporting existing software flow.
Sharing a how technical fundamentals of a system's functionality (p. 173).	• New suggestions for recognisable gestures from David after having the fundamentals of how accelerometers work explained to him.
Effective communication during contextual prototyping (p. 175).	• Through exploration of potential use case scenarios Jason is able to realise how speaking values to a voice recognition system would be able to assist in his work practice, cementing its inclusion in the prototype.
Accountability in design (pp. 180-181).	• Understanding the purpose of Jason's actions (educating the patient how serious their periodontal issues are) explained why dentists persist with a difficult interface for periodontal charting. Understanding what data is important to be shared with the patient means periodontal charting information is included in the prototype, while other patient record information (such as billing) is kept separate.

Table 6: Design outcomes

This chapter has discussed lessons for design that can be concluded from this research. The case study of participatory design with dentists in New Zealand has provided a framework for describing how relationships were developed with dental practitioners and a dental software provider, sufficient to lead to the design of a useful prototype, even though the dental practitioners could only offer limited time to the design endeavour. The importance of adapting design methods to support limited availability and unpredictable outcomes was discussed.

The design effort focussed on creating and maintaining fruitful exploratory design discussions with practitioners, facilitated by development of a series of low-fidelity prototypes that both explored and demonstrated technical choices in lay terms and allowed contingent use of technology in context to be revealed. In trialling speech recognition technology, context-dependent navigation did not always work and dentists acted differently than foreseen based on ethnographic studies, demonstrating that context is an emergent phenomenon. As such, the design question became whether the recognition, editing abilities and error recovery techniques were sufficient to support emergent behaviour during charting. A speech recognition based prototype was developed that made the periodontal examination results available to the patient as they are recorded by the dentist, and these properties of robustness and adaptability were considered.

Finally, this chapter reflected upon issues of accountability and the extent to which the research was participatory or user-centred design. This research has engaged different participants during a multi-stage design process in the spirit of participatory design, attempting to design with, rather than for, the practitioner. While the practitioner may not be directly affected by the outcome of the project and the completed prototype, their engagement in the process was still possible by employing participatory design methods. These methods also supported accountability both in the design process and the design itself, which allows for an improved speech recognition system.

The following and final chapter summarises the contributions of this dissertation and possibilities for future work.

7 Conclusion

This chapter discusses the outcomes and implications of the research findings of this thesis. Specifically, this dissertation has explored the benefits of ubiquitous computing and multimodal systems for interaction in novel contexts and suggested and evaluated the contribution and limitation of participatory design methods for satisfactorily achieving the philosophical ideals of ubiquitous computing.

It is suggested that employing a participatory design approach accounts for the social nature of complex systems in specific contexts of use and allows for an improved contribution by empowering the practitioner. Given the technically complex nature of the systems being prototyped, the inclusion of an engineer to the design process was recommended to both constrain and propel the design. This required the consideration of methods for improving collaboration with stakeholders from other disciplines and technically-competent individuals to ensure a level playing field between all stakeholders. A prototype system was developed to validate the framework for design described.

The results of this thesis are both methodological and empirical in nature, with findings that reflect upon how participatory design may be approached, and the reception by the participants. Lessons for design are suggested, with generalisable conclusions for design of complex systems made. The contributions of this thesis are framed by the original motivations, and recommendations for future work are presented.

7.1 Technical groundings of participatory design

In design, engineers allow the mapping of technology to practice. Knowledge of technical solutions provides an engineer with a dictionary that may contribute to designs that assist work practice. However, it is only with the respect and knowledge of practice an engineer can appropriately map technology to practice, and help facilitate finding a fit between technical capabilities and technical requirements.

While this is what normally takes place during design, there is a gap in common engineering design practices where the emphasis remains on technical requirements, and not a holistic view of all system requirements (technical, social, or otherwise). While methods such as user-centred design have been previously used as a means of trying to appropriately address practitioner requirements, such methods rely on simplistic user models, rather than comprehensive practitioner collaboration to inform the design process. Participatory design allows for a democratic approach to design, affording the practitioner with respect and empowerment in the design of system to better suit their work practice, tacit knowledge and context of use. In addition, appropriate communication with the engineer allows the practitioner to increase their technical understanding of the system and therefore contribute in new ways to the design process. Finally, by participating in such a process, an engineer may learn the skills for introducing technology to work practice in a way that respects the practitioner and their skills.

Participatory design by its nature is a qualitative process. In the introduction, it was hypothesised that difficulties in completing an appropriate design may be managed by incorporating technical knowledge into a participatory design approach. The need for a precise and technical contribution to such methods may seem counterintuitive, but this thesis shows that when designing complex systems, an engineer provides a new perspective of clarity for design. This expands the scope of the design process when employing participatory design and allows for a system that is grounded by its actual technical requirements in addition to the necessary means of supporting the practitioner.

The discussion chapter (chapter 5) has addressed the difficulties in integrating engineers into a participatory process, and suggested methods for accounting for these. In addition, practitioners' requirements should be managed according to the technical capabilities of the potential system. This is supported by a detailed analysis of a case study of participatory design that both discovered and demonstrated new methods for design. Lessons for future design studies were suggested using the case study as an example in for these lessons.

7.2 Creating and sustaining communication in design

This thesis has aimed to provide a rich description of the participatory design process, both its advantages and challenges, and how practitioners participated. The emphasis while employing participatory design was to facilitate communication between participants with varied backgrounds in research, design, engineering, dental practice and business. Doing so aimed to provide a variety of benefits (identified by the literature), but particular emphasis was placed on how to create and sustain technical communication, particularly given the complex nature of the system for design. Such communication went both ways. Technical understandings of the proposed design were required, but technical understanding of the nature of the practitioners work also assisted development of new systems.

As such, this thesis has described methods to better integrate engineers into the participatory design process as a whole. Primarily, there was a blurring of the delineation of each stakeholder's role in the design process. Educating practitioners empowered them to contribute to technical decisions. Finding appropriate ways for the engineer to participate in design activities, and understanding the practitioner, allowed the engineer to better fit the resulting technology to the tacit skills, work practice and context of use of the practitioner. For engineers with a strong technical background and an education and/or career that has emphasised problem solving, there may be distrust of new methods for requirements gathering and prototyping, in addition to an associated desire to develop a solution that is technically-sweet rather than a good fit for the context of use when considered as a whole. This thesis showed that an evolving and carefully chosen set of methods facilitates communication between participants and across disciplines. Providing this communication improves engagement in the design process, resulting in a detailed and holistic approach to the design. Furthermore, the methods may evolve and be improvised with the practitioners in the context of interaction itself. Finally, unlike most participatory design research, this thesis engaged a variety of practitioners in different circumstances and stages of their profession, allowing for a more holistic understanding of the domain and how the resulting system would be used by different practitioners from the same profession.

7.3 Designing for busy professionals

This research has attempted to explore more inclusive ways to design with practitioners with limited availability. There has been a demonstration of the utility of on-site design for timely feedback, greater stakeholder communication, and refinement in the design process. By its nature, participatory design is a relatively slow process and requires long-term commitment from stakeholders. Methods for achieving this commitment include creating a sense of ownership in the design, keeping all parties informed of progress, providing benefits for long term involvement other than the completion of design (which may be as simple as appealing to the personal interest of the practitioner), and facilitating design studies that accommodate the schedule and work requirements of the practitioner. Adapting methods to situated action using participatory bootstrapping (as described in section 6.2) allows for unforeseen disruptions in the process.

This dissertation has suggested several methods for allowing the participation of a busy professional in such an involved project, and has presented data to support their use. The methods include contextual prototyping, asynchronous communication (using wikis and emails), and design events. Dorst (2007) suggests that contemporary design methods focus on the process of design and its results, to the point of ignoring the context and people involved. Dorst argues that researchers should instead re-engage with practitioners and “design by doing”, the benefit of which is magnified when designing for busy professionals. By designing in-situ, benefits include the ability to directly reference the context of use when reflecting upon or propelling the design and a sense of empowerment for the practitioner in the design process. Importantly, by situating design within the practitioner’s domain, it allows for the professional to participate on their own terms.

On-site design also provides access to the rich context of the problem space (particularly situated action and insight to the variability of work) which is important for determining design steps to take. Rather than abstracting a problem in order to solve it, as is usual in engineering design, the problem remains grounded in the context of use. Designing in-situ reveals what the real problems are that need to be solved rather than the imagined ones. In turn it also requires an appreciation of what the human can and does do and what the machine should support, suggesting the need for accountability in design.

7.4 Accountability in design

From the case studies presented, it has been suggested that accountability is required to support the design of complex systems in unique contexts. This accountability refers to the making the design itself accountable (understandable to the practitioners), but also the methods for design (so that all participants understand the process and its purpose).

There is a tension between trying to make something work and seeing what really does work. While engaged in the design process, engineers should be asking the question of how much technology is 'pushed', and how much does reconfiguration of human practices create a useful outcome, rather than attempting to automate and converge devices for technology's sake. In achieving the philosophical ideals of ubiquitous computing, there is a requirement for understanding when automation is "worth it" in human machine systems.

To support accountability in the system being developed, technology needs to be robust and simple to appropriate to allow users to give insights on technology developments and also to allow users to discover for themselves how they would use the technology. Only through adequate testing in real work practice can all potential design deficiencies be revealed – interaction design is best done through interaction. The case studies in chapters 4 and 5 have shown that it is only by providing the practitioner with working prototypes that this may be explored.

7.5 Avenues for further work

The primary area for further work from this thesis is in extending the resulting prototype beyond speech as the only modality. For dentists in particular, there is still a strong need for a greater variety of possible methods of interaction as there were still limitations observed during prototype exploration. Through the result of design studies, these have been suggested as being digital pen and gesture based. There is significant potential for embedding computing in an environment such as a dental surgery, and it will take further research to investigate which technologies are appropriate and in what ways context may be used to further improve automation within the system, while respecting user agency and the invisible computing philosophies of ubiquitous computing. Specifically, such a system should aim to make human-computer interaction as naturalistic and functionally invisible as possible through embedding computing potential within a particular context to support human activity

For the prototype produced, there were several known limitations. Avenues for further work include the inclusion of other procedures to be supported by voice recognition charting, a more general speech recognition engine that supports a wide variety of genders, accents and domains (so that it may be specialised for use in new environments), and support for different patient record software. It should be noted that while it is suggested to increase the compatibility and possibilities for application, it is still advocated that the extension and integration of the system be carefully considered based on specific use contexts.

While the design was considered for a specific domain and with a small group of practitioners, the resulting prototype and suggested methods for design should be useful in a variety of other unique domains and for a large number of other practitioners. Examples of such domains are areas of healthcare (which require similar infection control procedures as dentistry), speech recognition applications, and even such industries as automotive design, where distraction from other tasks is of greatest importance for system design. Many of the issues faced by practitioners in the dental surgery are similar to those faced in a variety of other disciplines and these problems can be addressed using these methods and lessons regardless of the specific domain. These issues include that of interacting with a system while allowing for hygiene considerations, a diverse group of practitioners with different motives (for example, surgeons and nurses in an operating theatre), and the role of a patient within such work practice. Applying the findings of this thesis in other domains would require ongoing involvement of engineers, practitioners and participatory design processes.

This thesis also provided inspiration and lessons for the design of new ubiquitous computing and multimodal systems, particularly speech recognition applications. Methods for accommodating difficulties such as the need for suitable error correction in speech recognition systems, and how best to incorporate off-the-shelf components into the design process, have been considered. The data analysed has suggested what is required as part of the design to achieve ubiquitous computing ideals, included cost, privacy, availability and practitioner acceptance and integration into practice.

Bell and Dourish (2006) discuss ubiquitous computing of the present as requiring attention to the 'messiness' of its application. They state that an ideal vision assumed by many projects of a future interconnected world is "at best misleading ... at worst downright dangerous". Rather than waiting for the "proximate future" to dramatically introduce a clean foundation for ubiquitous computing, instead ubiquitous computing design should support improvisation and appropriation. This thesis suggests ways in which this property can be incorporated into future designs, and methods to explore and encourage such spontaneous adaptations of technology.

7.6 Concluding statement

This thesis has made several recommendations for design, specifically for when employing participatory design for the design of complex ubiquitous computing systems that support new interaction modalities. These recommendations have been illustrated by case studies conducted with a wide variety of practitioners, culminating in a final set of design activities and prototype testing.

The outcomes of this dissertation include a description of a set of methods for facilitating greater communication and involvement with an engineer, supporting the participation of busy professionals when employing participatory design, and allowing greater transparency and accountability in the design process. These methods were validated through the development of a prototype ubiquitous computing system that was evaluated by a dentist during everyday work practice for its usability and usefulness. The system's appropriateness for its everyday use was evaluated by how well it fitted existing practice (specifically, during charting during a periodontal examination) while supporting new means of interaction (speech recognition and context adaptation), allowing a reduction in the mental load when interacting with an information system. Quantifying an improvement in the cognitive load required by the practitioners is difficult, however this was justified through observation of the system in practice and feedback provided by the practitioners through the use of the system. The outcome of this thesis did not aim to reduce this to success metrics, such as reduced time per task or completion rates, rather a holistic view of the system was taken with a qualitative judgement of its effect on work practice and practitioner satisfaction.

By analysing the outcomes of the activities and resulting prototype, a set of lessons for designs have been presented. These lessons provide means for improving participatory design methods and describe how to design systems that fit ubiquitous computing ideals.

Finally, the involvement of a technically competent individual is an often unconsidered part of the design process. Much of the literature does little to explore the associated benefits of technical knowledge and guidance from the involvement of an engineer, with instead a stereotype existing (whether rightly or wrongly) that engineers can be 'difficult' to design with. Current engineering education and design practice focus on problem solving and technical innovation, and as such do not promote methods for integrating engineers to a more holistic approach to design, such as when employing participatory design. While innovation is a necessary part of design as a whole, a greater amount of emphasis should be placed on creating usable designs for practitioners without limiting the growth of nascent technologies.

The final outcome of the thesis was the creation of a prototype through an iterative series of design studies employing participatory design. This prototype supported speech and contextual recognition based methods of interaction to support work practice in a dental surgery. This prototype demonstrated that the methods and lessons suggested by this dissertation may be used to design new ubiquitous computing systems for interaction in complex information environments. Ultimately, it was the unique social and physical interactions identified that needed to be accounted for that represented much of what influenced the design. This showed that employing the participatory design approach in the engineering of ubiquitous computing systems empowers the practitioner and creates opportunity for improving human-computer interaction.

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9 Appendices

Quoted participants
Researcher #1 - Information Technology / Designer
Researcher #2 – Computer Systems Engineer
Researcher #3 – Information Technology / Human-Computer Interaction
James – Dentist
Scott – Dentist
Alison – Dental School Lecturer
John – Engineer / Business Owner / CEO
Peter – Dentist
David – Dentist
Jason - Dentist

Section A: 12th November 2003 – James interview

Researcher #1: So what we've got today is kind of a working version of the sensing table. So, for example, a scenario might be you’re waiting for a patient to come through, which might be the first patient of the day. You might look up some information, some details of previous appointments or something like that – whatever you need to prepare yourself for the appointment. And then when they come in, they’re seated in the chair and one of the first things you want to do is a fairly general check up of the patient’s mouth. We’ve noticed that some tools that are typically used are the mirror and sickle probe.

James: Yep

Researcher #1: So maybe when you grab these tools of the moveable bench beside your… we just have to…like, when you grab them off, it might, if it’s going to co-operate, load a representation of the patient’s teeth.

James: Oh wow. Wow.

Researcher #1: So then you can work away and look at that and maybe use speech recognition say to look at other things, forward back or chart or soft tissue or something like that.

James: Yep.

Researcher #1: And then maybe you put it down and it goes away or something like that, I'm not sure.

James: Yeah… that's a very interesting concept. And then like if you pick up a hand piece, a high speed or low speed hand piece, you can go into the chart or the template for doing a filling or a crown, give you a menu, what're you doing, why're you using this high-speed hand piece, is it a crown or is it a root canal or that kind of thing.

Researcher #1: So you think there's a couple of scenarios for you to use something like that?

James: Yeah, yep, for sure. Yep, that'd be great.

Researcher #1: Ok.

James: They already have the sensors on the bracket table.

Researcher #1: So that when you pull them out they turn on, yeah it's very similar.

James: Yep, very simple to connect up. That's a really good idea.

Researcher #1: So how accurate is that scenario? Is this something you would do generally?

James: Pretty much. It really depends on the patient and the appointment. Probably half the time we're doing a check up and we don't really know what we're going to be doing. The patient's booked in with a tooth-ache or a hole or a lost filling or something like that. So I mean we can probably make an assumption it's a filling but not necessarily and in those cases we always do a checkup. But if they're a repeat patient and we've done a treatment plan for them and they're going to come back and it's visit three and we know we're going to do a few fillings up there… that's where we know… we don't generally do an exam.

Researcher #1: Ok.

James: So there could be another parameter – “Is this an existing treatment plan we’re going through?” and in fact PracticeWorks knows that.

Researcher #1: So when I brought up that screen before on the patient. So this has got something like… so let’s recall appointment. Is this the screen that might indicate

James: What it’s going to be. That’s a 40 minute appointment and this is what they’re going to be doing. A 114 which is a clean, a couple of x-rays and a check up.

Researcher #1: For that appointment.

James: Yeah, and obviously if you’ve got a full treatment plan when we make the appointment, we’ll clip on which appointment it is. Because when we do a treatment plan we schedule each appointment every day as well as we can.

Researcher #1: Yep.

James: So it’s already got it on there what it’s doing. So that could also be a cue that the program could use.

Researcher #1: Ok. Cool, well that’s really interesting. And these would… was I right in saying these are typically the tools… I mean, we see the mirror a lot, and

James: The mirror’s used for virtually everything. You can use the sickle probe with the mirror just before starting the filling, just to check “ok, oh this is the area where the decay is” or “do we need to go to the back part of the tooth or only on the front part of the tooth?” But we wouldn’t necessarily be doing a full, I mean, we wouldn’t need to open up an exam for that one, even though we picked up those instruments there.

Researcher #1: Yeah, yep, I think there'd be instances where you picked up the instruments but didn't necessarily want to see what was... [trails off] But yeah that's something we're interested in, and I'm not sure.

James: Yeah the mirror and probe are used for virtually every procedure that we do, even if it's just for a bit of torture.

[laughter]

Researcher #1: Yeah that's right, so it's up and down a lot and I suppose if it's not on here then it might be still being used. Well we noticed in the dental school they often keep their instruments on the bench as well, so I mean, it might not be being used, but it could be put somewhere else.

James: Yeah. I don't really have room to put it anywhere else, so if it's not being used, it's on the bracket table, but on the odd occasion I've found I've put it in the dirty area.

Researcher #1: Sorry? The bracket table is the…?

James: The bracket table is our table, that's what it's called.

Researcher #1: Oh okay.

James: So I do on occasion find I've put it in the dirty area.

Researcher #1: Ok. So we're just using a Lego Mindstorms kit, just with three touch sensors and just an infrared connection. So it's something, you could have this wired into, cause you already have this table wired up to do various things.

James: Yeah it wouldn't be too much to wire that and add a few sensors or something like that. So that was purely by feel that it recognised you lifted up the mirror and probe… just a touch sensor was it?

Researcher #1: Yeah, the weight in the table just drops – it doesn't actually know that I've picked up the mirror in this case, we're just picking up 20g or whatever it might be. Yeah that's the way it's set up at the moment, but the problem I suppose with trying to detect which instrument is that they're not always laid out nice and pretty, they can be mixed up and that might even change the weight of the table.

James: Unless they were all encoded with some identifier that told the computer what the instrument was, that'd be very difficult.

Researcher #1: And then you have the problem of not being able to sterilise the tools.

Researcher #2: Unless they're a different colour or something each, and then you have a camera just detecting the colour.

Researcher #1: So that's where we at at the moment.

James: Gee I haven't seen a number 49 plugger in a while. We don't do amalgams at all, and that's used virtually exclusively for amalgams.

Researcher #1: Yeah we got these from the dental school.

[conversation]

James: We were talking last time about a mirror with a little screen in it. Have you thought at all about that one?

Researcher #1: It's something we've been thinking about, but we really haven't…

Researcher #2: A week after we had that discussion there was an article in New Scientist about having a two-way mirror…

Researcher #1: So the technology's out there, it's just big I think…

James: Right…

Researcher #2: It's just about compacting it to something that size.

James: Again, that you can sterilise somehow or other.

Researcher #2: Yeah, they're bringing out gadgets that charge by induction, so if you could perfectly seal it and then just have the battery get charged by induction it'd be doable – and they're getting the size of things down.

Researcher #1: Yeah that's a really interesting idea as well.

James: Yeah, it'd have to be still small and compact – not too thick either. Because sometimes you need it right up the back. And you need it as thin as possible because you want to hold the cheek out of the way and still see and get a drill hand piece up there. If you've got that much thicker than it is now, it's just not much space.

Researcher #2: I'm sure within 10 years, they'll be cramming electronics into something that size, but all we can do now is create a larger prototype. Something we'll talk about anyway.

Researcher #1: So that's the main thing we wanted to talk to you about today.

[conversation]

Section B: 27th February 2004 – Dental Lecturer interview

Alison: …during treatment, you're more likely to be going back, you're able enough throughout treatment… this thing, whatever that was, you need just at the beginning, but to check your radiographs, I mean you may do that three or four times during the course of the particular treatment for that patient. So that would be another [muffled]

Researcher #1: So I guess what we'd do for something like that is look at some of the other actions maybe away from the bracket that led up to the use of the radiograph and try and…

Alison: Well you're obviously going to have to stimulate the sensor when you want to see a radiograph, so you're maybe even have some particular area on this you can actually touch [points at the sensing table]

Researcher #1: Don't know, you could, I guess kind of like these. [points at bracket table]

Alison: I mean, almost like these, almost like this, if you want to tip the chair or try and put the light on or if you want water, you press one of those. If you've got a series of buttons there, one is radiograph, one is chart, one is treatment plan, one is medical history, that you actually just touch that, and that will just flip between … I don't know, I don't have any idea, don't ask me, I'm not a computer person. If you're going to alert the thing and you've got a sensor there I would've thought that made sense to actually have a point on that you can just touch rather than necessarily even having to pick up an instrument. So what you've actually got is a touch pad somewhere where you can just touch whichever one you want, it's probably only four or five, so you can pick which one you want. With the radiograph you'll go backwards, and forwards… and things like medical history, and initial charting, you'll only want to see at the beginning, but radiographs will be the one that you'll be referring to all the way through.

Researcher #1: Yeah, definitely.

Alison: As you quite rightly say, those two are very non-specific, they're really universal instruments. A perioprobe maybe if you're wanting to check perion pockets, because periodontists have periodontal charting, and that might pick up periodontal charting, which is not done in this clinic, but definitely for treating gums and things you've got a separate chart for charting the gums, which would again would go on this thing there, so I could see the sense in a perioprobe which is this one here being tied to that.

Researcher #1: Hmm…That's an interesting idea, you've got the space here for another four buttons.

Alison: Well you could either put them there or could you put them on here?

Researcher #1: Yeah, you can put them wherever.

Alison: Well that strikes me as being another alternative.

Researcher #1: So how come, why would you prefer to have them on here instead of on then?

Alison: No reason at all, I don't know, I don't know how easy it is, I've got no idea. No particular reason. I just thought because you've got a sense of that, I didn't know if you had to put it through to there. But you probably need to just sort of sit and work it out with the students anything else, you know, you've only got my view there, as to what students, when they see, what will be useful.

Researcher #1: Mmm…

Alison: So presumably at some stage, I mean we'll end up with voice activated computers so you can actually dictate your treatment plan. I guess you've got potential for more than four buttons anyway.

Researcher #1: We did have some basic voice recognition hooked up to this as well so you could, where's my patient chart again?, so you could flick between these different charting types, I'm not really sure what these are, I've never seen them before. Yeah but we did have something for that, so that was a combination of your physical actions

Alison: And your voice…

Simultaneously: Yeah.

Alison: But does it, does it respond to any voice? I don't know much about this at all, or is it specific voice activated?

Researcher #1: It's specific yeah, you've got like a …

Researcher #2: Do you mean a particular voice, or a particular phrase?

Alison: Yeah (during "particular voice")

Researcher #2: The voice recognition we've been playing with works with anyone, but you can only say really specific phrases, you can't just talk regularly and have the computer understand you. If you want to do that you have to train for a particular person, so there's a trade off there, and the training takes pretty much a day.

Alison: So the reality is to voice chart, is not to provide a whole series of charting as you heard the students do when they have a new patient and go through every tooth, that would be more complicated than just a phrase, like "examination" or "periochart". [muffled]

Researcher #2: Yeah, exactly.

Researcher #1: Do you want to show your pen, [Researcher #2]?

Researcher #2: So I've been having a look at… when I was talking with Chris, she was telling me about how many times the records are transcribed once the person has written down. So if the student marks it down on the throw-away bit of paper and in the end transcribes it to their record book, and then it goes out to reception and gets transcribed again, is that right?

Alison: Yes, yes…

Researcher #2: And so we were talking about the idea that you could just write things down once and what you wrote down was recorded digitally then it'd certainly make things a lot easier. So what I've done is converted part of the record onto digital paper. It's just like regular paper, except it has these dots on it, which tell the pen where it is… [garbled]. So you can actually just write wherever and it just comes up on the computer afterwards.

[long silence while Alison fills out the form]

Cool, that's great, I had no idea how that got filled out. So it should just be a matter of…

Researcher #1: Sorry [Researcher #2], I'm left handed.

Alison: I hate left-handed students. I just had left-handed students giving their first injection and it was nerve-wracking. Nerve-wracking for everybody. They give it on each other which is a very good way of being a patient and knowing the receiving end.

Researcher #2: So I think it's just downloading, I'm not sure what's happening here.

Alison: Is that cleanable or sterilisable or what?

Researcher #2: Well yeah, that's one thing I wanted to talk to you about. Because when they use pens in the surgery, don't they just wrap them in glad wrap?

Alison: Yes, they do.

Researcher #2: So would that be alright for that?

Alison: Yes, that could be alright because they wouldn't be touching… touching the tool. So that could be wrapped in glad wrap, and probably wiped down with disinfectant afterwards, would that affect anything?

Researcher #2: No, it's sufficiently packaged so you can wipe it down.

Alison: Isn't that neat? Isn't that cute?

Researcher #2: I'm not sure what's.

Alison: My writing's appalling anyway, so we'll see what happens.

Researcher #2: It's downloaded it, but the software's not loading – [Researcher #1]?

Researcher #1: Give it a bit of a click? There it is.

Researcher #2: It just wasn't coming up for some reason. So once you've got it loaded you can then

Alison: Will it give you the writing as well? (referring to the dental record)

Researcher #2: Eventually yeah. At the moment I've just taken the notebook that it... it's actually this notebook here. Because to buy the software to generate your own forms costs $5000. So what I did was I just got the notebook and digitally removed all this stuff so when you write on it, it still shows this background and I haven't figured out how to make it show…

Alison: …the other bits. So when you come to charting, how do you get onto the next page?

Researcher #2: It will be possible. [over the top of Alison]

Researcher #2: It's just over here, so it looks strange just sitting there, but one thing you can do is select things and move them around.

Alison: That's what's so scary isn't it? You can really can digitally manipulate records.

Researcher #1: Mmm.

Alison: Yes, you'd obviously have to have the background as well. So then you can copy that, or…?

Researcher #2: Yeah or you can even convert it to Microsoft Word and make it part of a Word document or whatever. And it's got some handwriting recognition but I've got this feeling that the trial has expired. Here we go.

Alison: So you actually just picked that up?

Researcher #1: How accurate was it?

Alison: Well it was alright. It was alright for the ones I'd written better, but for the other ones it's my writing. But you know… it's a bit like when you actually copy something and you actually use a scanner I mean again it doesn't use…

Researcher #2: This is actually a pretty basic recognition program, it's not particularly good compared to other ones I've seen.

Alison: Well I mean it picked up that bottom one and I wasn't making any effort to make it readable and I could've made it much better than that.

Researcher #2: Well, the idea behind it wasn't, I mean, this might be a nice bonus having it able to recognise it, but just so you can have an exact copy, because just from looking at the student's records, they don't tend to write in nice neat lines and stick between them and stuff they just tend to write whatever on the page so if we could have an exact copy of what they see in front of them on the computer and you print it out for whoever needed a copy, is sort of the idea behind it.

Alison: That’s very neat actually.

Researcher #2: So that’s it, imported into Microsoft Word. The other thing you can do is if you want to add stuff at the end…

Alison: So really very interesting legal point actually about records – because records you’re not meant to change and that’s one of the concerns about digital stuff and things – x-rays can be doctored and all sorts of things can happen to them.

Researcher #2: So at the end of a session, you wouldn’t really be allowed to to add text?

Alison: You shouldn’t do, you shouldn’t do – your records should be, you shouldn’t really come back a week later.

Researcher #2: No, no, like after the patient’s gone and you’ve finished writing.

Alison: Ah yes, you could at that point, yeah.

Researcher #2: Yeah, so… um, yeah anyway. So, I don’t know, do you see benefits in that system…or?

Alison: Yes, I think so actually, I think so. Again, you’d have to have a clinic which is completely set up for it, but I can see that… you see Chris has to transcribe it – I didn’t put item numbers and things like that, that’s what she needs to transcribe to the other records – so she needs, you know, to save her searching through everything, it might be, you know, it might well be…

Researcher #2: So, I was just thinking in terms of impact on a surgery, for example, here, no one uses computers. But if you just had a little cradle thing put in at each desk, and then when you put the pen in it sent all the pages over to the office then you could keep all your existing work practices, and just make life a bit easier for Chris I guess.

Alison: Yeah, no, I think it's an interesting concept actually, it's very neat. Very impressive. Very impressive. How much does that cost?

Researcher #2: I think it was $150.

Alison: Really? Then you've got to have the program obviously…

Researcher #2: The program came with it…

Alison: Really? That's not that bad.

Researcher #2: It's better than what I thought.

Alison: And then you can put it on to a Word document?

Researcher #2: Yeah, and the new pens actually..

Alison: That's actually very neat!

Researcher #2: The whole idea is mostly for business people who take notes during meetings and then have a searchable version of it – and at the end of each page you can put in keywords – it has better recognition in these boxes – and you can search for keywords lately and then you can actually just automatically send it as an email later on.

Alison: I think it's very neat – I love it. That's very neat. Yes, no I can see that could have some… and once you've actually got it onto there you can change it? I mean really, once you've actually got it into typed words, you can then modify and change it or correct any mistakes.

Researcher #2: Yeah, if you've added some stuff you've realised is wrong you can just select it… oh, it's going to delete the whole page. I think I had to click edit page first.

Alison: [laughter] Alright, but you could actually...

Researcher #1: Once you've used the software.

Researcher #2: I've actually been more focussed on actually getting the dental record working with it.

Alison: I think that's very neat, I think that's really neat – as I said the dental record, obviously, you'd have to get the whole thing which would be an expensive exercise, but once you've got it done.

Researcher #2: Just for prototyping purposes.

Alison: I think that's good.

Researcher #2: Cool, well, [Researcher #1] do you want to run your game?

Researcher #1: I'll show you... um, I don't know if we've got time to run the game.

Section C: 1st October 2004 – Scott interview

Written from the author's own perspective.

First thing Scott does is look at my record before he's cleaned his hands. This gives him a chance to shake my hand, say hello, and then as the assistants prepped me, he was able to turn around and bring up my record. I've told him that I've come in for a suspected cracked tooth (as I've had the symptoms before and thus had some idea of the cause) and have given him the area the pain is coming from. With this information, he knows to look at the history on my chart of that area of teeth.

He brings up my patient chart by double clicking on my name in his patient list for the day. He does not look me up from the patient list – I assume the patient list is used by the reception staff for scheduling purposes. Upon seeing that I have had fillings in that area, he brings up my digital x-ray. He then uses the enhance tool to zoom and highlight aspects of the x-ray.

While he is talking to me about determining whether it's a cracked tooth, he is using the mouse pointer to gesture where he is talking about. He also compared x-rays between 18 months and 36 months ago. He begins to think it might be worthwhile having another x-ray done, but before he does so he needs to check whether or not there has been an x-ray done which has not been scanned. He then goes to the tooth history (from a tiny button on the left hand side of a row of buttons on the upper right of the patient chart) and scrolls through my history to check for x-rays. He finds another one that has not been scanned and checks my physical record. It's not inside that so he sends an assistant to go check the archives for the x-ray.

While the assistant goes in search of the patient record Scott then washes his hands. It is interesting to note he is wearing a ring. While the assistant is out of the room he also takes the opportunity to put the bib on me and hand my some glasses. He then grabs some gloves and a mask to wear. During this time he also asks me questions regarding the symptoms of my tooth – how much pain I've had, sensitivity, what triggers it, etc. He also puts on his glasses at this point.

I am now seated in the chair and ready to go. However the assistant returns with some x-rays so Scott leaves me to go look at them to my right, close by. As he interprets them, he continues putting on his gloves without looking. Apparently these are old x-rays (2001) and the 2003 x-rays cannot be found. He brings up the tooth history chart again and checks the exact date and compares it to the scanned record. I think he finds that he actually does have the most recent record scanned but it is hard to tell as there is no communication as to what has happened (that we can hear anyway).

Scott then begins the procedure here and sits just to the right of my head with the bnacket table to his right but very close by. It should also be noted there is a lot of noise in the room – running taps, suction used in my mouth, a radio, drawers being opened and closed, instruments put on metal trays, etc.

(5:42)

The procedure takes place here. Much of the time is spent inspecting my mouth and asking questions regarding symptoms etc. I am made to take bite tests. The dental assistants are very active in the background but I am not sure what they are doing (not visible). During the initial examination the assistant is not present but then she sits down just in time to hand Scott an attachment he requires and then begin holding the suction tube as he examines my teeth for other cracks and fillings. (8:32) The timing is amazing, and it is fairly obvious they have worked together before. (9:45) Dead hand syndrome takes place here where both Scott and the assistant hold their hands very close to them, and almost perfectly still, or with small gestures to allow for infection control.

(12:29) Normal checkup begins.

(17:16) Upon concluding the check up, as I rinse, Scott brings up the patient chart again. He then selects (after scrolling through the list for a while, moving both up then down again) glass ionomer and applies it to my teeth.

It is interesting here to see that at my last check up, on the 2nd of February 2004 the following notes are entered:

“monitor 8s, and reassess next recall, stay or remove??” – I believe this refers to my wisdom teeth.

(18:01) He then places a “watch” label on my bottom right tooth which had some sign of decay and cracking showing. He then ticks off the fact that the check up has been done and updates the recall (by pressing a large button on the bottom right of the patient appointment plan). (18:50) Scott removes his glasses and throws away his gloves, and washes his hands again, but without soap. His gestures are now markedly larger and more informative then while he was wearing gloves.

(21:54) Questions regarding the computer begin. Scott points out that a protective barrier covering the mouse has been removed by the assistant and therefore he can use the computer again with his “semi-clean” hands. This is when he types notes, whereas before he was just updating the patient record.

He then brings up my patient history and puts through the “periodic checkup” for billing. He adds clinical notes to my history as follows:

Cts associated with the DP cusp of the upper 7. Pain on release of pressure (some correction here) and pt noted discomofort (sic) (error correction) with small hard foods of a short sharp nature. Transillumination (many errors corrected here) reveals the presence of crack lines running throught (sic) (more corrections) the Dp cusp and through the distal marginal ridge. Appointment to (24:15) be made to removed (sic) existing filling and to investigate crack.

He then right clicks on it and sends it to history. He adds more notes for future check ups.

Distal marginal ridge crack. Small occlusal pit to monitor.

Finally he makes changes to the cost of my next appointment. I think they are potential outcomes for my next appointment as he adds both the amalgam and the glass (temporary) fillings. There is also a 114 and a 121 fee which are not self explanatory. He adjusts the cost of the glass filling from Price 2 to Price 1.

I then ask what happens between my screen and the next patient's screen. If Scott needs to see who's coming next he uses his appointment screen. If he then clicks on their appointment and click patients it brings up their chart. If he was within my chart he simply double clicks on the door and it brings up his entire list of patients for the day. He can look up his paper printout and open the next patient that way. If the next patient has arrived the door icon adds a person and when he clicks on that it brings up only that person (but still must be accepted). (27:18) When a chart for the next patient is opened the icon changes to a seated person.

(27:40) I ask why the dentists have the other dentists' appointments shortcuts at the top of their screen, represented by their initials. The main reason is that each computer is used by all dental staff, in particular scout nurses. Scout nurses are assistants who are generally available and go from room to room as they are needed, particularly for cleaning. This is an interesting example of how the computer needs to be used by a diverse group of people but is setup to generally serve one person. This is their workaround as "artful integrators" to allow effective community access.

(28:15) Scott discusses the use of the scheduling system to see if other dentists are with a patient or not. Since the dentists at [Dental Surgery #2] are usually punctual, this system appears to work fairly well, but I am sure there are times where the dentist appears busy where he's not and vice versa. He also uses it to see whether a dentist is actually there at the practice (given there are 8 dentists at the practice, this becomes a useful tool). I then ask him where he usually checks this information. Scott replies that he usually performs these tasks in his personal office, but it does "depend on the situation" and sometimes will check at the end of a procedure.

(28:45) I confirm that the assistants use the computer as well. Scott explains that if a dentist is away the scouts will set up the computer differently to normal. They open up multiple dentists' windows (all of the dentists whose surgeries they are required to monitor) so that they can keep track of how they are needed more effectively.

(29:50) At this point I ask how their software was configured so that it was useful for them. EXACT came in in 1996 to set it up originally, but they have migrated these settings and made adjustments themselves. There are two dentists responsible for the computer system and they handle the configuration and evolution of the system as it is needed. Some of the configuration options they have set, for example (31:25) using different coloured texts for different dentists has been suggested by EXACT and tested and found to be useful. Perhaps I should find examples of configurations which have been less useful and discarded or even problematic. (32:00) I ask here how they decided on the system to start with. Scott explains it was before his time and done by EXACT. He then continues to show me how the patient history is set up.

(33:06) We are interrupted here by Scott being paged by the receptionists. In a way, this can be seen as a human speech recognition system. The phone beeps to let Scott know that there is about to be an announcement. The receptionist then announces that the next patient has arrived. Scott can then pause from his conversation (or normally, from his procedure) for a moment and simply call back “thank you”. He now knows that his next patient has arrived without having to check the computer screen and the staff/patient know that he knows they have arrived.

(33:10) Xrays seem to be very important. This is signified in that fact that there are only two shortcuts – one to the patient list and one to the x-rays (other than the shortcuts to other dentists).

(33:30) Many of the other functions are used primarily by the front desk. (33:48) Scott confirms this that accounts and payments and personal details are used by the front desk while the history and patient chart/x-rays are used by the dentists.

(34:16) I question here whether or not there are any periodontists at the surgery. While there are no dedicated periodontists it seems implied that all dentists there have training in at least measuring the periodontal state of a patient.

Researcher: “Do you ever use [the periochart]?”
Scott: “Not all that regularly – it’s a bit cumbersome. It’s a situation where you need to go from the patient to the computer on a repeated basis so when you have to keep

coming back and doing a lot of data entry, it gets too difficult. You've still got the issue of dirty hands operating the computer, and even though we've got barrier techniques we still try to minimise interaction with the computer."

Researcher: "So the periochart would be somewhere where you'd…"

Scott: "…definitely have voice recognition. Maybe gesture and voice."

Scott: "It's underutilised for those reasons. Having some sort of voice or gesture activation to use the charting would be the biggest benefit I think."

This is extremely interesting. The software offers the ability for the dentist to chart the periodontal information, but it is not used because it is simply too hard. There is no way to "artfully integrate" around this problem easily.

(35:40) General notes about the remaining discussion:
Coding of the teeth – is it memorised? How do they access it? Type of notation mentioned, etc.

Digital pen, Bluetooth headset, gyroscopic mouse shown to Scott, feedback gathered. Interest shown in the notebook for everyday use. Same question as Alison - how much does it cost?

Throat microphones, options of headsets discussed. Fixing the Bluetooth microphone to the glasses Scott uses or in his pocket would be useful.

Discussion of breaks in concentration in using the computer. Main benefit of voice/gesture is that they can reduce those breaks. Types of notes he wants to record discussed.

Section D: 11th April 2005 – Scott interview

Descriptions added from the author's own perspective.

I begin by checking if it is okay to record the conversation we have with just audio. I pull out the laptop, plug it in and begin setting it up while talking to Scott. It should be noted that throughout the voice recognition tests, there are other people in the room preparing for the next patient and plenty of ambient noise from the surgery providing an effective context for testing.

Researcher #2: Basically, at the moment I just want to get the perioprobe stuff working with a voice interface. So all I really want to do right now is see if it recognises your voice at an acceptable level and to also ask you a few questions about how you use the software and how you might like the prototype to work. So I'll just check if it's [the bluetooth audio] working...

I then proceed to turn on the Bluetooth headset and attach the Bluetooth dongle to the laptop. You can hear the Bluetooth connection be successfully made with the laptop. Then there is a period of silence as I try to troubleshoot it

Researcher #2: Of course it wouldn't wo- oh no, there we go. "Hello". I don't know if the internal microphone is picking it up or this one. "Hello". I have a feeling it is the internal one. [You can hear the Bluetooth connection being connected and disconnected as I try to override the internal microphone]. It's crazy, I guess it wouldn't be a prototype if it worked perfectly. [Scott laughs].

Unidentified female: What're you practicing?

Scott: We're trying to...

Unidentified female: communicate

Scott: [Researcher #2]'s doing a PhD on voice activation prototypes and transferring of data to the computer whilst doing dental work, charting, that's right.

Unidentified female: Oh, in the surgery, that's right. You've been here before haven't you?

Researcher #2: Yeah, a few times. [Bluetooth connection noises continue]

Scott: He's just getting some things set up for me to trial out so that when he comes in for his checkout he can have a bit of a play.

Scott and Unidentified female: [private conversation while I continue working on the prototype. I end up silencing the internal microphone which then allows the Bluetooth headset to work.]

Researcher #2: Okay, all working, thank goodness.

Scott: All working?

I then hand Scott the headset which he tries to put on unsuccessfully. He puts it on backward on the incorrect ear.

Scott: I just clip this on my ear?

Researcher #2: Which ear do you think you'd prefer it on? Left or right? That's set up for your right ear at the moment

Scott: Is it? Oh okay.

Researcher #2: It's so fiddly. So I'm guessing we'd just attach it to your glasses like that [Scott has accidently removed the ear hook and I am holding the microphone out by itself] on the day. [I then attach the ear hook and show him the correct way of putting it on]. You just flip it out, hook it on, and then [garbled]

Scott: Ok.

Researcher #2: So if... so, have you used EXACT to do any periocharting stuff?

Scott: Not to a huge degree, uh, mainly because it is fiddly.

Researcher #2: Yep, but so you have done it before?

Scott: I am familiar with it, yes.

Researcher #2: So if you had a patient in here, before you started the probing, would you - what would you do in EXACT? Just load up their records and...

Scott: Bring up the patient chart.

Researcher #2: Would you look at their history and stuff first, while you've still got them in the seat, or..?

Scott: Oh yeah, it just depends on how well I know the patient as well. If it's a patient I'm familiar with, I'll be familiar with their medical history as well but certainly I might go into details. Most situations I'll start out in chart. Just the standard chart area there. Just to see if there is any pending treatment or notes that I need to refer to that I've left behind in the chart area for next time that they come in, you know if it's just a standard clean, checkup and examination appointment, then I may also go up and check x-rays. So I go over and pull up the view x-ray screen, see if I've got any previous x-rays scanned on the computer and if that's the case I'll bring them up on the screen. So, just for instance, this patient comes in, check the chart, [points to the main chart of the patient, not the perio chart], you know, I've got some notes here, go into x-rays [Moves the mouse to open x-rays within EXACT], pull an x-ray up, I'll probably leave that up there because that'll give me an idea of the areas I'm looking at. So if I want to do a periochart of her teeth, then I've got that up on the screen to look at. If I'm going to use the perio software, then I'll...

Researcher #2: So would it be handy to have a voice shortcut that brought up the periocharting stuff, or would you set it all up before you started working?

Scott: I'd normally set it all up, I guess the only thing I'd do is maybe switch between that chart and the x-ray screen.

Researcher #2: So it might be useful to have a

Scott: Link

Researcher #2: between that and x-ray. Would you look at anything else you think while you're doing the perio?

Scott: The only potential thing I would look at is notes, back in chart. But you know, you also have an ability to write notes here, so the notes will be in that chart for me to refer to too.

Researcher #2: So, all I've really done so far is focus on getting the speech working and some minor tying in so far - it's hooked up the depth measurements at the moment. So, what would you use in the perio screen, like, what order would you do things in?

Scott: I'd pick up a probe and start probing their teeth basically, start in one particular area, let's just say I start with the 1-8 if it's present and basically start from the particular area of the tooth, the back perhaps, the distal, and work through and around that tooth, and then onto the next one further in the mouth. So if I was doing a full periochart, that's what I'll do. If I'm using this facility, then obviously I need to make recordings as I go along.

Researcher #2: Recordings?

Scott: Of teeth. If I start on the 1-8 [Scott sits down at the computer and begins to demonstrate how he'd use the software during a procedure], and you start with say pocket, then I'd have to go through and enter the details there.

Researcher #2: So you'd do the pocket, then recession then mobility for each tooth, or you'd go through and do pockets for all of them?

Scott: Well the pocketing is the most, in my opinion, important information as well, because you can have pocketing without recession and mobility, but you can have pocketing in the presence of both as well. So the pocketing is what we're looking for in particular, so I always start with the pocketing and the recession you can make a note of as well as you're going along.

Researcher #2: Okay, so it might be good to have it automatically go pocketing to pocketing but then if you say a command saying "record recession" it then swaps to recession for the tooth you were just working on.

Scott: Yes, yes, and then "record mobility" if you wish to drop down to that particular area on screen as well, but I'd start in pocketing.

Researcher #2: Yep. And so,

Scott: And you'd also go, you'd do one tooth at a time. So I'd record the information on the palatal, but at the same time I'd need to go down to the buccal,

Researcher #2: on the same tooth?

Scott: on the same tooth, and record the information there as well.

Researcher #2: Ok

Scott: That would be on the upper teeth, so then I go to 7, recording pocketing, recording recession, and/or mobility, and then go the buccal surface and vice versa as we go along, and then I'd go to the lower and do the same thing.

(9:30) Researcher #2: And what about furcation? Would you record that?

Scott: Again, furcation is only recorded if it is involved. So not every tooth has pocketing, recession or mobility, necessarily has furcation involved.

Researcher #2: So would furcation might be something you leave to the end or would you want to update it as you did it?

Scott: Again, furcation involvement I would quite possibly put down at that particular point in time as well, when I'm charting that particular tooth.

Researcher #2: So what do the different - why are there six up there but only three down there (referring to the furcation grading points listed above teeth).

Scott: Sorry? (long pause as he looks at the grading points to figure out why it's so). That's a good question as to why.

Researcher #2: I'm speaking to John W. tomorrow, who is the CEO of DentalSoft, so I might ask him.

Scott: I guess because the furcation involvement can be probed from either side of the palatal root (points to the two roots on the tooth)

Researcher #2: Ah right, I see.

Scott: Whereas the furcation involvement essentially on the buccal is in between the two [garbled]. So you're only going to record it and probe that one area there [points to where the furcation grading arrow points].

Researcher #2: Ohhh, I see, sure sure. [moment of understanding reached]. So that would be left and right then? [points to the different arrows on the one tooth on the upper left of the screen].

Scott: It would be mesial and distal.

Researcher #2: So mesial is right and distal is left?

Scott: In this particular case here [points to the opposite tooth on the top right of the screen], on the upper right hand side, distal is on the left, mesial is on the right. So it's just front and back. The closer you are to the middle is mesial, the closer you are to the back of the mouth is distal.

Researcher #2: Gotcha

Scott: Approaching around that, you have one large central root on the palatal, on the inside roof of the mouth you can probe. You've got either the mesial side of the root or the distal side. [points to the different recording points]. I presume this is why they have the two recording on the upper, on the palatal I suppose to one recording on the buccal on the outside surface. And on the outside you have the two roots here and you're only going to probe it through this one [points to a hole on the both]. I'd say then it'd be different for the lower. [brings up the lower chart where it is indeed different].

Researcher #2: Yep.

Scott: The distal one. Because generally, there are only two roots back on each side, slightly different.

Researcher #2: So with the plaque and bleeding; would you just fill that out at the end later or would you want to do it as you went as well?

Scott: You'd probably go through and do that later I'd say or otherwise you'll end up flipping through too many screens. So you'd just go through and do the plaque and bleeding scores depending on...

Researcher #2: And would you want to do your notes sort of similar to how you currently do your charting notes, in that at the end you just go through and fill them out?

(13:00) Scott: How do you mean? In the chart screen? Or the notes?

Researcher #2: Yeah, the notes [points to the notes on the screen]

Scott: Yeah, at the end I'd just go through and fill out the details, or basically give a synopsis of what I've been able to discover.

Researcher #2: So the main thing would be if you could get voice recognition when you're going through and doing those annoying movements, tooth by tooth, that would sort of take the annoying fiddly stuff out of the way, and do everything normal as per otherwise?

Scott: Yep, exactly.

Researcher #2: Alrighty. We'll see if this recognises you then. [Goes over to the laptop and opens the program] So at the moment, just so you know it's registered the right thing, it'll beep at you and a higher tone is a higher number and a lower tone, etc. So one question was would you like that, the ambient noise, or would you prefer it reading back the number to you that you just entered? [computer beeps twice as we're talking]

Scott: Um.. [long pause]

Researcher #2: It might be hard to say... maybe I should bring in two versions of the software.

Scott: Yeah, possibly.

Researcher #2: So you can just try it and...

Scott: ...see what works better. It may be annoying to actually have a number called out to you.

Researcher #2: So the other thing I've done is there's a check word to try and reduce when if you're just talking normally like we are now so it doesn't just pick up everything we say. Because it's got quite a limited dictionary it can misconstrue words.

Scott: Mmmhmm.

Researcher #2: So one thing we may also try different version on the day, is different checkwords. At the moment it's just "go" and then the number. So you can say "go" "0-9" or "go back" if you make a mistake. [computer goes back a space].

Scott: It's picked up for you anyway. So... [monotone voice] "go 5". [computer beeps and inputs 5]. "go 7". [computer beeps and inputs 7]. "go 1". [computer beeps and inputs 1]. "go 9". [computer beeps and inputs 1, easily noticeable because of the low beep]. "go 9". [computer beeps and inputs 9]. [changes tone here] "go 3". [computer beeps and inputs 3]. "go 4". [computer beeps and inputs 4]. "go 5". [computer beeps and inputs 5]. "go 7". [computer beeps and inputs 7]. "go 3". [computer beeps and inputs 3]. "go 2". [computer beeps and inputs 2]. "go 2". [computer beeps and inputs 2]. "go 1". [computer beeps and inputs 1]. "go 5". [computer beeps and inputs 5]. [changes tone here] "go 8". [computer beeps and inputs 8]. Alright.

Researcher #2: Just try "6".

Scott: "go 6". [computer beeps and inputs 6]. "go 6". [computer does nothing]. "go 6". [computer beeps and inputs 6].

Researcher #2: "6" has been a really tricky one, I have no idea why. I think it's because we've had to work with a free speech recognition app - it's for Americans,

Scott: Okay.

Researcher #2: so I've been trying to train it for the Aussie accent. But it's still...

Scott: "go 6". [computer beeps halfway through from recognizing part of the conversation and inputs 7].

Researcher #2: So just...

Scott: [with American accent] "go 6". [computer beeps and inputs 6]. [with American accent] "go 7". [computer beeps and inputs 7]. [Scott laughs]

Researcher #2: Cool, well, is that sort of reasonably accurate for you?

Scott: How do you stop it?

Researcher #2: To stop it there's just a button on the side [points to the microphone] - that was another thing I wanted to ask you. If you wrap that in plastic...You could just press it

Scott: [Disapproving noise]. Probably better uh...

Researcher #2: ...if it like had a magic word to turn it off?

Scott: Yeah, okay, because you've got "go" to start it, would having another number to stop it be an option?

Researcher #2: At the moment it listens for "go" and the next word, so technically it's listening all the time [computer beeps in the background as if to punctuate this] and then trying to interpret what's going on. So if you had a magic word that completely stopped all recognition until it heard the magic word again that might be better.

Scott: Mm-hmm, yeah.

Researcher #2: I might experiment with that and see what I can come up with.

Scott: Okay, well it seems to be working.

Researcher #2: Cool, well I think that's everything I wanted to test.

Scott: Great.

Researcher #2: Is there anything else you, any questions you had about my research at the moment or anything?

Scott: No that sounds good, are you planning to transfer it across to charting as well? Like, regular charting?

Researcher #2: Um, not at this stage because regular charting...

Scott: ...is more complicated?

Researcher #2: Yeah. And I just need something simple to test out the engine so I can then say "we can extrapolate on this" and because it also seems like for you guys and the other dentists we've been talking to is that you guys don't do any perioprobing because of how difficult it is to enter the data.

Scott: I've done very few, but in most cases because it's a pain to actually record data and go through and do it, I'll go around, probe, and from what I've done I'll just pull up treatment notes, and type in what I see, so basically drop down and type in the appointment, the notes. [Scott gets interrupted here by a phone saying "excuse me Dr [Scott’s surname], your 2 o'clock patient has arrived", to which he replies "Thank you"] So I'd say like "7mm pocketing in upper right molar, this tooth and this tooth", and basically give the minimal information.

Researcher #2: Mmmhmm, yep, okay. That's partly why we're looking at the perio stuff, is just because it's simple data entry - it's just numbers - and then also because it's been something we've seen as being problematic, we can hopefully make the greatest effect.

(18:45) Scott: Yeah.

Section E: Prototype speech recognition code extract

Below is an extract from one of the speech recognition prototypes, written in Visual Basic, employing the Microsoft Speech SDK 5.1.

This code was written by Tim Cederman-Haysom, but incorporates (adapted) samples from the Microsoft Speech SDK.

PerioprobeEngine.ctl

```
VERSION 5.00
Begin VB.UserControl SpeechEngine
   ClientHeight    =   690
   ClientLeft      =   0
   ClientTop       =   0
   ClientWidth     =   1815
   ScaleHeight     =   690
   ScaleWidth      =   1815
   Begin VB.ListBox InnerList
      Height          =   450
      Left            =   0
      TabIndex        =   0
      Top             =   0
      Width           =   1575
   End
End

Attribute VB_Name = "SpeechEngine"
Attribute VB_GlobalNameSpace = False
Attribute VB_Creatable = True
Attribute VB_PredeclaredId = False
Attribute VB_Exposed = True
```

```
' Require all variable names to be defined.
Option Explicit

' See UserControl_Resize() for how iLevelInResize is used.
' It's needed to make sure our control resizes correctly.
' Needed to have a nice listbox representation of the grammar we can add to.
Dim iLevelInResize As Integer

' declare all speech related variables
Const m_GrammarId = 10                                ' grammarID is used to identify different groups of grammar.
Dim bSpeechInitialized As Boolean                     ' is speech initialized?
Dim WithEvents RecoContext As SpSharedRecoContext   ' controls the context of the recognition
Attribute RecoContext.VB_VarHelpID = -1
Dim Grammar As ISpeechRecoGrammar                     ' there can be many different grammars for each different
context, we only need one (so far)
Dim TopRule As ISpeechGrammarRule                     ' Rules for the grammar...
Dim ListItemsRule As ISpeechGrammarRule
Const SpeechOn = 0
Const SpeechOff = 1
Dim SpeechActivated As Integer
Dim ToothCount As Integer
Dim ToothQuadrant As Integer
Dim ToothNumber As Integer
Dim NumberSaid As Boolean
Dim Mobility As Boolean
Dim ToothSelect As Integer
Dim ToothChosen As String

' Variables for tracking location (context) in EXACT
Const XRAY = 1
Const PERIO = 2
Dim CurrentScreen As Integer

'Event Declarations:
Event ItemCheck(Item As Integer) 'MappingInfo=InnerList,InnerList,-1,ItemCheck
Event OLEStartDrag(Data As DataObject, AllowedEffects As Long) 'MappingInfo=InnerList,InnerList,-1,OLEStartDrag
```

```
Event OLESetData(Data As DataObject, DataFormat As Integer) 'MappingInfo=InnerList,InnerList,-1,OLESetData
Event OLEGiveFeedback(Effect As Long, DefaultCursors As Boolean) 'MappingInfo=InnerList,InnerList,-1,OLEGiveFeedback
Event OLEDragOver(Data As DataObject, Effect As Long, Button As Integer, Shift As Integer, X As Single, Y As Single,
State As Integer) 'MappingInfo=InnerList,InnerList,-1,OLEDragOver
Event OLEDragDrop(Data As DataObject, Effect As Long, Button As Integer, Shift As Integer, X As Single, Y As Single)
'MappingInfo=InnerList,InnerList,-1,OLEDragDrop
Event OLECompleteDrag(Effect As Long) 'MappingInfo=InnerList,InnerList,-1,OLECompleteDrag
Event Scroll() 'MappingInfo=InnerList,InnerList,-1,Scroll
Event Validate(Cancel As Boolean) 'MappingInfo=InnerList,InnerList,-1,Validate

'Default Property Values:
Const m_def_PreCommandString = "go to" ' The precommand string is used for making the user say a "magic word" before
a word to be recognised.
Const m_def_PreCommandStringAlt = "set" ' The precommand string is used for making the user say a "magic word"
before a word to be recognized.
Const m_def_PreCommandStringOtherAlt = "move" ' The precommand string is used for making the user say a "magic word"
before a word to be recognized.
Const m_def_SpeechEnabled = True  ' Let's enable our speech!

'Property Variables:
Dim m_PreCommandString As String
Dim m_PreCommandStringAlt As String
Dim m_PreCommandStringOtherAlt As String
Dim m_SpeechEnabled As Boolean
Private Declare Function Beep Lib "kernel32" (ByVal dwFreq As Long, ByVal dwDuration As Long) As Long



Private Sub InitializeSpeech()
    On Error GoTo ErrorHandler

    If Not bSpeechInitialized Then
        Debug.Print "Initializing speech"

        Dim AfterCmdState As ISpeechGrammarRuleState
        Set RecoContext = New SpSharedRecoContext
```

```
    Set Grammar = RecoContext.CreateGrammar(m_GrammarId)

    ' Add two rules. The top level rule will reference the items rule.
    Set TopRule = Grammar.Rules.Add("TopLevelRule", SRATopLevel Or SRADynamic, 1)
    Set ListItemsRule = Grammar.Rules.Add("ListItemsRule", SRADynamic, 2)

    Set AfterCmdState = TopRule.AddState

    ' The top level rule consists of two parts: "<magic word> <items>". So we first
    ' add a word transition for the <magic word> part, then a rule transition
    ' for the "<items>" part, which is dynamically built as items are added
    ' or removed from the listbox.
    TopRule.InitialState.AddWordTransition AfterCmdState, _
        m_PreCommandString, " ", , "", 0, 0
    TopRule.InitialState.AddWordTransition AfterCmdState, _
        m_PreCommandStringAlt, " ", , "", 0, 0
    TopRule.InitialState.AddWordTransition AfterCmdState, _
        m_PreCommandStringOtherAlt, " ", , "", 0, 0

    AfterCmdState.AddRuleTransition Nothing, ListItemsRule, "", 1, 1

    ' Now add existing list items to the ListItemsRule
    RebuildGrammar

    ' Now we can activate the top level rule.
    Grammar.CmdSetRuleState "TopLevelRule", SGDSActive

    ToothCount = 0
    ToothQuadrant = 1
    ToothNumber = 8
    Mobility = False
    ToothSelect = 0

    bSpeechInitialized = True
End If
```

```
    Exit Sub

ErrorHandler:
    MsgBox "SAPI failed to initialize. This application may not run correctly."
End Sub

Friend Sub EnableSpeech()
    Debug.Print "Enabling speech"
    If Not bSpeechInitialized Then Call InitializeSpeech

    ' once all objects are initialized, we need to update grammar
    RebuildGrammar
    RecoContext.State = SRCS_Enabled
End Sub

Friend Sub DisableSpeech()
    Debug.Print "Disabling speech"

    ' Putting the recognition context to disabled state will stop speech
    ' recognition. Changing the state to enabled will start recognition again.
    If bSpeechInitialized Then RecoContext.State = SRCS_Disabled
End Sub


Private Sub RebuildGrammar()
    ' In this funtion, we are only rebuilding the ListItemRule, as this is the
    ' only part that's really changing dynamically.

    On Error GoTo ErrorHandler

    ' First, clear the rule
    ListItemsRule.Clear

    ' Now, add all items to the rule
    Dim i As Integer
    For i = 0 To InnerList.ListCount - 1
```

```
        Dim text As String
        text = InnerList.List(i)

        ListItemsRule.InitialState.AddWordTransition Nothing, text, " ", , text, i, i
    Next

    Grammar.Rules.Commit
    Exit Sub

ErrorHandler:
    MsgBox "Error when rebuiling dynamic list box grammar: " & Err.Number
End Sub


Private Sub RecoContext_Hypothesis(ByVal StreamNumber As Long, _
                                   ByVal StreamPosition As Variant, _
                                   ByVal Result As ISpeechRecoResult _
                                   )

    ' This event is fired when the recognizer thinks there's possible
    ' recognitions.
    Debug.Print "Hypothesis: " & Result.PhraseInfo.GetText & ", " & _
        StreamNumber & ", " & StreamPosition
End Sub


Private Sub RecoContext_Recognition(ByVal StreamNumber As Long, _
                                    ByVal StreamPosition As Variant, _
                                    ByVal RecognitionType As SpeechRecognitionType, _
                                    ByVal Result As ISpeechRecoResult _
                                    )

    ' This event is fired when something in the grammar is recognized.
    Debug.Print "Recognition: " & Result.PhraseInfo.GetText & ", " & _
        StreamNumber & ", " & StreamPosition
```

```
Dim index As Integer
Dim selection As String
Dim Position As Integer
Dim oItem As ISpeechPhraseProperty
Dim Command As String

Command = Left$(Result.PhraseInfo.GetText, 3)

Set oItem = Result.PhraseInfo.Properties(1).Children(0)

' Process the speech recognized by the engine in the background
For Position = 1 To Len(Result.PhraseInfo.GetText)
    If Mid$(Result.PhraseInfo.GetText, Position, 1) = Chr$(32) Then
        selection = Mid$(Result.PhraseInfo.GetText, Position + 1, Len(Result.PhraseInfo.GetText))
        Exit For
    End If
Next Position

If selection = "" Then selection = Result.PhraseInfo.GetText

' Check to see if speech is to be activated
If selection = "speech on" Then
    SpeechActivated = SpeechOn
    Beep 975, 300
End If

If SpeechActivated = SpeechOff Then selection = ""

NumberSaid = False

' Check to see what the trailing words were and based on
' this then figure out which commands were to be activated,
' and if a magic word was said first.

' Code kept deliberately simple (read: ugly) here to allow fast on-site prototyping.
' (this is what happens to code without a spec!)  Future revisions require refactoring
```

```
' after finalization of functionality.
Select Case selection
    Case "furcation zero"
        SendKeys "^{F12}^p^0"
        Beep 50, 100
    Case "furcation one"
        SendKeys "^{F12}^p^1"
        Beep 200, 100
    Case "furcation two"
        SendKeys "^{F12}^p^2"
        Beep 400, 100
    Case "furcation three"
        SendKeys "^{F12}^p^3"
        Beep 600, 100
    Case "zero"
        SendKeys ("0")
        NumberSaid = True
        Beep 50, 100
    Case "one"
        If Command = "set" Then
            SendKeys ("1")
            NumberSaid = True
            Beep 150, 100
        End If
    Case "two"
        If Command = "set" Then
            SendKeys ("2")
            NumberSaid = True
            Beep 250, 100
        End If
    Case "three"
        If Command = "set" Then
            SendKeys ("3")
            NumberSaid = True
            Beep 350, 100
        End If
```

```
Case "four"
    If Command = "set" Then
        SendKeys ("4")
        NumberSaid = True
        Beep 450, 100
    End If
Case "five"
    If Command = "set" Then
        SendKeys ("5")
        NumberSaid = True
        Beep 550, 100
    End If
Case "six"
    If Command = "set" Then
        SendKeys ("6")
        NumberSaid = True
        Beep 650, 100
    End If
Case "seven"
    If Command = "set" Then
        SendKeys ("7")
        NumberSaid = True
        Beep 750, 100
    End If
Case "ayte"
    If Command = "set" Then
        SendKeys ("8")
        NumberSaid = True
        Beep 850, 100
    End If
Case "noine"
    If Command = "set" Then
        SendKeys ("9")
        NumberSaid = True
        Beep 950, 100
    End If
```

```
Case "down"
    SendKeys "{DOWN}"
Case "up"
    SendKeys "{UP}"
Case "back"
    If Mobility = True Then
        SendKeys "{LEFT}"
        If ToothNumber > 0 Then ToothNumber = ToothNumber - 1
    Else
        If ToothCount = 0 Then      ' Need to do some border checks here.
            SendKeys "^{F12}^p^b"   ' If we've reached the beginning of palatal, move
            SendKeys "{LEFT}"       ' to buccal, and we'll need to go to the previous tooth
            ToothCount = 5
        ElseIf ToothCount = 3 Then
            SendKeys "^{F12}^p^p{RIGHT}{RIGHT}" 'Otherwise we need to go to palatal
            ToothCount = 2                      'and get in the right spot
        Else
            ToothCount = ToothCount - 1
            SendKeys "{LEFT}"
        End If
    End If
Case "to next"
    SendKeys "{RIGHT}"
    NumberSaid = True
Case "forward"
    SendKeys "{RIGHT}"
    NumberSaid = True
Case "to exray"
    SendKeys "^{F12}^x^x"
    CurrentScreen = XRAY
Case "to payshent"
    If CurrentScreen = XRAY Then
        SendKeys "^{F12}^t^t", 0.1
        CurrentScreen = PERIO
        SendKeys "+{TAB}+{TAB}"
    End If
```

```
Case "to upper"
    SendKeys "^{F12}^p^u"
    'Need to reset the position when swapping between upper and lower
    SendKeys "^{F12}^p^g^0^{F12}^p^p"
    ToothCount = 0
    ToothQuadrant = 1
    ToothNumber = 8
Case "to lower"
    SendKeys "^{F12}^p^l"
    'Need to reset the position when swapping between upper and lower
    SendKeys "^{F12}^p^g^0^{F12}^p^p"
    ToothCount = 0
    ToothQuadrant = 3
    ToothNumber = 8
Case "to mobility"
    Mobility = True
    ToothCount = 0
    SendKeys "^{F12}^p^m"
Case "to palatal"
    If ToothQuadrant <= 2 Then               'Palatal only exists on the upper
        If ToothCount > 2 Then          'So if we're there and in the buccal section
            SendKeys "^{F12}^p^p"       'Then move to the palatal
            ToothCount = ToothCount - 3
        End If
    End If
Case "to lingual"
    If ToothQuadrant > 2 Then                'Lingual only exists on the lower
        If ToothCount <= 2 Then          'So if we're there and in the buccal section
            SendKeys "^{F12}^p^b"       'Then move to the lingual
            ToothCount = ToothCount + 3
        End If
    End If
Case "to buckle"
    If ToothQuadrant <= 2 Then               'If we're on the upper teeth and
        If ToothCount <= 2 Then          'if we're on the palatal
            SendKeys "^{F12}^p^b"       'then move to the buccal
```

```
            ToothCount = ToothCount + 3
        End If
    Else                                'Otherwise if we're on the lower teeth
        If ToothCount > 2 Then          'And we're on the lingual
            SendKeys "^{F12}^p^p"       'then move to the buccal
            ToothCount = ToothCount - 3
        End If
    End If
Case "to pocket"
    SendKeys "^{F12}^p^k"  ' need to add a variable in here so when it's in mobility mode...
    If Mobility = True Then
        ToothCount = 0                              'set the counter to 0
        Mobility = False
    End If
Case "to recession"
    SendKeys "^{F12}^p^r"
    If Mobility = True Then
        ToothCount = 0
        Mobility = False
    End If
Case "to next tooth"
    If ToothCount > 2 Then
        ToothCount = 3
    Else
        ToothCount = 0
    End If
    If Mobility = False Then SendKeys "^{RIGHT}"
    If Mobility = True Then SendKeys "{RIGHT}"
    ' Now we need to do some context detection to make sure if we need to, we can move to the next tooth
    ' elsewhere.
    If ToothQuadrant = 1 Then
        If ToothNumber = 1 Then
            ToothQuadrant = 2
        Else
            ToothNumber = ToothNumber - 1
        End If
```

```
        ElseIf ToothQuadrant = 2 Then
            If ToothNumber = 8 Then
                ToothQuadrant = 3
                SendKeys "^{F12}^p^l^{F12}^p^g^0"
            Else
                ToothNumber = ToothNumber + 1
            End If
        ElseIf ToothQuadrant = 3 Then
            If ToothNumber = 1 Then
                ToothQuadrant = 4
            Else
                ToothNumber = ToothNumber - 1
            End If
        ElseIf ToothQuadrant = 4 Then
            If ToothNumber = 8 Then
                ToothQuadrant = 1
                SendKeys "^{F12}^p^u^{F12}^p^g^0"
            Else
                ToothNumber = ToothNumber + 1
            End If
        End If
    Case "to last tooth"
        If ToothCount > 2 Then
            ToothCount = 3
        Else
            ToothCount = 0
        End If
        If Mobility = False Then SendKeys "^{LEFT}"
        If Mobility = True Then SendKeys "{LEFT}"
        ' Now we need to do some context detection to make sure if we need to, we can move to the next tooth
        ' elsewhere.
        If ToothQuadrant = 1 Then
            If ToothNumber = 8 Then
                ToothQuadrant = 4
                SendKeys "^{F12}^p^l^{F12}^p^g^f"
            Else
```

```
                TothNumber = ToothNumber + 1
            End If
        ElseIf ToothQuadrant = 2 Then
            If ToothNumber = 1 Then
                ToothQuadrant = 1
            Else
                ToothNumber = ToothNumber - 1
            End If
        ElseIf ToothQuadrant = 3 Then
            If ToothNumber = 8 Then
                ToothQuadrant = 2
                SendKeys "^{F12}^p^u^{F12}^p^g^f"
            Else
                ToothNumber = ToothNumber + 1
            End If
        ElseIf ToothQuadrant = 4 Then
            If ToothNumber = 1 Then
                ToothQuadrant = 3
            Else
                ToothNumber = ToothNumber - 1
            End If
        End If
    Case "speech off"
        SpeechActivated = SpeechOff
        Beep 75, 300

' Here is the crazy bit of individual teeth
' Future code revisions would use a lookup table, however for adjusting
' to the accent I needed to be able to spell out words differently and make
' quick adjustments.
'
' Need to set here -
'   if it's 1 or 2 then an upper command must be sent
'   if it's 3 or 4 it needs to be lower
    Case "to one one"
        ToothSelect = 11
```

```
    ToothChosen = "7"
Case "to one two"
    ToothSelect = 12
    ToothChosen = "6"
Case "to one three"
    ToothSelect = 13
    ToothChosen = "5"
Case "to one four"
    ToothSelect = 14
    ToothChosen = "4"
Case "to one five"
    ToothSelect = 15
    ToothChosen = "3"
Case "to one six"
    ToothSelect = 16
    ToothChosen = "2"
Case "to one seven"
    ToothSelect = 17
    ToothChosen = "1"
Case "to one eight"
    ToothSelect = 18
    ToothChosen = "0"
Case "to two one"
    ToothSelect = 21
    ToothChosen = "8"
Case "to two two"
    ToothSelect = 22
    ToothChosen = "9"
Case "to two three"
    ToothSelect = 23
    ToothChosen = "a"
Case "to two four"
    ToothSelect = 24
    ToothChosen = "b"
Case "to two five"
    ToothSelect = 25
```

```
    ToothChosen = "c"
Case "to two six"
    ToothSelect = 26
    ToothChosen = "d"
Case "to two seven"
    ToothSelect = 27
    ToothChosen = "e"
Case "to two eight"
    ToothSelect = 28
    ToothChosen = "f"
Case "to three one"
    ToothSelect = 31
    ToothChosen = "8"
Case "to three two"
    ToothSelect = 32
    ToothChosen = "9"
Case "to three three"
    ToothSelect = 33
    ToothChosen = "a"
Case "to three four"
    ToothSelect = 34
    ToothChosen = "b"
Case "to three five"
    ToothSelect = 35
    ToothChosen = "c"
Case "to three six"
    ToothSelect = 36
    ToothChosen = "d"
Case "to three seven"
    ToothSelect = 37
    ToothChosen = "e"
Case "to three eight"
    ToothSelect = 38
    ToothChosen = "f"
Case "to four one"
    ToothSelect = 41
```

```
        ToothChosen = "7"
    Case "to four two"
        ToothSelect = 42
        ToothChosen = "6"
    Case "to four three"
        ToothSelect = 43
        ToothChosen = "5"
    Case "to four four"
        ToothSelect = 44
        ToothChosen = "4"
    Case "to four five"
        ToothSelect = 45
        ToothChosen = "3"
    Case "to four six"
        ToothSelect = 46
        ToothChosen = "2"
    Case "to four seven"
        ToothSelect = 47
        ToothChosen = "1"
    Case "to four eight"
        ToothSelect = 48
        ToothChosen = "0"
End Select

If ToothSelect > 0 Then                  'Here we need to figure out the identification of the tooth selected
    Beep 1300, 200
    Dim TempKeys As String
    If ToothCount >= 3 Then
        ToothCount = 3
    Else
        ToothCount = 0
    End If
    ToothQuadrant = ToothSelect / 10
    If (ToothQuadrant * 10) > ToothSelect Then ToothQuadrant = ToothQuadrant - 1
    ToothNumber = ToothSelect - (10 * ToothQuadrant)
    Debug.Print ("ToothSelect " & ToothSelect & " ToothQuadrant " & ToothQuadrant)
```

```
    If ToothQuadrant = 4 Then
        ToothQuadrant = 3
    ElseIf ToothQuadrant = 3 Then
        ToothQuadrant = 4
    End If
    If ToothQuadrant < 3 Then TempKeys = "^{F12}^p^u^{F12}^p^g^" & ToothChosen
    If ToothQuadrant >= 3 Then TempKeys = "^{F12}^p^l^{F12}^p^g^" & ToothChosen
    SendKeys (TempKeys)
    ToothSelect = 0
End If

' Here we allow for some automatic movement within the mouth while charting
If NumberSaid = True And Mobility = False Then
    ToothCount = ToothCount + 1
    If ToothCount = 3 Then
        SendKeys "^{F12}^p^b"   ' If we've reached the end of palatal, move to buccal, and we'll need to go to
        If (ToothQuadrant = 1) Or (ToothQuadrant = 3) Then SendKeys "^{LEFT}"      ' the previous tooth
        If ((ToothQuadrant = 2) Or (ToothQuadrant = 4)) And (ToothNumber < 8) Then SendKeys "^{LEFT}"
        If ((ToothQuadrant = 2) Or (ToothQuadrant = 4)) And (ToothNumber = 8) Then SendKeys "{LEFT}{LEFT}"
    End If
    If ToothCount = 6 Then
        SendKeys "^{F12}^p^p"
        ToothCount = 0
        ' Here we need to now correctly adjust for which tooth we're moving to depending on the quadrant
        Select Case ToothQuadrant               'Check for our border cases
        Case 1
            If ToothNumber > 1 Then             'If we're anywhere but the end, decrement by 1
                ToothNumber = ToothNumber - 1
            Else
                ToothQuadrant = ToothQuadrant + 1  'Otherwise we're in a new quadrant
            End If
        Case 2
            If ToothNumber < 8 Then
                ToothNumber = ToothNumber + 1
            Else
                ToothQuadrant = (ToothQuadrant + 1) Mod 4  ' same deal again
```

```
                SendKeys ("^{F12}^p^l^{F12}^p^g^0")
            End If
        Case 3
            If ToothNumber > 1 Then             'If we're anywhere but the end, decrement by 1
                ToothNumber = ToothNumber - 1
            Else
                ToothQuadrant = ToothQuadrant + 1  'Otherwise we're in a new quadrant
            End If
        Case 4
            If ToothNumber < 8 Then
                ToothNumber = ToothNumber + 1
            Else
                ToothQuadrant = (ToothQuadrant + 1) Mod 4  ' same deal again
                SendKeys ("^{F12}^p^u^{F12}^p^g^0")
            End If
        End Select
    End If
ElseIf NumberSaid = True And Mobility = True Then 'If we're in mobility mode we need to detect where we are
        Select Case ToothQuadrant                 'Check for our border cases
        Case 1
            If ToothNumber > 1 Then               'If we're anywhere but the end, decrement by 1
                ToothNumber = ToothNumber - 1
            Else
                ToothQuadrant = ToothQuadrant + 1  'Otherwise we're in a new quadrant
            End If
        Case 2
            If ToothNumber < 8 Then
                ToothNumber = ToothNumber + 1
            Else
                ToothQuadrant = (ToothQuadrant + 1) Mod 4  ' same deal again
            End If
        Case 3
            If ToothNumber > 1 Then             'If we're anywhere but the end, decrement by 1
                ToothNumber = ToothNumber - 1
            Else
                ToothQuadrant = ToothQuadrant + 1  'Otherwise we're in a new quadrant
```

```
                End If
            Case 4
                If ToothNumber < 8 Then
                    ToothNumber = ToothNumber + 1
                Else
                    ToothQuadrant = (ToothQuadrant + 1) Mod 4  ' same deal again
                End If
            End Select
    End If

    ' To aid prototyping
    Debug.Print ("Tooth count: " & ToothCount)
    Debug.Print ("Tooth number: " & ToothNumber)
    Debug.Print ("Tooth quadrant: " & ToothQuadrant)

    If Result.PhraseInfo.GrammarId = m_GrammarId Then

        ' Check to see if the item at the same position in the list still has the
        ' same text.
        ' This is to prevent the rare case that the user keeps talking while
        ' the list is being added or removed. By the time this event is fired
        ' and handled, the list box may have already changed.
        If oItem.Name = InnerList.List(index) Then
            InnerList.ListIndex = index
        End If
    End If
End Sub


Private Sub UserControl_Initialize()
    iLevelInResize = 0
    bSpeechInitialized = False
End Sub

Private Sub UserControl_Resize()
    ' When the user control is resized, the inner listbox has to be resized
```

```
    ' so that it takes up all the area.
    iLevelInResize = iLevelInResize + 1

    If iLevelInResize = 1 Then
        InnerList.Move 0, 0, Width, Height
\        Height = InnerList.Height
        Width = InnerList.Width
    End If

    iLevelInResize = iLevelInResize - 1
End Sub

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,AddItem
Public Sub AddItem(ByVal Item As String, Optional ByVal index As Variant)

    ' Since we can't add the same word to the same transition in the grammar,
    ' we don't allow same string to be added multiple times.

    Item = Trim(Item)

    If Item = "" Then
        Exit Sub
    End If

    If InnerList.ListCount > 0 Then
        Dim i As Integer
        For i = 0 To InnerList.ListCount - 1
            If StrComp(Item, InnerList.List(i), vbTextCompare) = 0 Then
                Exit Sub
            End If
        Next
    End If

    ' if it doesn't exist yet, add it to the list
    InnerList.AddItem Item, index
```

```
    ' if speech is enabled, we need to update the grammar with new changes
    If m_SpeechEnabled Then RebuildGrammar
End Sub

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,Appearance
Public Property Get Appearance() As Integer
    Appearance = InnerList.Appearance
End Property

Public Property Let Appearance(ByVal New_Appearance As Integer)
    InnerList.Appearance() = New_Appearance
    PropertyChanged "Appearance"
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,BackColor
Public Property Get BackColor() As OLE_COLOR
    BackColor = InnerList.BackColor
End Property

Public Property Let BackColor(ByVal New_BackColor As OLE_COLOR)
    InnerList.BackColor() = New_BackColor
    PropertyChanged "BackColor"
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,CausesValidation
Public Property Get CausesValidation() As Boolean
    CausesValidation = InnerList.CausesValidation
End Property

Public Property Let CausesValidation(ByVal New_CausesValidation As Boolean)
    InnerList.CausesValidation() = New_CausesValidation
    PropertyChanged "CausesValidation"
```

```
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,Clear
Public Sub Clear()
    InnerList.Clear
End Sub


'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,Columns
Public Property Get Columns() As Integer
    Columns = InnerList.Columns
End Property

Public Property Let Columns(ByVal New_Columns As Integer)
    InnerList.Columns() = New_Columns
    PropertyChanged "Columns"
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,DataMember
Public Property Get DataMember() As String
    DataMember = InnerList.DataMember
End Property

Public Property Let DataMember(ByVal New_DataMember As String)
    InnerList.DataMember() = New_DataMember
    PropertyChanged "DataMember"
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,DataSource
Public Property Get DataSource() As DataSource
    Set DataSource = InnerList.DataSource
End Property
```

```
Public Property Set DataSource(ByVal New_DataSource As DataSource)
    Set InnerList.DataSource = New_DataSource
    PropertyChanged "DataSource"
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,Enabled
Public Property Get Enabled() As Boolean
    Enabled = InnerList.Enabled
End Property

Public Property Let Enabled(ByVal New_Enabled As Boolean)
    InnerList.Enabled() = New_Enabled
    PropertyChanged "Enabled"
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,FontUnderline
Public Property Get FontUnderline() As Boolean
    FontUnderline = InnerList.FontUnderline
End Property

Public Property Let FontUnderline(ByVal New_FontUnderline As Boolean)
    InnerList.FontUnderline() = New_FontUnderline
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,FontStrikethru
Public Property Get FontStrikethru() As Boolean
    FontStrikethru = InnerList.FontStrikethru
End Property

Public Property Let FontStrikethru(ByVal New_FontStrikethru As Boolean)
    InnerList.FontStrikethru() = New_FontStrikethru
End Property
```

```
'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,FontSize
Public Property Get FontSize() As Single
    FontSize = InnerList.FontSize
End Property

Public Property Let FontSize(ByVal New_FontSize As Single)
    InnerList.FontSize() = New_FontSize
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,FontName
Public Property Get FontName() As String
    FontName = InnerList.FontName
End Property

Public Property Let FontName(ByVal New_FontName As String)
    InnerList.FontName() = New_FontName
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,FontItalic
Public Property Get FontItalic() As Boolean
    FontItalic = InnerList.FontItalic
End Property

Public Property Let FontItalic(ByVal New_FontItalic As Boolean)
    InnerList.FontItalic() = New_FontItalic
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,FontBold
Public Property Get FontBold() As Boolean
    FontBold = InnerList.FontBold
End Property
```

```
Public Property Let FontBold(ByVal New_FontBold As Boolean)
    InnerList.FontBold() = New_FontBold
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,Font
Public Property Get Font() As Font
    Set Font = InnerList.Font
End Property

Public Property Set Font(ByVal New_Font As Font)
    Set InnerList.Font = New_Font
    PropertyChanged "Font"
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,ForeColor
Public Property Get ForeColor() As OLE_COLOR
    ForeColor = InnerList.ForeColor
End Property

Public Property Let ForeColor(ByVal New_ForeColor As OLE_COLOR)
    InnerList.ForeColor() = New_ForeColor
    PropertyChanged "ForeColor"
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,hWnd
Public Property Get hWnd() As Long
    hWnd = InnerList.hWnd
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,IntegralHeight
Public Property Get IntegralHeight() As Boolean
```

```
    IntegralHeight = InnerList.IntegralHeight
End Property

Private Sub InnerList_ItemCheck(Item As Integer)
    RaiseEvent ItemCheck(Item)
End Sub

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,ItemData
Public Property Get ItemData(ByVal index As Integer) As Long
    ItemData = InnerList.ItemData(index)
End Property

Public Property Let ItemData(ByVal index As Integer, ByVal New_ItemData As Long)
    InnerList.ItemData(index) = New_ItemData
    PropertyChanged "ItemData"
End Property


'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,ListIndex
Public Property Get ListIndex() As Integer
    ListIndex = InnerList.ListIndex
End Property

Public Property Let ListIndex(ByVal New_ListIndex As Integer)
    InnerList.ListIndex() = New_ListIndex
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,ListCount
Public Property Get ListCount() As Integer
    ListCount = InnerList.ListCount
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
```

```
'MappingInfo=InnerList,InnerList,-1,List
Public Property Get List(ByVal index As Integer) As String
    List = InnerList.List(index)
End Property

Public Property Let List(ByVal index As Integer, ByVal New_List As String)
    InnerList.List(index) = New_List
    PropertyChanged "List"
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,MousePointer
Public Property Get MousePointer() As Integer
    MousePointer = InnerList.MousePointer
End Property

Public Property Let MousePointer(ByVal New_MousePointer As Integer)
    InnerList.MousePointer() = New_MousePointer
    PropertyChanged "MousePointer"
End Property


'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,MouseIcon
Public Property Get MouseIcon() As Picture
    Set MouseIcon = InnerList.MouseIcon
End Property

Public Property Set MouseIcon(ByVal New_MouseIcon As Picture)
    Set InnerList.MouseIcon = New_MouseIcon
    PropertyChanged "MouseIcon"
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,MultiSelect
Public Property Get MultiSelect() As Integer
```

```
    MultiSelect = InnerList.MultiSelect
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,NewIndex
Public Property Get NewIndex() As Integer
    NewIndex = InnerList.NewIndex
End Property

Private Sub InnerList_OLEStartDrag(Data As DataObject, AllowedEffects As Long)
    RaiseEvent OLEStartDrag(Data, AllowedEffects)
End Sub

Private Sub InnerList_OLESetData(Data As DataObject, DataFormat As Integer)
    RaiseEvent OLESetData(Data, DataFormat)
End Sub

Private Sub InnerList_OLEGiveFeedback(Effect As Long, DefaultCursors As Boolean)
    RaiseEvent OLEGiveFeedback(Effect, DefaultCursors)
End Sub

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,OLEDropMode
Public Property Get OLEDropMode() As Integer
    OLEDropMode = InnerList.OLEDropMode
End Property

Public Property Let OLEDropMode(ByVal New_OLEDropMode As Integer)
    InnerList.OLEDropMode() = New_OLEDropMode
    PropertyChanged "OLEDropMode"
End Property

Private Sub InnerList_OLEDragOver(Data As DataObject, Effect As Long, Button As Integer, Shift As Integer, X As
Single, Y As Single, State As Integer)
    RaiseEvent OLEDragOver(Data, Effect, Button, Shift, X, Y, State)
End Sub
```

```
'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,OLEDragMode
Public Property Get OLEDragMode() As Integer
    OLEDragMode = InnerList.OLEDragMode
End Property

Public Property Let OLEDragMode(ByVal New_OLEDragMode As Integer)
    InnerList.OLEDragMode() = New_OLEDragMode
    PropertyChanged "OLEDragMode"
End Property

Private Sub InnerList_OLEDragDrop(Data As DataObject, Effect As Long, Button As Integer, Shift As Integer, X As
Single, Y As Single)
    RaiseEvent OLEDragDrop(Data, Effect, Button, Shift, X, Y)
End Sub

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,OLEDrag
Public Sub OLEDrag()
    InnerList.OLEDrag
End Sub

Private Sub InnerList_OLECompleteDrag(Effect As Long)
    RaiseEvent OLECompleteDrag(Effect)
End Sub

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,RemoveItem
Public Sub RemoveItem(ByVal index As Integer)
    InnerList.RemoveItem index
    If m_SpeechEnabled Then RebuildGrammar
End Sub

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,Refresh
```

```
Public Sub Refresh()
    InnerList.Refresh
End Sub

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,RightToLeft
Public Property Get RightToLeft() As Boolean
    RightToLeft = InnerList.RightToLeft
End Property

Public Property Let RightToLeft(ByVal New_RightToLeft As Boolean)
    InnerList.RightToLeft() = New_RightToLeft
    PropertyChanged "RightToLeft"
End Property

Private Sub InnerList_Scroll()
    RaiseEvent Scroll
End Sub

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,Selected
Public Property Get Selected(ByVal index As Integer) As Boolean
    Selected = InnerList.Selected(index)
End Property

Public Property Let Selected(ByVal index As Integer, ByVal New_Selected As Boolean)
    InnerList.Selected(index) = New_Selected
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,SelCount
Public Property Get SelCount() As Integer
    SelCount = InnerList.SelCount
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
```

```
'MappingInfo=InnerList,InnerList,-1,Style
Public Property Get Style() As Integer
    Style = InnerList.Style
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,Sorted
Public Property Get Sorted() As Boolean
    Sorted = InnerList.Sorted
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,Text
Public Property Get text() As String
    text = InnerList.text
End Property

Public Property Let text(ByVal New_Text As String)
    InnerList.text() = New_Text
    PropertyChanged "Text"
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,ToolTipText
Public Property Get ToolTipText() As String
    ToolTipText = InnerList.ToolTipText
End Property

Public Property Let ToolTipText(ByVal New_ToolTipText As String)
    InnerList.ToolTipText() = New_ToolTipText
    PropertyChanged "ToolTipText"
End Property

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,TopIndex
Public Property Get TopIndex() As Integer
```

```
    TopIndex = InnerList.TopIndex
End Property

Public Property Let TopIndex(ByVal New_TopIndex As Integer)
    InnerList.TopIndex() = New_TopIndex
    PropertyChanged "TopIndex"
End Property

Private Sub InnerList_Validate(Cancel As Boolean)
    RaiseEvent Validate(Cancel)
End Sub

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MappingInfo=InnerList,InnerList,-1,WhatsThisHelpID
Public Property Get WhatsThisHelpID() As Long
    WhatsThisHelpID = InnerList.WhatsThisHelpID
End Property

Public Property Let WhatsThisHelpID(ByVal New_WhatsThisHelpID As Long)
    InnerList.WhatsThisHelpID() = New_WhatsThisHelpID
    PropertyChanged "WhatsThisHelpID"
End Property

'Load property values from storage
Private Sub UserControl_ReadProperties(PropBag As PropertyBag)
    Dim index As Integer
    Dim Count As Integer

    InnerList.Appearance = PropBag.ReadProperty("Appearance", 1)
    InnerList.BackColor = PropBag.ReadProperty("BackColor", &H80000005)
    InnerList.CausesValidation = PropBag.ReadProperty("CausesValidation", True)
    If PropBag.ReadProperty("Columns", 0) <> 0 Then
        InnerList.Columns = PropBag.ReadProperty("Columns", 0)
    End If
    InnerList.DataMember = PropBag.ReadProperty("DataMember", "")
    Set DataSource = PropBag.ReadProperty("DataSource", Nothing)
```

```
    InnerList.Enabled = PropBag.ReadProperty("Enabled", True)
    Set InnerList.Font = PropBag.ReadProperty("Font", Ambient.Font)
    InnerList.ForeColor = PropBag.ReadProperty("ForeColor", &H80000008)

    Count = PropBag.ReadProperty("ListCount", 0)
    For index = 0 To Count - 1
        InnerList.ItemData(index) = PropBag.ReadProperty("ItemData" & index, 0)
        InnerList.List(index) = PropBag.ReadProperty("List" & index, "")
    Next

    InnerList.MousePointer = PropBag.ReadProperty("MousePointer", 0)
    Set MouseIcon = PropBag.ReadProperty("MouseIcon", Nothing)
    InnerList.OLEDropMode = PropBag.ReadProperty("OLEDropMode", 0)
    InnerList.OLEDragMode = PropBag.ReadProperty("OLEDragMode", 0)
    InnerList.RightToLeft = PropBag.ReadProperty("RightToLeft", False)
    InnerList.text = PropBag.ReadProperty("Text", "")
    InnerList.ToolTipText = PropBag.ReadProperty("ToolTipText", "")
    InnerList.TopIndex = PropBag.ReadProperty("TopIndex", 0)
    InnerList.WhatsThisHelpID = PropBag.ReadProperty("WhatsThisHelpID", 0)
    m_PreCommandString = PropBag.ReadProperty("PreCommandString", m_def_PreCommandString)
    m_PreCommandStringAlt = PropBag.ReadProperty("PreCommandStringAlt", m_def_PreCommandStringAlt)
    m_PreCommandStringOtherAlt = PropBag.ReadProperty("PreCommandStringOtherAlt", m_def_PreCommandStringOtherAlt)
    Me.SpeechEnabled = PropBag.ReadProperty("SpeechEnabled", m_def_SpeechEnabled)
End Sub

'Write property values to storage
Private Sub UserControl_WriteProperties(PropBag As PropertyBag)
    Dim index As Integer

    Call PropBag.WriteProperty("Appearance", InnerList.Appearance, 1)
    Call PropBag.WriteProperty("BackColor", InnerList.BackColor, &H80000005)
    Call PropBag.WriteProperty("CausesValidation", InnerList.CausesValidation, True)
    Call PropBag.WriteProperty("Columns", InnerList.Columns, 0)
    Call PropBag.WriteProperty("DataMember", InnerList.DataMember, "")
    Call PropBag.WriteProperty("DataSource", DataSource, Nothing)
    Call PropBag.WriteProperty("Enabled", InnerList.Enabled, True)
```

```
    Call PropBag.WriteProperty("Font", InnerList.Font, Ambient.Font)
    Call PropBag.WriteProperty("ForeColor", InnerList.ForeColor, &H80000008)

    Call PropBag.WriteProperty("ListCount", InnerList.ListCount, 0)
    For index = 0 To InnerList.ListCount - 1
        Call PropBag.WriteProperty("ItemData" & index, InnerList.ItemData(index), 0)
        Call PropBag.WriteProperty("List" & index, InnerList.List(index), "")
    Next

    Call PropBag.WriteProperty("MousePointer", InnerList.MousePointer, 0)
    Call PropBag.WriteProperty("MouseIcon", MouseIcon, Nothing)
    Call PropBag.WriteProperty("OLEDropMode", InnerList.OLEDropMode, 0)
    Call PropBag.WriteProperty("OLEDragMode", InnerList.OLEDragMode, 0)
    Call PropBag.WriteProperty("RightToLeft", InnerList.RightToLeft, False)
    Call PropBag.WriteProperty("Text", InnerList.text, "")
    Call PropBag.WriteProperty("ToolTipText", InnerList.ToolTipText, "")
    Call PropBag.WriteProperty("TopIndex", InnerList.TopIndex, 0)
    Call PropBag.WriteProperty("WhatsThisHelpID", InnerList.WhatsThisHelpID, 0)
    Call PropBag.WriteProperty("SpeechEnabled", m_SpeechEnabled, m_def_SpeechEnabled)
    Call PropBag.WriteProperty("PreCommandString", m_PreCommandString, m_def_PreCommandString)
    Call PropBag.WriteProperty("PreCommandStringAlt", m_PreCommandStringAlt, m_def_PreCommandStringAlt)
    Call PropBag.WriteProperty("PreCommandStringOtherAlt", m_PreCommandStringOtherAlt,
m_def_PreCommandStringOtherAlt)
End Sub

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MemberInfo=0,0,0,True
Public Property Get SpeechEnabled() As Boolean
    SpeechEnabled = m_SpeechEnabled
End Property

Public Property Let SpeechEnabled(ByVal New_SpeechEnabled As Boolean)
    If m_SpeechEnabled <> New_SpeechEnabled Then
        m_SpeechEnabled = New_SpeechEnabled

        If Ambient.UserMode Then
```

```
            If m_SpeechEnabled = True Then
                Call EnableSpeech
            Else
                Call DisableSpeech
            End If
        End If

        PropertyChanged "SpeechEnabled"
    End If
End Property

'Initialize Properties for User Control
Private Sub UserControl_InitProperties()
    m_PreCommandString = m_def_PreCommandString
    m_PreCommandStringAlt = m_def_PreCommandStringAlt
    m_PreCommandStringOtherAlt = m_def_PreCommandStringOtherAlt
    Me.SpeechEnabled = m_def_SpeechEnabled
End Sub

'WARNING! DO NOT REMOVE OR MODIFY THE FOLLOWING COMMENTED LINES!
'MemberInfo=13,1,0,Select
Public Property Get PreCommandString() As String
    PreCommandString = m_PreCommandString
End Property
Public Property Get PreCommandStringAlt() As String
    PreCommandString = m_PreCommandStringAlt
End Property
Public Property Get PreCommandStringOtherAlt() As String
    PreCommandString = m_PreCommandStringOtherAlt
End Property


Public Property Let PreCommandString(ByVal New_PreCommandString As String)

    ' These properties are not available during run time.
    ' To support it in run time, you will need to dynamically rebuild the top
```

```
    ' level rule when this property changes.

    ' If a run time attempt is made to change this property, error is raised.
    If Ambient.UserMode Then Err.Raise 382
    m_PreCommandString = New_PreCommandString
    PropertyChanged "PreCommandString"
End Property
Public Property Let PreCommandStringAlt(ByVal New_PreCommandString As String)

    If Ambient.UserMode Then Err.Raise 382
    m_PreCommandStringAlt = New_PreCommandString
    PropertyChanged "PreCommandStringAlt"
End Property
Public Property Let PreCommandStringOtherAlt(ByVal New_PreCommandString As String)

    If Ambient.UserMode Then Err.Raise 382
    m_PreCommandStringOtherAlt = New_PreCommandString
    PropertyChanged "PreCommandStringOtherAlt"
End Property
```

PerioProbeListBox.frm

```
VERSION 5.00
Object = "{917C9C16-D624-4433-A4CA-D327557B2C52}#3.0#0"; "Peroprobe.ocx"
Begin VB.Form ListInterface
   BorderStyle     =   1  'Fixed Single
   Caption         =   "Perioprobe control debugger"
   ClientHeight    =   4215
   ClientLeft      =   45
   ClientTop       =   330
   ClientWidth     =   4935
   Icon            =   "PerioProbeListBox.frx":0000
   LinkTopic       =   "Form1"
   MaxButton       =   0   'False
   ScaleHeight     =   4215
   ScaleWidth      =   4935
   StartUpPosition =   3  'Windows Default
   Begin VB.CommandButton cmdRemove
      Caption         =   "&Remove"
      Height          =   355
      Left            =   3700
      TabIndex        =   3
      Top             =   3200
      Width           =   1100
   End
   Begin VB.CheckBox chkSpeechEnabled
      Caption         =   "Speech &enabled"
      Height          =   255
      Left            =   120
      TabIndex        =   2
      Top             =   3250
      Width           =   1695
   End
   Begin VB.CommandButton cmdAdd
      Caption         =   "&Add"
```

```
   Height          =   355
   Left            =   3700
   TabIndex        =   6
   Top             =   3720
   Width           =   1100
End
Begin VB.TextBox txtNewItem
   Height          =   315
   Left            =   1320
   TabIndex        =   5
   Text            =   "occlusal splint"
   Top             =   3740
   Width           =   2175
End
Begin PerioProbeSpeechApp.SpeechEngine SpeechListBox
   Height          =   2205
   Left            =   120
   TabIndex        =   1
   Top             =   840
   Width           =   4680
   _ExtentX        =   8255
   _ExtentY        =   3889
   BeginProperty Font {0BE35203-8F91-11CE-9DE3-00AA004BB851}
      Name            =   "MS Sans Serif"
      Size            =   8.25
      Charset         =   0
      Weight          =   400
      Underline       =   0   'False
      Italic          =   0   'False
      Strikethrough   =   0   'False
   EndProperty
End
Begin VB.Label Label2
   Caption         =   $"PerioProbeListBox.frx":014A
   Height          =   615
   Left            =   120
```

```
      TabIndex        =   0
      Top             =   120
      Width           =   4680
   End
   Begin VB.Label Label1
      Caption         =   "&Phrase to add:"
      Height          =   255
      Left            =   120
      TabIndex        =   4
      Top             =   3720
      Width           =   1035
   End
End
Attribute VB_Name = "ListInterface"
Attribute VB_GlobalNameSpace = False
Attribute VB_Creatable = False
Attribute VB_PredeclaredId = True
Attribute VB_Exposed = False

Private Sub Form_Load()

    If SpeechListBox.SpeechEnabled Then
        chkSpeechEnabled = 1
    Else
        chkSpeechEnabled = 0
    End If

    ' Use of a Listbox allows dynamic additions during prototyping and testing. A final
    ' version of the software would use a fixed lookup table and not have a debug window visible.
    SpeechListBox.AddItem ("zero")
    SpeechListBox.AddItem ("one")
    SpeechListBox.AddItem ("two")
    SpeechListBox.AddItem ("three")
    SpeechListBox.AddItem ("four")
    SpeechListBox.AddItem ("five")
    SpeechListBox.AddItem ("six")
```

```
SpeechListBox.AddItem ("seven")
SpeechListBox.AddItem ("ayte")
SpeechListBox.AddItem ("noine")
SpeechListBox.AddItem ("exray")
SpeechListBox.AddItem ("payshent")
SpeechListBox.AddItem ("upper")
SpeechListBox.AddItem ("lower")
SpeechListBox.AddItem ("mobility")
SpeechListBox.AddItem ("palatal")
SpeechListBox.AddItem ("lingual")
SpeechListBox.AddItem ("buckle")
SpeechListBox.AddItem ("pocket")
SpeechListBox.AddItem ("recession")
SpeechListBox.AddItem ("furcation zero")
SpeechListBox.AddItem ("furcation one")
SpeechListBox.AddItem ("furcation two")
SpeechListBox.AddItem ("furcation three")
SpeechListBox.AddItem ("next")
SpeechListBox.AddItem ("forward")
SpeechListBox.AddItem ("back")
SpeechListBox.AddItem ("next tooth")
SpeechListBox.AddItem ("last tooth")
SpeechListBox.AddItem ("speech on")
SpeechListBox.AddItem ("speech off")
SpeechListBox.AddItem ("one one")
SpeechListBox.AddItem ("one two")
SpeechListBox.AddItem ("one three")
SpeechListBox.AddItem ("one four")
SpeechListBox.AddItem ("one five")
SpeechListBox.AddItem ("one six")
SpeechListBox.AddItem ("one seven")
SpeechListBox.AddItem ("one eight")
SpeechListBox.AddItem ("two one")
SpeechListBox.AddItem ("two two")
SpeechListBox.AddItem ("two three")
SpeechListBox.AddItem ("two four")
```

```
    SpeechListBox.AddItem ("two five")
    SpeechListBox.AddItem ("two six")
    SpeechListBox.AddItem ("two seven")
    SpeechListBox.AddItem ("two eight")
    SpeechListBox.AddItem ("three one")
    SpeechListBox.AddItem ("three two")
    SpeechListBox.AddItem ("three three")
    SpeechListBox.AddItem ("three four")
    SpeechListBox.AddItem ("three five")
    SpeechListBox.AddItem ("three six")
    SpeechListBox.AddItem ("three seven")
    SpeechListBox.AddItem ("three eight")
    SpeechListBox.AddItem ("four one")
    SpeechListBox.AddItem ("four two")
    SpeechListBox.AddItem ("four three")
    SpeechListBox.AddItem ("four four")
    SpeechListBox.AddItem ("four five")
    SpeechListBox.AddItem ("four six")
    SpeechListBox.AddItem ("four seven")
    SpeechListBox.AddItem ("four eight")
End Sub

Private Sub chkSpeechEnabled_Click()
    SpeechListBox.SpeechEnabled = (chkSpeechEnabled = 1)
End Sub

Private Sub cmdAdd_Click()
    ' Add the new item. Internally to SpeechListBox, this will cause a rebuild
    ' of the dynamic grammar used by speech recognition engine.
    SpeechListBox.AddItem (txtNewItem)
    txtNewItem = ""
End Sub

Private Sub cmdRemove_Click()
    ' Just remove the current selected item. Same as AddItem, removing an item
    ' causes a grammar rebuild as well.
```

```
    If SpeechListBox.ListIndex <> -1 Then
        SpeechListBox.RemoveItem SpeechListBox.ListIndex
    End If
End Sub

Private Sub txtNewItem_Change()
    ' Disallow empty item.
    cmdAdd.Enabled = txtNewItem <> ""
End Sub

Private Sub txtNewItem_GotFocus()
    ' When user focuses on the new item box, make the Add button default
    ' so that return key is same as clicking on Add button.
    cmdAdd.Default = True
End Sub
```