REVEALING THE NATURE OF INTERACTION BETWEEN DESIGNERS AND PHYSICAL AND VIRTUAL ARTIFACTS TO SUPPORT DESIGN REFLECTION AND DISCOVERY

Salvatore Bucolo

Doctor of Philosophy (PhD)

Humanities Program
Queensland University of Technology

2008

Statement of Authorship

“The work contained in this thesis has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made”.

Signature:

Date:

ABSTRACT

This thesis aims at developing a better understanding of the design process and the tools required to support it. Specifically it focuses on the early or conceptual stages of the industrial design process and the role of emerging technology based artifacts in supporting this activity.

The starting point for this thesis is that industrial design focuses on discovery of new knowledge and that this process of discovery is reflective in nature. Further designers make use of artifacts throughout the design process to support them in this discovery and their reflection. To reveal the role of artifacts in this process, a study of the interaction between designers and their artifacts has been undertaken. To intensify these relationships this thesis has focused on design review activity undertaken in the early stages of industrial design process.

Two ethnographic case studies were conducted which allowed for teams of final year industrial design students to be observed during a conceptual design review. The first case study focused on the student designers interacting with traditional artifacts such as sketches, form studies and illustrations as part of the design review session. In the second case study, the student designers made use of low fidelity digital models which were displayed in a highly immersive virtual reality environment to support the design review. Both case studies captured a time slice of a larger design project which the students were undertaking as part of their university studies.

The design project focused on the redesign of a consumer product where the students were required to innovate on an existing design based on a number of technology and market constraints. The design review session which formed the basis of the case study was part of a weekly design critique which required the students to bring to the class all of their design development progress. Students were offered an additional review session which was held in a virtual reality facility to supplement their weekly design review session which formed the basis of the second case study. The objective of the review sessions were for the designers to discuss their progress, identify where they were having difficulty, be challenged on design decision and develop a shared understanding of their direction with the class.

The case study approach has allowed for an authentic in situ account of how designers make use of artifacts within the early stages of an industrial design process. It has allowed for a comparison between traditional and technology based artifacts and has revealed how they impact on the nature of discovery and reflection. Through a detailed qualitative analysis of the video data which was captured from the case studies, this thesis makes a number of substantial contributions to the current knowledge gaps on the role of artifacts and to our understanding of this phase of design activity.

It substantiates conceptual design activity as a reflective process allowing for new discoveries to be made by representing our existing knowledge and understandings in artifacts which can be reflected upon and extended to create new meaning and innovation. From this grounded perspective it has enabled further understandings into the role of the artifact in supporting the design activity.

Artifacts are seen as critical in supporting early stage design activity. However it is the nature of the interaction between the designers and their artifacts within the different settings which have been revealed through this research which is of significance. The affordances of the different artifacts have been shown to alter how the students situate their activity and modify their actions within a design review.

Further designers are required to make use of additional resources such as gestures and rich design language to supplement their design engagement; and they are required to adapt to the environment where the review is being undertaken to ensure that the objective of the design review can be achieved.

This thesis makes its primary contribution in outlining the differences between the various types of artifacts and how they can be used to positively support early stage design activity. It is recommended that both traditional and virtual artifacts have a role in supporting activity, but future approaches should consider them as complimentary and consider ways in which they can be merged.

The significance of the research is three fold. Firstly, from a pedagogical perspective, within an educational or practiced based setting, it provides a framework to consider the use of emerging technology based artifacts to support early stage design activity. Secondly, from a technology development perspective the grounded observation in authentic experience of design activity, it provides the foundation to inspire and develop new interfaces to support designer interactions with artifacts. Finally, it makes a substantial contribution to the growing body of design research substantiating and revealing new understanding between designers and their artifacts to support early stage design activity.

Keywords

Design Artifacts, Design Process, Conceptual Design, Virtual Reality, Interaction Design and Design Research

ACKNOWLEDGEMENTS

This thesis has consumed a large percentage of my professional life, as both a practicing designer and design academic. During this period my thoughts on design as a practice and a process, and its future direction, have been challenged and refined. It is the people I have met and who have become my friends along this journey, whether they have directly or indirectly contributed to this thesis, which I would formally like to acknowledge and thank.

Firstly, I would like to thank the students who volunteered to be part of the study. Without them this research would not have been possible. Your ability to accept new approaches and challenges is a credit to your generation.

I would also like to thank the many students of the industrial design program at QUT. I came to QUT as a young academic and have since seen many classes graduate. Each year I am amazed by the enthusiasm, dedication and uniqueness each cohort brings to the design studio. It is this energy which has maintained my level of interest in design and why I continue to see a bright future for the profession.

I would also like to thank many of the staff within the industrial design discipline and other disciplines within the Faculty of Built Environment and Engineering at QUT. Although many of you have not been directly linked to this research, the many discussions over endless coffees and the occasional red wine have influenced my thinking as a designer and helped contextualise my research and passion for design.

To the staff and students within the ITEE program at the University of Queensland where I formally began this doctoral research. You offered me an alternative perspective of the nature of interaction and were willing to put up with my rants about design. These complimentary approaches will become a very powerful combination over the coming years.

I am also especially thankful to my principal supervisor Dr Barbara Adkins who stepped in at the last minute to see me complete this research. Your ability to pick up a body of research, immediately make sense of it and then offer meaningful comments from other domains of research is truly amazing. You are an inspiration and I am honoured to have been able to work with you in completing this thesis.

I would also like to thank my two associate supervisors, Professor Greg Hearn and Professor Terry Flew, who also stepped in at the last minute to ensure that this thesis was completed to the standard presented. Your honesty and support is greatly appreciated.

Finally, I would like to thank my best friend and wife, Lisa, who has supported me on this journey with her laughter, love and practical advice. Together we have seen many changes over this period. We have extended our family with the births of our two lovely boys, Nathan and Matthew. We have managed to move homes, change jobs and live in another country. With all this change you have still been there to support me and embrace me each night while I undertake this research – I love you and thank you.

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

Industrial Design is a relatively new profession which broadly focuses on the creation of innovative products and systems which meets an identified end user need. Since its recognition as a profession in the early to mid 1900's, the profession has evolved to meet the demands of both economic and social development. As we move from an Industrial into a Post-Industrial society the profession once again finds itself reflecting on the role it will play in this new environment. Although the core values of industrial design, creating new knowledge through discovery, will not radically change it is the design process and tools used by designers which will need to be modified and refined to best meet this new development environment. Developing a better understanding of the industrial design process and the tools required to support it, is a focus of this thesis.

However, this thesis goes much deeper than trying to define new tools to support industrial design activity. It aims to develop a better understanding of the complex relationships between the role of a designer's interactions with design artifacts and the impact on the nature of design discovery. The process of industrial design provides an ideal context to further this understanding. However in order to reveal these new understandings, the research has gone beyond the domain of industrial design and considers the nature of interaction and design discovery from a broader research perspective.

This chapter discusses my motivations for embarking on this research, which has been heavily influenced by my position as a design educator and practitioner. The research claims are then presented and I provide an overview of the structure of this dissertation.

1.1 Research Context

My starting point for this research is that design follows a process and that this process is reflective in nature. Schön's (1983) Reflection in Action paradigm provides a useful foundation to begin the discussion on the nature of design practice.

A designer makes things. Sometimes he makes the final product; more often he makes a representation... He works in particular situations, uses particular materials and employs a distinctive medium and language…There are more variables – kinds of possible moves, norms and interrelationships of these – that can be represented in *a finite model. Because of this complexity, the designer's moves tend, happily or unhappily, to produce consequences other than those intended. When this happens the designer may take account of the unintended changes he has made in the situation by forming new appreciations and understandings and by making new moves. He shapes the situation, in accordance with his initial appreciation of it, the situation 'talks back' and he responds to the situation's back-talk. In a good process of design, this conversation with the situation is reflective. In answer to the situation's back-talk, the designer reflects in action on the construction of the problem, the strategies of the action or the model of the phenomena, which have been implicit in his moves* (Schön 1983, p.78).

It is the nature of the discovery within the design process which Schön refers to as reflection which is of interest within this research.

The work of Polanyi (1998) and Ehn (1988) provide a further foundation to consider early stage or conceptual design activity, where discovery is intensified and can be observed. Both works (further discussed in Section 2) refer to design as a process of making new discoveries by constructing alternative futures. In all three approaches the interaction between the designer and their artifacts during this phase of design activity is seen as a contributor to discovery and new knowledge.

In Schön's (1983) initial description of the reflection in action paradigm he describes the sketch as talking back and revealing issues to the designer. He notes that the evolving physical prototype is a yet more active and evocative participant than the sketch as it responds through physical behaviour allowing the designer to obtain feedback through seeing, smelling and hearing the prototype.

As outlined in the review of the literature (Section 2), artifacts are central to the practice of design and much has been written on the role of artifacts in supporting design activity. However, a considerable part of this existing research focuses on the latter stages of the design process, specifically recent research which considers emerging technologies as artifacts to support design activity.

A gap in our current understanding of artifacts is how technology based artifacts support the nature of discovery within the early phases of design activity. As new technology based artifacts, such as virtual representations, are introduced into this phase of the design process, what features should they contain to ensure that they support early stage design activity? Rather than trying to answer this question by developing a technology specification for virtual environments, this thesis aims to reveal the nature of interaction between designers and their artifact within the early stages of design activity, to better understand their role in supporting new discoveries and reflection.

My experience as a practitioner and academic indicates that technology based artifacts have the potential to extend current support tools and approaches within the early phases of design activity. However, to ensure that they are appropriate to the task, a detailed understanding of the designers' interactions with artifacts during this phase of design activity, together with an understanding of the affordances of the technology, is required.

As shown in the review of the literature, much has been written on the role of design activity and artifacts. Schön, Polanyi and Ehn's work allows us to ask the question of the nature of design activity and the role of the artifact. However it does not provide us with an insight into specific design contexts, or indeed how to identify such insights within new contexts. Therefore, where this thesis aims to make its contribution and extend our existing general knowledge on reflective practice and the role of artifacts is through focusing on a specific context of activity, namely industrial design and the early phase of design activity.

The foundation for the new knowledge generated through this research is an ethnographic case study allowing observations of moment to moment interactions between designers and their artifacts to be captured, which would reveal new understandings of the nature of early stage design activity. I have drawn on the theories of Distributed Cognition (Hutchins 1995), Activity Theory (Nardi 1996) and Situated Actions (Suchman 1987) as a basis to develop my understanding of the interaction between designers and artifacts. These theories have been selected as they contextualise cognitive activity within the social and physical environment and provide a framework to consider design activity not solely as a cognitive activity but one that includes the use of artifacts and their environment. This research, like many others, does not see design as a solely cognitive activity, but one where the nature of the interaction between designers, their artifacts and their environment is critical. Further, these theories provide a framework to study the moment to moment activity of interaction with artifacts to bring about new understandings within different contexts.

An educational setting was selected as the basis for my case study, as it allowed the interaction between student designers and their artifacts to be slowed, providing a time paused insight into this activity. The pedagogical implications of student designers provide an additional affordance which allows a time paused insight into the studying of design activity, allowing concepts to reveal themselves which may otherwise go unnoticed. The educational setting is also representative of the pedagogical demands of professional design practice. Therefore the term “designer” is used within this thesis to mean both student designers and practicing designers undertaking design activity within the early stages of the design process.

The field work for this thesis consisted of two case studies (discussed in detail in Section 3) which studied final year industrial design students within a design exercise. The first case study observed students during an early stage design critique session where the students made use of a number of traditional artifacts (sketches, technical drawings and models) to support their design activity. In the second study, students were able to use a technology based artifact, a low fidelity 3D Virtual Reality Model, as the basis for their design engagement. This second case study was created as the affordance of the technology exposes greater relationships of activities within this phase of design and allowed for an understanding of the role of technology based artifacts to be revealed. In both studies, the objective of the design activity was kept identical, allowing a comparison between both approaches to be made.

To capture the activity I have drawn on the methods commonly found within the social sciences, namely an Abductive research strategy. As discussed further in Section 3, Blaikie (1995) notes it is the role of the social scientist to discover “why people do what they do … it is the everyday beliefs and practices, the mundane and taken for granted, which have to be grasped and articulated in order to provide an understanding of these actions” (p.176). The use of video data was employed extensively to capture the moment to moment interactions between the designers and their artifacts. This allowed for an ethnographic analysis of the activity which has led to a number of findings reported later within this thesis.

By contextualising this research within the above theories and using the analytical approach briefly discussed, this thesis has made a substantial contribution to furthering our understanding of early stage industrial design activity and the role of artifacts in supporting it. It has revealed new interactions between designers and their artifacts and identified how technology can be adopted to positively support design reflection and discovery.

The following section further contextualises this research, by providing my personal motivation for undertaking this study.

1.2 Motivation and Background

During the past 20 years as a practicing designer, academic and student of design, I have experienced first hand some of the changes undertaken within the profession of Industrial Design. From an economic perspective there has been a move from a focus on manufacturing development to a focus on serviced based product development. At a more pragmatic level there has been the introduction of new technologies into the design process, such as the replacement of the drawing board with 2D CAD and the use of 3D CAD, Rapid Prototyping Technologies and Computer Visualisations to support 3D form exploration and visual communication.

As a student of industrial design in the late 1980's I recall vividly lectures on how the role of Computer Aided Design / Computer Aided Manufacture (CAD / CAM) would influence the practice of industrial design, with some heated debate often citing that it would replace the need for the industrial design practitioner. In my middle years of study, I was introduced to 2D CAD, which quickly replaced the need for my trusted drawing board, technical pens and drafting machine. During my later years of study, 3D CAD was being introduced and concepts such as solid modelling and Boolean operations became part of the language of design. As a junior designer, my skills in the operation of CAD packages were highly sought after. These skills provided design firms with a perceived market competitive advantage. In these initial years of my practice I observed a clear distinction between those who designed and those who represented the design artifact. As a design educator I observed student cohorts begin to insist that extra time and facilities were provided for the learning of CAD applications as it was perceived as a highly desirable industry skill. As a design educator, I had an opportunity to influence the profession's view of this technology which would, in turn, influence students' perceptions of knowledge and skills required from an undergraduate professional design program.

During this period, what I was witnessing was an acceptance of new technology based artifacts within the design process with a limited understanding of their impact on the nature of discovery and reflective practice. Although the work of Schön and others has revealed the importance of the interaction with artifacts as a foundation for reflective practice in a general sense, my personal perspective of technology based artifacts were seen as a means to an end and were not considered a critical aspect of design activity which led to discovery.

In an attempt to bridge this gap, my overarching research interest for the past 15 years has been to investigate and develop emerging technology based tools to support reflective industrial design practice. This interest has been considered from both an academic and professional practice perspective.

My initial research studies (Bucolo and Curran 1995; Bucolo 1999) focused on the use of 3D scanning technologies to allow designers to create artifacts in traditional media (such a polystyrene, timber, plasticine) and then rapidly create a 3D digital representation of this for use in a concurrent engineering cycle. The aim of the research was to identify if new technology can be integrated into the product development process which allowed the designer to control design intent from a concept model to CAD model without altering the design process described. To evaluate this, usability, time and quality of result were measured, which were used as a basis for a comparative analysis between the traditional and integrated methods. Although there were limitations in the technology at that time, the research found that the technology did provide accurate information, quickly and economically, for use in the transfer of physical data into a digital environment. In this instance the design intent was accurately captured and reduced the risk of misinterpretation between the designer and the CAD operator.

My later work (Bucolo and Chan 2001) investigated the use of Haptics as an alternative interface to keyboard and mouse interfaces for 3D CAD modelling. As with my initial research, such an approach offered advantages over traditional approaches. Further, the importance and continual support of physical model making was clearly identified within the context of such emerging design tools.

My early research provided me with a strong understanding of the emerging technologies which may be suited to supporting design activity, however it did not provide me with a greater understanding of the design activity which was also required. The ability to consider both aspects in parallel was the primary motivation to undertake my doctoral studies.

In the late 1990's as part of my role as a design educator I was responsible for establishing a design based Virtual Reality facility (QUT SELab www.selab.qut.edu.au) which supported collaboration between students of the disciplines within the Faculty of Built Environment and Engineering (Architecture, Interior Design, Industrial Design, Urban Design, Landscape Architecture, Mechanical Engineering, Civil Engineering and Electrical Engineering). Significant infrastructure was purchased as part of the establishment of this facility, including a table based immersive virtual reality system (a Fakespace Immersadesk which at the time was one of only two in Australia).   This particular interface allowed students within the Faculty to explore digital design reviews, allowing them to import CAD models and, without knowledge of complex computer programming, to interact with the model in a co-located highly immersive virtual environment (Figure 1). Through the establishment of this laboratory, I was provided with an opportunity to explore the use of immersive virtual reality for industrial design and related design discipline reviews (architecture, interior design, mechanical engineering).

Figure 1 – QUT SELab's Fakespace Immersadesk V2

This new facility allowed me to explore the concept of low fidelity virtual prototypes (referred to as 3D Virtual Sketch Models and discussed in greater detail in Section 3) for design critiques as compared to other early stage prototyping techniques. This research infrastructure allowed me to study both the technology as a potential to support design activity and also to reveal new understandings of the early stages of industrial design activity, with the findings from this research being presented in this thesis.

1.3 Research Aims and Significance

This research aims to make a significant contribution to our understanding of how artifacts affect the nature of discovery and reflection within the early stages of industrial design activity. A core question of the research is trying to identify what attributes are required for technology based artifacts to support design engagement within the early stages of design process. However, rather than trying to define these attributes as a technology specification, the research will reveal the activities and nature of the interaction between the designer and the artifact to support design reflection and discovery.

The contribution of the research is furthering our understanding of the early stages of industrial design activity, substantiating the notion of Schön's Reflection in Action paradigm and the notion of discovery as broadly described by Polanyi and Ehn. Further it defines the nature of the interaction between designers and their artifacts, based on our understanding of the relationships between cognition and physical interaction. In doing this it will serve to better inform the use of technology and identify opportunities for technology based design artifacts for this stage of design activity.

The significance of this body of research is threefold.

Firstly, from a pedagogical perspective, within an educational or practice based environment it provides a framework to consider the use of emerging technology based approaches to support design activity. As mentioned, technology based artifacts have the potential to positively support early stage design activity. However, the technology needs to match the needs of the activity it is trying to support rather than the activity being modified.

Secondly, from a technology development perspective, it is hoped that by revealing the needs of the designer in supporting design activity, new human interfaces will be developed to ensure that the technology is appropriate to early stage design activity.

Finally, from a design research perspective, it will make a substantial contribution to our current understanding of design activity, through revealing interactions between designers and their artifacts within the early stages of industrial design activity.

1.4 Guide to the Thesis

The thesis is broken into three main areas, a review of the literature, the research approach and a presentation of the findings and their significance to the discipline of industrial design.

Section 2 provides a detailed review of the literature which relates to the role of artifacts within design reviews. As noted above it draws on the fields of design research, Human Computer Interaction and the Social Sciences. I also provide an overview of the study of Presence and how this approach was considered in studying the role of virtual prototypes and early stage design activity.

Section 3 provides an overview and justification of the research methods used. Within this thesis I have drawn on methodologies commonly found within the social sciences, namely ethnographic methods, to describe and explain the interactions between designers and physical and virtual conceptual representations within the concept design process.

Also in this section I introduce my field data used within the study. A comparative study was undertaken to study the interaction between designers and design artifacts (sketches and models as compared to low fidelity virtual prototypes) during a weekly design review session. The context for the study was a final year undergraduate industrial design exercise.

As the research was interested in understanding the moment-to-moment interactions with media, video was chosen to capture the interactions. Video Interaction Analysis (Jordan and Henderson 1995) was used to analyse the video transcripts. This was then compared to a secondary analysis of the video data using the Video Card Game method (Buur and Soendergaard 2000). Students' reflections captured through interviews at the end of the study were further compared to the outcomes of the first two studies. Data triangulation was used to relate the findings from these three approaches to the data analysis.

Sections 4, 5 and 6 present the findings from the research study. Three main findings have been observed. Firstly, identifying the difference between traditional and virtual artifacts in supporting design reflection. Secondly, how the artifacts represented the abstract knowledge during a design review. Thirdly, the impact of the overhead of the virtual environment is presented. These findings are supported through the use of transcripts to verify the actual interactions which were observed during the study. The use of students' reflections is also embedded within these sections to support the findings.

Section 7 concludes the thesis and presents a summary of the findings and their significance to the education and practice of industrial design. This is presented as a comparative framework of interaction with artifacts, identifying the role of traditional and virtual artifacts within design reviews. A concluding statement on the implications of these findings is also made.

2.0 DESIGN ARTIFACTS SUPPORTING INDUSTRIAL DESIGN ACTIVITY - A REVIEW OF THE RELEVANT LITERATURE

"(Design) constitutes an intervention in the background of our heritage, growing out of our already-existent ways of being in the world and deeply affecting the kind of beings that we are. In creating new artifacts, equipment, buildings, and organizational structure, it attempts to specify in advance how and where breakdowns will show up in our everyday practices and in the tools we use, opening up new spaces in which we can work and play. Ontologically oriented design is therefore necessarily both reflective and political, looking backwards to the tradition that has formed us but also forwards to as-yet-untreated transformations of our lives together. Through the emergence of new tools, we come to a changing awareness of human nature and human action, which in turn leads to new technological development. The designing process is part of this 'we' in which our structure of possibilities is generated" (Winograd and Flores 1986, p163).

Artifacts are central to the practice of design. They can be considered either the final outcome from a design process or a mechanism which supports the creation of the final outcome. It is the relationship between the activity and the artifact which is the focus of this thesis. Specifically it is the analysis of an artifacts role within the design process which aims to reveal new understandings of design activity. In introducing an emerging technology based artifact, the Virtual Prototype, into the design process, new understandings of design activity are exposed.

As mentioned in Section 1, this thesis makes a substantial contribution to the understanding of early stage design activity. Through the examination of the interaction between designers and artifacts within this stage of the design process, new understanding of this activity will be revealed. With this focus in mind the following section provides a summary of the review of the literature undertaken related to this study. The review begins with a broad overview of the role of design artifacts and their current role in supporting design activity. However, in order to develop a detailed understanding of design artifacts, an understanding of the design paradigms they support must also be understood. Therefore, artifacts are then contextualised within the competing paradigms of design activity, specifically a positivist and constructivist view of design.

This understanding is explored further by probing into the relationship between design activity, artifacts and specific design contexts. To develop this understanding, the theories of Human Computer Interaction have been used to contextualise designer's interactions not solely as cognitive activity but within the social and physical environment.

Finally, when artifacts are no longer tangible and take on a virtual form, how does this impact on design activity? The concept of Presence is reviewed to determine characteristics of virtual prototypes which may make them suitable as early stage design artifacts.

The literature review is organised in a manner that provides background information to the project and has identified similar studies that have assisted in the formation of the research question presented in Section 1. As this research spans a wide range of disciplines, a broad review of the literature has been undertaken which spans Design, Human Computer Interaction, Social Sciences and Virtual Environments. Studies from these domains have been included and cited throughout the review rather than isolating research within each of these fields. This section does not intend to provide a complete review of the literature within these fields, however has served as a foundation to the research study undertaken.

2.1 Industrial Design Artifacts

The term 'Industrial Design' describes the creation of products and systems that satisfy human needs and improve people's lives. In understanding the needs of the end user, the industrial designer represents a communication link between the consumer and all other participants in the product development process. This responsibility requires highly developed research and visualisation skills (concept sketching, model making and presentation skills), as well as an intimate knowledge of a vast range of manufacturing processes. Within industry, the designer uses these skills to provide a competitive edge through the development of value added, globally competitive products.

In broad and general terms, industrial designers follow a design process from which the outcomes are manifested as consumer artifacts (this is indeed a narrow view of industrial design and has only been used in an attempt to illustrate the difference between artifacts associated in the process of design to that of the outcome of a design). It is not the intention of this thesis to consider the final outcomes of a design process, but to consider the role of the artifact in generating knowledge within a design process.

Industrial design can also be described as a communicative activity. This communication is facilitated through artifacts “which allows for the externalisation and representation of objects, constraints, form, function, assembly, materials and so on” (Perry and Sanderson 1998, p.275). As design is the process of communicating among various audiences, the design team must ensure that they create a shared understanding among the participants within the design process – typically this is done through the creation of artifacts that are accessible and comprehensible to all (Erickson 1995). These development artifacts which will be considered as part of this thesis will be referred to from here on as design artifacts.

There is no definition or universal understanding of what does or does not constitute a design artifact. “They are created to inform both design process and design decisions. They range from sketches and different kind of models at various levels – ‘look like’, ‘behaves like’, ‘works like’ – to explore and communicate propositions about the design and its content” (Buchenau and Suri 2000 , p.424).

A designer may start with a blank sheet of paper to begin an ideation process, or alternatively begin by interacting with an existing product which is the focus of the design. Throughout the stages of the design process, the designer may be given physical constraints (such as electronic components) to work within and be provided with material samples which are to represent the final properties of the product. The designer (design team) may also create mockups of the intended design (or subsets of the design) using a variety of materials such as paper, clay, foam, wood, rapid prototype etc to assist in refining the appearance or ergonomics of the product. They may also create prototypes demonstrating a particular function such as an electric - mechanical function for the design. As computer technology is introduced into the design process, an artifact can also be considered virtual representations of the intended design concept.

Stoll (1999) defines four types of physical models (artifacts)

- appearance models – communicating how the product might look;
- behavioural models – investigate how the design idea might be used or operated;

- functional models – how the concept may operate or perform its function; and
- design verification units – used to validate or confirm the final design.

Erickson (1995) further defines categories of physical models. He argues that to be most effective as a medium for interaction, prototypes should have two properties - accessibility and roughness. Any member of the team, regardless of location or skill level, should be able to modify the prototype. Roughness decreases the level of commitment to the design, therefore leaving the design team more open to considering change. Figure 2 illustrates a range of artifacts which may be used within a design process for consumer product design.

Figure 2 – Artifact Examples

The artifact examples described above are an integral aspect of the design process. They are carried by the designer, brought to review meetings, taken to trade shows. People other than the creator of the artifact are encouraged to draw on, reshape, or possibly destroy the artifact as a means of furthering the design of the final solution. Although no definite rules exist as to what a design artifact can be, a common element is that they have physical properties to allow them to be used and reused by the design team throughout the design process. Although artifacts are often defined by their physical properties, it is the application of the artifact to the design process which of interest to this thesis. Therefore, artifacts can be summarised as a “medium through which the design team can interact, collectively advancing the design” (Erickson 1995, p.40).

The following section categorises artifacts into 3 distinct groups – Sketching, Physical and Virtual, and considers what role they play in the design process. A review of the literature which surrounds the role of these artifact groups within a design context is then provided.

2.2 Artifacts Supporting Design Activity

Sketching

The role of sketching within the broad category of designing has been researched extensively. Sketches are considered a core capability of the designer for idea generation and creativity (Schön 1983; Goel 1995; Suwa and Tversky 1997; Purcell and Gero 1998). A useful categorisation of sketches is that provided by Ferguson (1992) who identifies three types of sketches - the thinking sketch, the talking sketch and the prescriptive sketch. Thinking Sketches help the designer to focus of the task and guides the designer with non verbal thinking. Talking Sketches relate to those sketches which support group discussion, spontaneously generated during discussion within the team. Prescriptive Sketches are used to communicate to members outside of the design team.

Fish and Scrivener (1990) note that sketches allow for designers to move the design from a general description to a specific description. They note that designers make use of sketches to see the outcome of a sketch without the need to realise it.

Goldschmidt (1991), through her study of architects, observed that designers used sketches for two purposes. She describes this as a dialectic type of argumentation between seeing-as, extracting new meaning from the sketch and seeing-that, identifying what impacts could be seen from the sketch.

Purcell and Gero's (1998) study of design sketches and their impact on creativity and cognition note that sketches play a key role in re-interpretation within the design process and that this leads to new knowledge and that this new knowledge leads to further re-interpretation.

Van der Lugt (2005), in a summary of the major theories, notes that there are two general roles of sketching. "Firstly sketching is said to allow for tentative and noncommittal moves from general description towards specific description. Second sketching is said to involve a cyclical process of reinterpretation" (p.105).

Bilda and Demirkan (2003) note that most of the studies related to sketching have used free hand sketches as the basis of the study. The number of studies which focus on digital sketching is limited as such a medium is not perceived to be supporting creativity within the early stages of the design process. They argue that digital media can be used within the conceptual stage and that the designer's visual thinking could be altered. They suggest that "the cognitive process of designers in both media should be analysed, to explore the effect of media transition and different media interactions of designers" (p.28).

Schön and Wiggins (1992) observe that the designers engage with the sketch through an interactive conversation with the medium. "Working in some visual medium … the designer sees what is 'there' … draws in relation to it and sees what has been drawn, thereby informing further designing" (p.135). It is this reflective process identified which provides a foundation to study other contexts and different mediums such as physical artifacts.

Harrison (1996) notes that "while much has been made of the role of sketching in design activity, little has been done to shed light on the myriad of ways that solid objects play into design activity. How do artifacts function in the generative, performative processes of taking ideas to realities? What purposes do the artifacts serve? When do designers turn to the physical world" (p.418)? Brereton (2000) notes "although the utility of physical objects is often asserted, we know relatively little about how they (physical objects) help us to think and to solve problems. In particular we do not understand much about how physical and virtual objects differ in their abilities to support our activities" (p.217). The following section explores these issues in greater detail.

Physical Artifacts

The importance of design teams and the role of physical artifacts to support and unify these teams has been explored through both Engineering and Design as well as Computer Supported Collaborative Work (CSCW) literature (Tang and Leifer 1991; Bucciarelli 1994; Henderson 1998; Valkenburg 1998). Henderson (1995) has undertaken extensive ethnographic studies within the field of visual representation in design development. She argues that interaction with design artifacts, defined broadly as paper and object pairs: "Acts as a vehicle for organising interactively shared cognition in design work; act as devices to capture threads of tacit knowledge; act as a control gate to determine who could or could not participate in manipulating the design concept; act as emissaries to strengthen political networks; and act as evidence with which to attack design concepts" (p.2). She suggests that the role of the prototype is "both the source of old knowledge and the vehicle for generating new knowledge, while sketches serve to record the change as a form of visual note taking" (p.8). The type of interaction with the prototype is also of importance as it helps elicit and construct individual observations and knowledge whilst also serving to build communal knowledge through the interplay between individual contributions. Finally she notes that the role of artifacts "serves as a social glue between individuals and groups and hence both structure worker networks and the work process itself" (p.2).

Perry and Sanderson (1998) furthered the work of Henderson by investigating the importance of the social and organisational interactions and the ongoing nature of the knowledge representation and work transformations that takes place through the use of design artifacts. Their study found that the design process was tightly bound up with the creation and modification of a variety of design artifacts (drawing, sketches and prototypes). These were the public representations of the state of the design process. Design changes were identified through the modification or generation of new artifacts through communicative activity. Modification took place initially through verbal discussions and then the artifact was altered. The artifact was therefore a resource for discussion as well as the medium to generate change through the discussion. The communication channels used included gesture, voice and gaze awareness to interact with the artifacts face to face. It was suggested that extremely sophisticated technology would be needed before spatially distributed discussions could be held easily. They concluded by noting that "design work can no longer be adequately conceptualised in terms of individual intelligence nor as a linear process with a set of design stages, but rather a situation in which joint, coordinated learning and work practices evolve and in which artifacts help to mediate and organise communication" (p.286).

Chandrasekaran (1999), studied the use of visual representation (sketches) and external representation (physical representations) to contain spatial information and functional information. He identified that kinesthetic representations (interactions with physical representations) are not essential to extract functional information as an experienced designer can make such inferences directly from visual representations.

Lindemann, Assmann and Stetter (1999) undertook a study observing the interaction with various types of models within a design process. They identified that interplay between the various types of models was beneficial to the design process. They argue for the role of mixed prototyping (multiple models types) within design development to be encouraged and that if virtual models are employed they should be kept imprecise to assist in enhancing spatial reasoning.

Logan and Radcliffe (1998) studied the use of artifacts, gestures and talking within the design process. They defined the process of “artefacting” as the combinations of utterance and physical interaction used to communicate complex messages that have design implications. They identified that participants engaged in “artefacting” because the combination of talk and action provides more detailed (highly specific) design information to other participants than solely oral presentation. They concluded by stating, “artefacting reduces the complexity and sophistication of oral discourse that would be needed to impart the same design information" (p.10).

Brereton (2000) found through her study of multi-year engineering students engaging in project work, that engineers continually challenge the discrepancies between the physical representation and their conceptual understanding in order to advance both the design process and their conceptual understanding. She identified that: “design thinking is heavily dependant on physical objects; that designers are active and opportunistic in seeking out physical props; and that the interpretation of and use of an object depends heavily on the activity” (p.217).

Yang and Epstein (2005) studied advanced mechanical engineering students who in teams were required to design, build and test a mechanical device. The outcomes of the teams were compared in a design competition and the competition placing’s were related to the role of the artifact during the design process. Groups who had fewer parts to their prototypes, and were therefore considered a simpler prototype, performed better in the design content. Further, those groups which spent less time on fabricating the prototype also had greater outcomes in the competition. They concluded that prototypes should remain simple and spending proportionately more time on prototyping in the conceptual phases of the process will lead to better outcomes.

The studies identified above focus on the interaction between behavioural and functional models (as defined by Stoll (1999)) within the design process. Their role within the design process has been clearly shown to be integral to the design process rather than an outcome of this process. It is also evident from these studies their role as a means of communication within the team environment. This is further emphasised by Bucciarelli -

To fully understand the production and use of design representations in engineering, one must see them in context. One must see them as terms of design discourse, but within the object world where the discourse is often a monologue … and within the more social and collective enterprise of negations across object worlds (Bucciarelli 1999, p.173).

The majority of the studies on physical artifacts have focused on the use of artifacts within the latter stages of the design process and also within a mechanical engineering context. However, this thesis extends our current understanding of interaction with artifacts by focusing on a specific context where discovery through artifact interaction and reflection is intensified. By focusing on an early stage industrial design context, the role of aesthetics and human factors, together with engineering constraints which are communicated through artifacts, will be highlighted and extend our current understanding. It is this stage where artifacts must be kept simple and imprecise.

A further departure on our current understandings on the role of artifacts to support design activity is the focus on an emerging type of artifact, the 3D Virtual Sketch Prototype, which is explored in the following section.

Virtual Artifacts

As noted previously, artifacts have been traditionally defined by their physical properties, thereby preventing any object which did not have a physical characteristic to be considered a design artifact. However this thesis has used a more general definition of the term artifact, one that is less concerned with their physical properties and more concerned with their application to the design process. Therefore it is feasiable to consider an artifact to have no physical properties such as a virtual artifact as it embodies design concepts and knowledge through their virtual representation. This section further outlines examples of virtual artifacts as used within the design process.

Weisberg (1995) describes three types of software tools currently used by industrial designers for product development. The first type describes desktop illustration tools which generally assist the designer in sketching 2D representations of 3D forms using a computer mouse and monitor rather than a pen and paper. The second type of software tools has been defined as CAD, which is typically used for detailed engineering design. A design concept is represented using 3D geometry (surfaces or solids) allowing for downstream manufacturing integration. The final software type is CAID, which enables the designers to rapidly sketch and visualise design concepts as true 3 Dimensional objects allowing for real time form manipulation within a software package. The following section provides an overview of the literature which relates to the role of virtual representations of artifacts for design activity.

The introduction of CAD related technologies has altered the cost and time necessary for consumer product development. Downey (1992) noted how CAD/CAM technologies promised to streamline product innovation in American industries by allowing them to respond to consumer demands as the technology allowed the merger of design and engineering, which were thought of previously as distinct activities.

Various studies have been published which examine the benefit of incorporating such tools within industrial design practice (Buckner 1993; Mahoney 1994; Potter 1994; Laurenceau 2000; Tovey, Porter et al. 2003). These studies suggest that a major contribution of their introduction be in the reduction in time within the product development process. Further analysis of these studies show that the actual time savings are often made during the later stages of the design process, once the design concept is finalised. During this phase the design can be “entered” into the software as a 3-D model providing downstream manufacturing benefits. Arguments for the incorporation of CAD in the concept stage of the design process are still being offered. Benefits of this incorporation as suggested by Buckner (1993) include:

- Minimisation in the scope for mis-interpretation from design to manufacture;
- Reduction in duplication of effort (design modelling / engineering modelling); and
- Possibilities for concurrent product development.

In a study undertaken by Laurenceau (2000) he notes that physical models remained an important integral part of the design process. His study of US based industrial design practitioners identified that traditional modelling is still an essential tool used primarily for initial client presentation and form studies. However, computer models were favoured for detailing, refinement and revision of a design concept. Factors which influenced decisions about the choice of physical model or computer model were based on time required, budget, the technological capabilities of the team, the number of designers on a project, the complexity of the product's shape and size, and the client needs and a particular stage of the design process.

Goel (1995) provided a framework on why CAD interfaces may not be appropriate for conceptual design. Goel shows that a design sketch is a good example of an ill-structured mental representation as they are imprecise, ambiguous, fluid, amorphous, indeterminate and vague as opposed to well-structured representations, which are precise and unambiguous. CAD systems require precision making them inappropriate for ill-structured representations.

The IDEATE research project led by Jim Hennessey, focused on the conceptual phase of the industrial design process and identified ways in which this activity could be supported through computer based tools (Hennessey 1994). This project stemmed from the notion that CAD systems of the period did not allow the designer to employ all of their skills, like clay modelling, during conceptual design. Tovey (1989; 2003) in his group's extensive studies on the role of sketching for Automotive Design, also comments that most CAD systems are unsympathetic to the processes and techniques commonly used by designers, particularly at the early stages of the design process.

In an attempt to overcome the limitations of the CAD interface, several research groups have attempted to integrate the approaches traditionally used by designers (such as sculpting) with digital representations. This has involved moving away from the traditional notions of desktop computing to that of Weiser's vision of ubiquitous computing, "making many computers available throughout our physical environment, while making them effectively invisible to the user" (1993, p.75). He notes that "the computer today is isolated from the overall situation, however, and fails to get out of the way of the work. In other words, rather than being a tool through which we work, and thus disappearing from our awareness, the computer too often remains the focus of attention" (Weiser 1993, p.76).

The work of Ishii and Ullmer (1997) furthered Weiser's vision when they introduced the concept of *Tangible User Interfaces (TUI)*. They noted that TUI's "would augment the real physical world by coupling digital information to everyday physical objects and environments" (p.2). Abowd, Mynatt and Rodden (2002) suggest that the vision of ubiquitous computing assumes that "physical interactions between humans and computers will be less like the current keyboard, mouse and display paradigm and more like the way humans interact with the physical world. We speak, gesture and write to communicate with other humans and alter physical artifacts. The drive for the correct ubicomp experience has resulted in a variety of important changes to the input, output and interactions that define the human experience within computing" (p.48).

There is extensive literature reporting the development of novel interfaces for the review of design concepts which relate to the field of Ubiquitous Computing. A non exhaustive list of research within this domain includes Cutler, Frlich and Hanrahan (1997) who have developed a system that allows users to naturally manipulate virtual 3D models with both hands using a workbench environment. Their work is grounded on observations of how humans distribute work between two hands. Ullmer and Ishii's (1997) (1997) metaDESK is one example from MIT's Media Lab group using augmented reality to emphasise human interaction with the physical world. Through the manipulation of physical objects on a display surface the user is able to intuitively manipulate computer generated data. Hummels and Overbeeke (1998) describe a Virtual Clay Modeller, which is a computer aided version of traditional clay modelling for use with automotive designers. The project considers the entire spectrum of the styling design process to develop intuitive computer aided tools for the automotive industry.

Bucolo and Curran (1995; 1999) investigated the use of 3D Scanning technologies to allow designers to work in traditional media (such as polystyrene, timber, plasticine) and then rapidly create a 3D digital representation of this for use in a concurrent engineering cycle. The aim of the research was to identify if new technology could be integrated into the product development process which allowed the designer to control design intent from a concept model to CAD model without altering the design process described. This work was then expanded to include the use of Haptics as an alternative interface to keyboard and mouse interfaces for 3D CAD modelling (Bucolo and Chan 2001).

The above studies focus on the development of a new interaction device embracing the notion of ubiquitous computing which has been developed to assist the designer in the generation of digital artifacts, or to allow the designer to evaluate a digital artifact within a multi modal environment. These studies make a significant contribution to the limitation of CAD interfaces used within a desktop computing model. However, few studies have been identified which identify how the role of virtual artifacts impacts on the design activity within a design process, specifically the conceptual design phase. This thesis aims to contribute to this body of research by revealing new understandings of the nature of discovery through the use of emerging technology based artifacts. In doing so, new concepts for such interfaces can also be developed.

Few studies have been reported which directly compared the use of virtual and physical prototypes within a design environment. Deisinger (2000) evaluated three immersive based modelling tools (Naegeli RT – a volumetric Based Modelling tool; Lotus – a polygon based 3D Sketching Tool; and VE CAD – a Free Form Surface Sketching Tool) by design professionals. His findings identified spatial visualisation, full scale modelling and immersion as important criteria for the design process in immersive modelling. Further, he identified that the designers perceived shutter glasses, cables, and button interfaces as hindrances or inadequate for drawing and sketching.

Dahan and Srinivasan (2000) developed an internet-based product concept testing method. They compared the use of four approaches to market research: verbal descriptions; physical prototypes; online 2D visual representations (statistic prototypes); and VRML representations (virtual prototypes). Their research aimed to identify what form a design concept needs to take in order to make accurate predictions about the market potential of new products. They question whether physical prototypes are necessary or whether visual representations are sufficient. The reasons they suggest for adopting virtual prototypes include: the cost of building and testing the virtual prototypes is considerably lower than that of physical prototypes thereby allowing parallel testing of numerous concepts within the design development cycle; and access to respondents is efficient and expedient as compared to traditional approaches. They compared the physical against the virtual approach to predict customer tradeoffs on multiple product attributes and prices for the design of a bicycle pump. Their results identified that the virtual approach provides a close match to the results generated using physical prototypes. However, they caution against the generalisation of their results to various product categories as they note that sensory experiences such as smell, touch and taste are yet to be easily replicated in virtual environments. They believe future research is required to determine which product characteristics affect customer choice through physical prototypes before this approach is fully adopted.

Söderman (2002) notes that while there are different types of product representation used within a design process, little is known of how these different types of representations affect the potential end user of the design. His study compared computer based representations to hand drawn sketches and real products in an attempt to determine how product representations impacted on the understanding of the proposed product with potential end users. The study found that when comparing VR models to hand drawn sketches, little difference in the participants' understanding of the end product was observed. He has also identified that when participants rotated and zoomed on a virtual product it did not enhance the participants' understanding of the product they were viewing.

The above studies on the use of virtual artifacts for design evaluation are an initial attempt to identify the impact of such tools within the industrial design process. Although they present some significant findings they do not report on the impact the introduction of such tools has on the activity of design, specifically the initial stages of design activity. Further, they do not reveal new understandings of the design activity. Both of these points are points of departure for this thesis, where the aim is to build upon the foundations of Schön, Polanyi and Ehn to reveal the role of the artifact in contributing to reflection in action and discovery.

2.3 Design Paradigms

As noted previously, the review of the literature has highlighted the role of the artifact within the development or later stages of design activity. To develop a better understanding of the role of artifacts in the early stages of design activity, a greater understanding of design activity is required. To fully appreciate the design activity / artifact relationship, a review of the competing paradigms of design and their theoretical foundations is presented in the following section.

Gedenryd (1998) accurately summarizes initial theoretical perspectives on design "as an orderly, stringent procedure which systematically collects information, establishes objectives and computes the design solution, following the principles of logical deduction and mathematical optimization" (p.1). The initial work of Alexander (1964; 1977) and Jones (1970) exemplified the methods which prescribed initial thoughts on design activity. Further, the work of Herbert Simon's (c1996.), *The Science of the Artificial*, provided a framework for studying the designers and design problems within the paradigm of technical rationality. As noted by Dorst and Dijkhuis (1995), "the positivist background of these theories made for design being seen as a rational (or rationalizable) process" (p.261). Artifacts become less relevant in such an approach as design activity was seen as an internal cognitive activity, separated from the interaction and its environment.

In contrast to this theoretical perspective, a counter view based on authentic experience of design activity has emerged, as noted by Dorst and Dijkhuis (1995). Schön proposed an "alternative epistemology of practice, based on a constructionist view of human perception and thought process. He sees design as a 'reflective conversation with the situation'. Problems are actively set or 'framed' by designers, who take action (makes 'moves') improving the (perceived) current situation" (p.263). Therefore, Schön's work is firmly grounded in the actual experience of design practice. There has been a wide rejection of a rationalist design methodology as the studying of actual design activity demonstrates that designers do not behave as the theory proposes (Alexander (1977), Lawson (1980) and (Cross 2007)).

The work of Polanyi and Ehn complements Schön's description of design activity. Polanyi (1998) addresses the relationship between enquiry and creativity and difficulty is bridging the "logical gap" which is found between existing knowledge and any potential significant new discovery or innovation. Polanyi (1998) refers to the need for leap a of illumination, "the plunge by which we gain a foothold in another shore of reality" (p.123) and assist in visualising new concepts. Ehn furthers this by referring to the concept of traditional and transcendence. He outlines how design is concerned with the social and creative activity founded in our traditions, however, it must still aim to transcend these by constructing alternative futures (Ehn 1988). If this is the essence of creative design activity, what role do artifacts play to support such activity?

The UTOPIA project led by Ehn in the 1980's developed cooperative design methodology which provided users with a 'voice' in the early stages of the design process with a specific focus on the future design of computer applications. The use of low-tech prototypes early in design sessions with end users was also reported. A more recent example of this approach is the ATELIER project (architecture and technology for inspirational learning) (http://atelier.k3.mah.se/home/) which aimed to contribute to the understanding of inspirational forms of learning and to building augmented environments. Prototypes which explored approaches to mixing physical and digital artifacts and integrating them into the physical space of the students' learning activities were developed. From the deployment of such prototypes an understanding of face to face interactions with people and material artifacts in physical spaces could be reported on.

Ehn notes that "use of design artifacts (models, prototypes, mock-ups, descriptions, representations, etc) brings earlier experiences to our mind and it 'bends' our way of thinking of the future. It is in this meaning we should understand them as representations, not in the meaning of mirror-images of the 'reality'" (Ehn 1988, p.145). This thesis will build upon this understanding, by focusing on a specific context - early stage industrial design activity. It also aims to further this understanding by comparing traditional artifacts (models, mock ups) with emerging design artifacts - a virtual prototype during this stage of design activity.

2.4 Early Stage Design Activity

Erickson (1995) makes reference to three stages of a design process which include exploration, refinement and transition. He notes that although all three stages are present in a design project, they can not often be clearly separated as such. During the exploration stage the focus is on problem setting and team building. The refinement stage focuses on design development and obtaining feedback from the user. The transition stage is the move from product concept to design detail, ensuring it moves to market.

This research focuses on the exploration and refinement stage, referred to hereafter as conceptual design. Conceptual design consists of both development and review activities. Design development as defined within this study refers to activities such as design research, sketching, model making, talking to users etc. Design reviews (also know as design critiques) is the stage when teams of designers come together to further develop the design concept and develop a shared understanding of the design concept. A commonly cited example of a design review is that provided by Schön (1983) in the protocol of Quist reflecting on Petra's initial designs for an architectural project. Design review sessions differ to design presentations, as the goal is not to 'present' the design concept for approval to the design team, but to discuss and further the design concept. By focusing on this stage of the design process it intensifies the nature of discovery and reflection which can be observed, as it is this stage of the process where the designers have maximum interaction with their artifacts and are required to create new knowledge and move the design problem forwards.

Bucciarelli (1994) describes this as a process of enabling that there is a consensus among participants who may share different interests. Bucciarelli notes that the participants of the design team do not always have the same interests and may differ in their technical expertise and experience. As with Schön's (1983) design review example, Petra (the student) believes her design solution has come to a dead end. Quist (the academic), within a design review, begins to sketch over Petra's drawing while talking to her about the problem in an attempt to help her reframe the problem. Through this shared dialogue of drawing and talking, new discoveries are made providing Petra with an ability to move forward on her design solution. Schön (1983) refers to this as a reflective conversation with the situation. "Three dimensions of this process are particularly noteworthy: the domains of language in which the designer describes and appreciates the consequences of his moves, the implications he discovers and follows and his changing stance toward the situation with which he converses" (p.95).

Typically such review sessions (critiques) regularly occur throughout these early stages of the design process. They may occur randomly or be formally set within the schedule of the design process. They may involve all members of the design team or just a subset of the team. Session times vary depending on the type of meeting but generally last from 10 minutes to many hours. The location of the design review also varies but often occurs within the design studio or office meeting space.

Schön's "alternative epistemology of practice, based on a constructivist view of human perception and thought process" (Dorst and Dijkhuis 1995, p.263) provides a useful foundation to this thesis. Through a focus on the artifact, Schön reveals new dimensions of design activity and engagement. Schön describes the design process as an interactive process of framing the design problem, discovery mediated by the materials and subsequent reframing of the problem in the light of the discoveries made during designing. In his initial description of the reflection in action paradigm (Schön 1983) he describes the sketch as talking back and revealing issues to the designer. He notes that the evolving physical prototype is a yet more active and evocative participant than the sketch as it responds through physical behaviour allowing the designer to obtain feedback through seeing, smelling and hearing the prototype.

However, Schön's understandings were not specific to design alone (Visser 2006). Schön used examples from many domains (eg medicine) to demonstrate the phenomena of reflection practice. In order to reveal new understanding, further analysis of the in situ practice of design is required. Where Schön's works help us to understand 'why' a particular phenomena exists, an understanding of 'what' is occurring will also lead to new understandings.

This is further expressed by Hutchby (2001) where he notes that the "social constructivist consensus has usefully brought to the forefront the recognition that social processes are involved in all aspects of technology and not simply in its effects upon society. But we can become too fixated on the social shaping of technology at the expense of an equally pressing, though differently framed, concern with the technological shaping of social action" (p.453). By interjecting a new technology artifact into the design process and using methodologies to study the altered design activity, this thesis will reveal these new understandings. It will achieve this through the use of 3D Virtual Sketch Model as a technology probe to develop a better understanding of the design review activity within early stage design development. Two points of departure will be made through this research. Firstly, the fidelity of the virtual representation is a unique contribution to the research. Previous studies focusing on Virtual 3D Sketch Models have not been identified. Secondly, the focus on the use of virtual representations during a design review embedded within actual industrial design practice has not been widely reported.

However, in order to reveal new understandings, methodologies to investigate the intricate nature of the in situ artifact / activity relationship are required.

2.4 Analysing In Situ Design Activity

Making use of artifacts to support our thinking is not confined to design activity. Each time we make a note to ourselves on a piece of note paper to remember a particular detail, stack files to sort later we are using the physical properties of an artifact to help with our internal cognitive processes. In the case study provided by Kirsh and Magilo (1992) being an observation of players using the computer game 'Tetris', they found that players rotated the blocks on screen to visually see the impact it will have on the game rather than try to visualize the rotation of the block in the players mind. Kirsh and Magilo (1992) note that "certain cognitive and perceptual problems are more quickly, easily, and reliably solved by performing actions in the world rather than by performing computational actions in the head alone" (p.224). Lave (1988) found that people demonstrated greater mathematical skills within a shopping centre when compared to completing abstract mathematical questions as the participants were able to draw on the resources of the shopping centre environment in determining their solution.

The field of Human Computer Interaction has made a significant contribution to the understanding of the role of the physical world in understanding human cognition. As noted by Nardi, "a broad range of work in psychology, anthropology and computer science has shown that it is not possible to fully understand how people learn or work if the unit of study is the unaided individual with no access to other people or to artifacts for accomplishing the task at hand. Thus we are motivated to study context to understand relations among individuals, artifacts, and social groups" (Nardi 1996, p.35). Three approaches to study context are often cited - Distributed Cognition, Activity Theory and Situated Action which, are briefly discussed below.

Hutchins' (1995) notion of distributed cognition expands the notion of traditional cognitive sciences to account for people drawing upon their social and physical context. Its focus is on representations, both internal and external and the relationships between them to support cognition. Hutchins' (1995) study of marine navigation illustrates how the relationship between the navigational equipment, the crew of the vessel and the actual environment contribute to the act of navigation. Although he agrees with the traditional notions of cognition, it is only when it is applied broadly to larger sociocultural systems and not restricted to only mental process. Therefore he expands traditional cognitive science to account for cognitive properties which occur from people and their interaction with artifacts and their environment.

Nardi describes Activity Theory as a powerful and clarifying descriptive tool rather than a strongly predictive theory (Nardi 1996). It provides a framework for understanding how people act in the world by focusing on the broader ‘activity system’ rather than their individual elements. As noted by Leont’ev (1974), an activity consists of subjects, objects, actions and operations. A ‘subject’ is a person or a group who is engaged in the activity. The ’object’ is the motivation of the person or group. The ‘actions’ are the goals (or tasks) which are required for the person or group to achieve their objective and operations are the unconscious routine tasks to achieve the objective. It is also noted that the elements of an activity are not fixed and can change dynamically as the situation changes. A further aspect of Activity Theory is the concept that artifacts are mediators of human activity and therefore it is not the interaction which is of interest in Activity Theory but the activity which surrounds this interaction.

Lucy Suchman (1987) introduced the term Situated Actions in her book, *Plans and Situated Actions*: the problem of human-machine interaction, which grew out of PhD thesis based on work undertaken at Xerox PARC. Suchman notes that the aim of the research was not to produce a formal model of knowledge and action, but rather to assist with in the exploration of the many relationships which occur between knowledge and action, focusing specifically on the contexts in which these relationships occur. Situated Actions has at its core the premise that a person’s actions are influenced by their specific situations. People will map out plans in their minds, but these can be changed depending on what is happening in a specific situation. Their plans are constantly changing and evolving dependent on the situation which needs to be considered at the moment by moment level of detail. Nardi notes that all three frameworks “are valuable in underscoring the need to look at real activity in real situations and in squarely facing the conflux of multifaceted, shifting, intertwining processes that compromise thought and behaviour” (Nardi 1996, p.30). The common thread between these theories is that they discount traditional notions of cognition as being associated solely with the mind and interlock cognition with the mind, activity and the world.

These frameworks provide a foundation to explore the notions of artifacts within design reviews. Rather than consider the role of the artifact in isolation, but within a broader context of activity, situation and mind, it will allow for new insights to be gained on the early stage design review activities. However, before this can be explored, a review of the literature which considers the unique properties of the artifact (3D Sketch Virtual prototypes) and its impact on human interaction is also required.

2.5 Analysing Virtual Design Activity

Much has been written on the broad topic of Virtual Reality. The term can be discussed from a hardware interface perspective (eg Head Mounted Display), an application (eg Virtual Surgery), an industry (eg entertainment industry) or as an emerging communication system (Biocca and Levy 1995). In terms of this study, it is the interaction with the computer-generated data which is of particular interest. Such interaction can be defined as the full or partial immersion of the human sensorimotor channels within a co-located computer generated environment.

While advancements have been made in both application and performance of Virtual Environments, a conceptual and analytical framework to guide this research and a set of metrics to measure performance within virtual environments, is currently lacking (Draper 1998). Barfield (1995) notes that it is generally accepted that the concept of Presence represents the underlying theme or conceptual framework for the work being undertaken in Virtual Environments. There is an assumption that an increase in Presence will better the user performance of the task. This notion that there is a causal relationship between performance and Presence has been reported by Witmer (1998), however, a strong relationship has not been identified within the literature to date.

Presence research is of interest to this study because interaction between designers and virtual prototypes may be affected by the quality of Presence in a virtual environment. Numerous definitions of Presence have been reported within the literature. The following provides a summary of the various definitions commonly cited.

Sheridan (1992) defines Presence (telepresence) as an experience. He describes it as a sense of the person losing their awareness of their local environment, believing that they are within a computer mediated environment. The strength of the experience can be described across three determinants. The first determinant being the fidelity and richness of sensory information being presented to the user. The second determinant is the dexterity of sensory control. The final determinant being the ability to affect the virtual environment. These three determinants, together with an understanding of the task (ie task difficulty and task automation), combine to affect the level of Presence achieved.

Slater, Usoh and Steed (1994) define Presence as the belief that the user is in another world other than where their bodies are. Presence can be described in terms of two sets of determinants - external and internal factors. External factors include: display qualities; consistency of presentation; two-way interaction with the environment; anthropomorphism of the user representation in the virtual world (ie avatar representation); relationship between user actions and reactions within the VE. Two internal factors are defined based on Neurolinguistic Programming (NLP). These include system representation (ie how a user interprets images) and perceptual position (point of view of information presentation eg first (actor), second (observer) or third person (abstract meaning not present). Through the use of NLP they hypothesise that persons who prefer visual presentations may be more inclined to feel a higher sense of Presence than those who prefer another representation, thereby indicating that Presence may be based on individual differences.

Witmer and Singer (1994) define Presence as a subjective experience of being in one place when physically in another. They further described the notion of Presence with that of individual characteristics which Slater referred to. They describe Presence using a combination of four categories. These include: control factors (the level of user control over the VE and how responsively and intuitively control inputs are translated to changes in the VE); sensory factors (the richness and consistency of the multimodal information); distraction factors (the ability for the user to focus attention through system immersiveness); and realism factors (the match between the VE and real world).

Mantovani (1999) describes Presence based on the concept we have of reality and that different ontological positions generate different definitions. He argues that the level of Presence does not depend on the faithfulness of reproduction of the physical aspects of the external reality but through capacity to produce a context in which social actors may communicate and cooperate. For example, a virtual environment, which represents an office space, would not produce a high level of Presence if the socio-cultural aspects of that environment were not represented.

Although the various technological approaches presented above differ in their definition, Draper (1995) offers the following summary. Presence "is an existential phenomenon that is triggered by features of the Virtual Environment and moderated by user characteristics".

Nichols (2000) notes that there is "no universally accepted measures of Presence because, like other manifestations such as mental workload and mental models, it is multifactorial and may be psychologically displayed in different ways by different people" (p.474). Objective Measures include: user report of Presence, observation of user behaviour and physiological measures. Sheridan (1996) objectively measured Presence by means of how people discriminate between real and virtual worlds. An experiment was developed where real and virtual environments were presented randomly to subjects. The degree of Presence they experienced was equal to the probability that an individual would say they were physically present when they were experiencing the virtual environment. Images were altered throughout the experiment based on reducing resolution or changing frame rate. A correlation could then be made between image specification and sense of Presence to determine conditions of Presence. Other authors who have reported studies related to objective measures of Presence include Slatter (1994), Barfield (1995) and Nichols (2000).

Subjective Measures rely on self-report and questionnaires to determine the level of Presence within a Virtual Environment. One example of this approach is the Witmer and Singer (1998) Presence Questionnaire (PQ) and Immersive Tendency Questionnaire (ITQ). Through their research they have identified that both involvement and immersion are independent variables, which will impact on the level of Presence a user experiences within a Virtual Environment. Involvement is defined as "a psychological state experienced as a consequence of focusing one's energy and attention on a coherent set of stimuli or meaningful related activities and events". Immersion is "a psychological state characterized by perceiving oneself to be enveloped by, included in and interacting with an environment that provides a continuous stream of stimuli and experiences" (p.226). They note that while immersion is a function of hardware used to display the Virtual Environment, it goes beyond a description of the VE technology (as defined by Slater, 1996) and should be considered an individual experience. They argue that the strength of how someone perceives their level of Presence in a virtual environment is dependent on both their individual differences and the characteristics of the Virtual Environment. In order to obtain a measure of Presence, which addresses both, they developed the Presence Questionnaire (PQ) and the Immersive Tendency Questionnaire (ITQ). The ITQ was developed to measure the capability or tendency of individuals to be involved or immersed. The PQ measures the degree to which individuals experience Presence in a VE and the reports on their influence of the possible factors which can impact on the intensity of the experience. Both questionnaires rely on self-report.

The ITQ consists of 18 items related to three empirically derived subscales defined as Involvement (likeliness of the respondent to become engrossed in mundane activities), Focus (measures the mental alertness of the respondent) and Games (measures the frequency and intensity with which the respondent plays video games). The PQ includes 19 questions aimed to measure three empirically derived subscales described as Involved / Control (how interactive and vivid was the experience), Natural (did the interface distract from task performance and concentration on the task) and Interface Quality (the degree to which the interaction seemed natural and consistent with the real world) (Draper 1998).

Various studies (Blake 2000) and (Casanueva and Blake 2000) have used the ITQ and PQ as a means of measuring Presence within Virtual Environments and have validated the finding with other measures. The authors note that they do not believe that they have identified all of the factors that affect Presence, however they have made considerable progress.

Draper (1998) notes that the benefits of Presence remains a vague concept due to the lack of research in developing objective measure of Presence, determining the relationship between Presence and performance and identifying settings which may enhance Presence. Part of the difficulty of developing objective measure to compare virtual environments is that different virtual environments support different activities that elicit different kinds of human interaction to achieve different goals.

This study provides an opportunity to overcome this limitation of previous studies of Presence as it will examine a specific kind of activity - the interaction between designers and physical and virtual prototypes. Although Presence provides an opportunity to understand *what* qualities of a virtual artifact may impact on design activity, it does not contribute to *how* such artifacts are considered more than just sources of information within the design process within the context of this study. It is not intended to criticise the concept of Presence as a valid measure, indeed the notion of understanding the impact from virtual environments which are high or low in Presence to would be of interest to the design community.

However, as the data to undertake such a study would require constructing specific virtual environments which demonstrate different degrees of Presence, this does not align to the spirit of my study where I was interested in observing authentic interactions between designers and their artifacts and therefore has not been included as part of this study. I was not interested in constructing artificial environments, but observing designers in the environments which they had access to and were utilizing on a daily basis.

I have previously studied Presence (Bucolo 2004) as a means to compare the cross-cultural differences between individuals interacting within immersive virtual environments. Such an approach provided a unique insight into viewers interaction with the virtual world and further studies specifically focusing on the role of Presence and its impact on design activity is warranted, however, should be considered a self contained study, and therefore outside the scope of this research.

2.6 Summary of Section

This section has provided an overview of the literature which has informed the foundation of this research. In an attempt to focus the research, an understanding of industrial design as a discipline was initially presented. Industrial design is described (within the context of this thesis) as a communication link between the consumer and all other participants in the product development process. To achieve this, the use of design artifacts within the design are used by the designer to ensure a shared understanding is maintained between the participants of the design process.

A detailed review of what constitutes a design artifact and what role artifacts have within design activity was then provided. Studies which have identified the role of sketches, physical models and prototypes were reviewed, highlighting that artifacts are more than representation of the outcomes of the design process. Harrison and Minneman's (1996) description of artifacts as "constituents of the activity … they are constituents of and frames for the communications … they alter the dynamics of interaction, especially in multi-designer settings" (p.432), is a useful summary of the role of artifacts within the literature.

The emergence of virtual artifacts within the design process has also been reviewed. The literature shows that the introduction of CAD based technology showed a reduction in time and cost for design development, but has not supported the designer within the early stages of the design process. This has led to the development of emerging technology based solution, which move beyond the desktop metaphor of CAD systems. These new tools have allowed the designer to utilise many modalities when interacting with the virtual representations during the design activity, thereby overcoming the limitation of CAD based systems. However, it was noted that limited research exists which identified the role of such tools within early stage design practice and during design review activities.

Artifacts were then contextualized within the competing paradigms of design to gain a greater understanding of the role of artifacts with specific activities. As this research is dealing with early stage design activity, Schön's (1983) reflection in action paradigm is a useful foundation for describing the design activity within the phase. Schön (1983), in his initial description of the reflection in action paradigm, describes the sketch as talking back and revealing issues to the designer. He notes that the evolving physical prototype is a yet more active and evocative participant than the sketch as it responds through physical behaviour allowing the designer to obtain feedback through seeing, smelling and hearing the prototype. This research questions if the physical model has been shown to be more evocative than the sketch, does the virtual model provide additional advances to design thinking? Further, what additional information does this technology reveal about design activity, specifically early stage design activity?

To further investigate this understanding, artifacts have also been reviewed in terms of our understandings of the nature of the interaction between designers and their artifacts and the environment. The notion that design is not only an internal (cognitive) process, but needs to be considered in relation to how the designer's action and interaction impacts on cognition, was presented. To better understand this distributed notion of cognition, theories from the field of Human Computer Interaction provide a useful foundation. These theories underpin the role of artifacts and their impact on cognition within specific instances. The frameworks identified will form part of the foundation on how to reveal new understandings of design activity when a virtual prototype is introduced into the early stages of design activity.

Finally, the broad field of Presence was reviewed to provide insight into the potential impact of properties of a virtual environment may have on design review activities. Understanding and controlling the many dimensions of the virtual environment will be essential in any study which aims to review virtual prototypes. However, considering Presence within this study was discounted as it was found it did not provide an insight into how artifacts may impact on design activity.

Section 3 provides an overview of how an enhanced understanding of the role of artifacts has been achieved through the use of two ethnographic case studies. It also outlines in detail the data capture and analysis phase of the project.

3.0 CAPTURING IN SITU EARLY STAGE DESIGN ACTIVITY: STRATEGIES FOR DATA SELECTION, COLLECTION AND ANALYSIS

Thinking is one of the most notoriously intractable parts of psychology since the thought process is not easily observed… the designer, however, has never resembled Rodin's "thinker" who sits in solitary meditation, but has in contrast always externalised his thoughts, not only as an end-product in the form of a design, but as an integral part of the process itself in the form of drawings and sketches (Lawson 1980, p.96).

This section outlines the study and methods used to reveal new understandings of design activity within the early stages of the industrial design process. As mentioned in the review of the literature, design is not solely a cognitive activity, but relies on interaction with artifacts and their environment. Therefore, the field data for this research has focused on capturing the activity within a design review to reveal the nature of the interactions between the designers and their artifacts. I have used my knowledge of the theories of Distributed Cognition, Situated Action and Activity Theory to frame my understanding of interaction and extended this through the creation of an ethnographic case study described in detail within this section. Using a rigorous approach to my data capture and analysis, utilising the framework of Miles and Huberman (1984), I have been able to observe interactions within and across multiple case study sites, which have led to the findings presented later in this thesis.

In this section I will first describe the data selection and collection stages, which consisted of an ethnographic case study, to allow me to identify the elements of the nature of the design activity. This activity was captured using multiple data sources including video and interviews. The data analysis stage is then discussed. Using Miles and Huberman's (1984) approach, I outline the stages of data reduction and data display which enable me to analyse the data across the case study sites and make meaning of the observations. I describe how this process of data collection and analysis was an iterative one which help me to find patterns across the multiple cases being analysed.

I then outline the data findings made from this analysis. By looking at the multiple data sources, I have made a series of findings which form the basis of my conclusion from this thesis. These findings are then discussed further in the final part of this thesis.

3.1 Data Selection - Analysing In Situ User Interaction

My study aim was to develop a detailed understanding of the role of artifacts in supporting design engagement through observations of designer's interaction with virtual and physical representations during a design review. I was not interested in formulating a new model of design activity for the use of these new tools, but to build upon the findings of Schön, Polanyi and Ehn through reporting on the actual uses of such artifacts and to witness how this impacted on design activity. For this reason I have chosen to ground my work in the interpretation of empirical qualitative data.

To achieve this I have drawn on the methodologies commonly found within the social sciences, namely an Abductive research strategy. "Abduction is the process used to produce social scientific accounts of social life by drawing on the concepts and meanings used by social actors and the activities in which they engage" (Blaikie 1995, p.176). As noted by Blaikie, it is the role of the social scientist to discover "why people do what they do … it is the everyday beliefs and practices, the mundane and taken for granted, which have to be grasped and articulated in order to provide an understanding of these actions" (p.176).

The Abductive strategy has many layers, however at its core is the translation of moving from every day concepts and meanings of social life to a technical description or theories of that social life (Blaikie 1995). In order to make this translation I have drawn on methods commonly found within the social sciences, namely ethnography. Blomberg et al (1993) identify four main principles to undertake ethnographic work:

- First hand encounters: A commitment to study the activities of people in their everyday settings;
- Holism: A belief that particular behaviours can only be understood in the everyday context in which they occur;
- Descriptive rather than prescriptive: Describe how people actually behave, not how they ought to behave;
- Members point of view: Describe behaviours in terms which are relevant and meaningful to study participants (p.125).

Although the use of ethnography has been widely claimed within design research, Button (2000) questions if most studies are undertaking ethnographic analysis or simply conducting fieldwork. He notes that "investigations that currently call themselves ethnographies are not cast in the mode of classical anthropological ethnographies, as they do not necessarily propose the application of a favoured social theory to the particular group or work domain under study" (p.325). However, although Ball (2000) makes a similar observation, he notes that in a design context the role of the ethnographic method is more applied in nature. He notes that applied ethnography differs from pure ethnography on three levels. Firstly, the nature of data being collected is often limited to samples of snap shots of ongoing behaviour. Secondly, observations are generally theory driven or based on a prior hypothesis. Thirdly, there is a need for verifiable objective data.

It is important to note that ethnographic methods have been adopted to suit design research and that design studies using these methods should be very clear to explain their assumptions (physiological, epistemological and ontological) claimed and methods in detail.

For this study, the ethnographic analysis goes beyond what Button refers to as simply fieldwork. The study was created to allow me to build upon Schön's, Reflection in Action Paradigm, allowing me to reveal new insights into the nature of discovery and reflection occurring within this setting. I have chosen to develop a case study which spans multiple sites (a traditional setting and one where the use of 3D Virtual Sketch artifacts are used during a design review) to allow me to focus on the interaction between student designers and design artifacts within an actual early stage design review process.

The use of the multiple sites allowed me to observe patterns of activity within each setting and then to consider what was generalisable and unique to each setting through a comparative analysis. As noted by Miles and Huberman (1984), "having multiple sites increases the scope of the study and thereby, the degrees of freedom. By comparing sites or cases, one can establish the range of generality of a finding or explanation and at the same time pin down the conditions under which that finding will occur" (p151). To ensure I was able to analyse across the multiple sites this I kept most variables within the study identical (design project, study group) and altered only the design artifacts being used to support the design activity and the physical review environment. The study design is described in greater detail in the following section.

3.1.1 Study Design – Overview

In undertaking this research I wanted to identify new ways of working by understanding the role of these new approaches in actual practice specifically the use of virtual artifacts within the early stages of the design process. I wanted to compare and contrast the role of these digital representations with that of the analogue tools I had been taught and had used throughout my professional practice. Further, I wanted to reveal more about the early stages of design activity by using such tools.

As previously mentioned, at the time of writing this thesis I was responsible for delivering an industrial design studio and CAD based units within QUT's Industrial Design program. The motivation for this thesis came partially from my observations over a decade of students' interactions in non-technology based design studios (referred to as traditional environments) as compared to working in highly immersive digital environment for design critiques or reviews. In the spirit of Schön's Reflection in Action Paradigm (discussed throughout this thesis as a grounding for understanding the role of artifacts within a design review, but in this section I specifically refer to it as my foundation for understanding a particular phenomena) I was able to immerse myself in the data through my practice. As Schön (1983) notes:

"Practitioners do reflect on their knowing-in-practice. They may do this in a mood of idle speculation, or in a deliberate effort to prepare themselves for future cases. But they may also reflect on practice while they are in the midst of it. Here they reflect-in-action … (however) the pace and duration of episodes of reflection-in-action vary with the pace and duration of the situations of practice" (p.62).

My expertise in practice, grounded in human centred design, naturally allowed me to consider this problem in the spirit of a participatory design or action research agenda. Using these approaches as a foundation, my approach led me to situating myself in the domain of the study. The goal was to reveal new understandings based on Schön's Reflection in Action Paradigm, by undertaking an in situ review of authentic early stage design activity.

This studio environment within the industrial design program at QUT provided an ideal opportunity for the study. Firstly, as the students were final undergraduate or post graduate students it provided an authentic case of a design review without the commercial constraints (such as limited access and commercial in confidence discussions) to undertake the study. Secondly, the pedagogical implications of student designers provide an additional affordance which allows a time paused insight into the studying of design activity, allowing concepts to reveal themselves which may otherwise go unnoticed.

3.1.2 Case 1 Study Description – Traditional Setting

The case study was captured within the final year industrial design studio unit at the Queensland University of Technology (QUT). In groups of two the students were required to select and purchase a consumer white goods product and undertake a redesign of this product based on their analysis of the market, usability and manufacturing considerations. The students were required to maintain the existing market position of the product, which required them not to increase the cost of their new design. Innovation was encouraged, which provided a strategic point of difference for their new design within the existing market, however any new features which were introduced need to be justified in terms of cost to the product. They were also required to maintain manufacturing constraints from the existing product within their new design.

From a pedagogical perspective, this design unit allowed students to explore the constraints of a design for manufacture approach focusing on a conceptual design exploration stage. As with the case of many professional design projects, innovation versus manufacturing and cost constraints is a daily challenge. In this project students were required to reconcile their highly innovative design solutions with the real constraints of product components, manufacturing and costs. Creating and evaluating these alternative futures was the core underpinnings of the design unit. The design students were seen evaluating the multiple, often conflicting constraints, whilst generating new design discoveries throughout the course of the project.

The duration of the project was 13 teaching weeks and formed the basis of their major project for the semester. The project was constructed to provide students with an insight into the practice of consumer product redesign, following closely the challenges a professional designer would face within such a project. Students were encouraged to adopt a professional design studio model in the class, considering themselves as employees of a design consultancy and the teaching staff as senior design members of that firm.

The unit was delivered on a weekly basis, with each class (studio) having 6 contact hours (fours hours in the morning session, then breaking for lunch and two hours in the afternoon session). Fourty-eight students were enrolled in the unit and as a pre-requisite were required to complete 5 previous design units throughout their degree program. The studio was delivered in a large open plan space, where students had the flexibility to rearrange the furniture to suit the activity.

As the preferred choice of medium to record design activity / notes was A3 sketch pads, considerable 'pin up' wall space was available, allowing students to visualise their work in small group discussions. The unit was delivered, where possible, in a way which reflected professional practice, however on occasions formal lectures were provided as part of the unit.

Typically the studio would begin with a formal introduction by the studio leader who would outline objectives for the day and contextualise the day's activity within the broader projects progress and academic setting. No more than 15 minutes would be spent on this. The majority of time would then be spent undertaking discussions with peers and design staff on the progress of the students' projects in either small group design critiques or in larger scheduled design reviews. Students were encouraged to bring all work to the studio which they had undertaken during the week for review within these sessions.

As is typical in such a process, the students communicated design details and their relationship to the original design brief through a series of sketches and form studies. Peers and local industry experts (teaching staff) then critiqued the design on a weekly basis. Each review consisted of the design teams updating the teaching staff and their peers on the progress of the project. The goal of the review was to obtain a shared understanding of the concept among the team (staff and students) whilst determining the suitability of the concept to meeting the original design brief. The review sessions were approximately 20 minutes in duration and within a class the staff and students contributed to 8 teams reviews in the one session (4 hours in duration). Each session was fairly informal, reviewers and designers engaged in considerable discussion and clarification throughout the process. Figure 3 illustrates the studio setting and shows some examples of the physical objects used within the design review.

Figure 3 – Design Review Setting

As mentioned previously, design reviews refer to the occasions when teams of designers come together to further develop the design concept. It is here where the team develops a shared understanding of the concept through group discussions and interaction with the many sketches and models brought to the meeting. Design review sessions differ from design presentations, as the goal is not to 'present' the design concept for approval to the design team, but to discuss and further the design concept. Therefore the design review is an accurate summary of the weekly design activity which has been undertaken by the students, allowing the design discussions and decisions to be intensifies and revealed during a short period of time.

Outside of these set studios the design process continued, however without the time pressures of a design review. The students would develop their design solutions, create the various artifacts in any medium that was appropriate to them (sketches, 3D foam form models, CAD representations), evaluate their ideas against the original design brief and had discussions with peers to further clarify their design decisions. At the conclusion of the project, the students would submit the design concept journal (typically up to 300 A3 pages), which provided a mechanism for them to document and reflect on their design activity.

The studio environment did not have a workshop attached to it. This facility was available in a separate building a few minutes walk away from the studio. No technologies such as CAD equipped computers were available within this studio. Students were able to make use of their own laptops if they had them available to them, however an extensive computer laboratory was available to them which was located in the same building two floors below the studio. Depending on the format for the studio (and availability of these facilities), students were able to freely move between the studio, workshop and CAD laboratory during the allocated studio time or make use of these facilities outside of class time.

As mentioned, the project focused on the redesign of an existing consumer product of the student's own choice. It required them to explore the market, usability, tooling and specification stage of their final design solution and how these impact on concept design decisions. The students were required to control their design concept from a final design freeze through to manufacturing specification – a design-balancing act. Students were required to form their own group of two and purchase a product suitable for redesign. They were then required to undertake a feature analysis of competitor products within their product's market segment. They were also required to determine the user profile of their product's market segment. In addition to this initial analysis, they were required to conduct a usability evaluation of the functioning product and then disassemble the product to undertake a Design For Manufacturing Analysis (DFM) of the product to determine component specification, assembly procedure and component and assembly cost. The Design for Manufacturing Analysis approach as described by Ulrich and Eppinger (2000) was used as the foundation for undertaking this analysis.

This activity occurred during the first 7 weeks of the unit and the students were required to submit a design proposal (as a series of A2 presentation boards) which outlined key areas (manufacturing, usability and aesthetics / market) which their redesign would focus on.

Following this submission, students were required to generate multiple product variations (minimum 30) based upon the design constraints, which addressed their design proposal. The use of sketches, early stage CAD models and foam form studies were encouraged at this stage. These were then to be evaluated and refined as two final designs. Within a design review session, one final design was to be selected and was to be 'frozen' from this point. This activity occurred during the 11th week of the project.

Once the final concept was selected the remainder of the project related to refining manufacturing detail of the selected frozen design. Students were required to evaluate decisions and modify design detail as required. CAD / Technical representation was recommended at this stage of the project. Students were only able to alter the design intent of the concept presented in week 11 based on tooling / manufacturing / costing requirements. An educational objective of the project was to demonstrate to students the difficulty in controlling design intent of a concept when final manufacturing considerations must be realised.

The final outcome for the project was a series of A2 presentation boards communicating their final design solution, a final manufacturing report documenting tooling and costing for their design and their concept development journal for the entire process.

The design approach (Figure 4) used within this unit was outlined in the project brief and summarised below (The full project brief can be found in Appendix A).

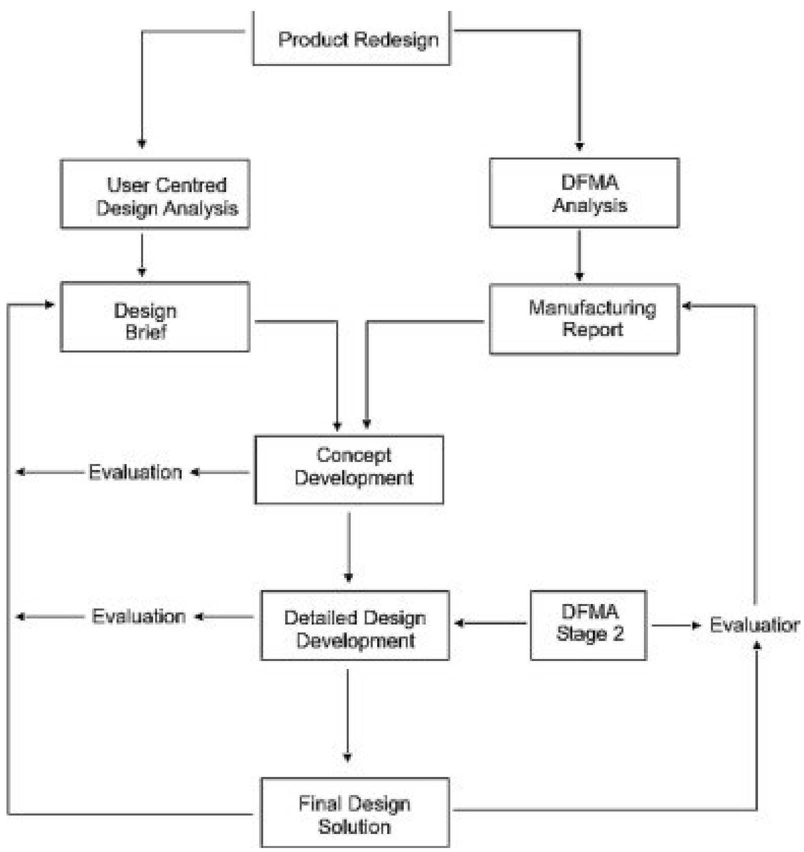


Figure 4 – Project Design Approach

To study the role of artifacts and design activity, the unit described above was used as the basis of my data collection. Specifically it was the design review session undertaken at week 11 which was of most interest. As students were required to select a final design concept at this stage, the review session took the form of an intensive reflection in action paradigm, where the students and the design staff were to consider two design concepts based on the unique design criteria developed by the design team in order to determine which concept was most suited to investing additional time to progress to the next level.

As part of the review process the group (staff and peers and the student teams) were required to frame small problems related to a certain aspect of the concept and make discoveries based on the interactions with the materials brought to the review which allows them to re-assess their design decisions to progress their design. As noted by Schön (1983) the design approach may differ for each particular discipline however … "if they are good designers, they will reflect-in-action on the situation's back-talk, shifting stance as they do from 'what if?' to recognition of implications, from involvement in the unit to consideration of the total and from exploration to commitment" (p.103).

The 2003 student cohort enrolled in the unit ADB206 was given the opportunity to participate in the study. The study was granted ethics clearance and adhered to university ethics guidelines. Students were informed that their participation in the case study was entirely voluntary. If they decided to withdraw from the study, they would not be penalised or judged in any way and could discontinue participation at any time without any comment. They were informed that no additional work was required from them to undertake this study and that by agreeing to participate in the study they were allowing the research team to collect video data of their interaction with the physical concept models and their conversation during the design critique undertaken as part of their design studies. Thirty students had agreed to participate in the study, from which video footage of their design reviews as part of the project described above was collected.

3.1.3 Case Study 2 Description – Virtual Design Setting

In addition to being responsible for delivering this unit, I was also responsible for the Computer Aided Industrial Design (CAID) program for the industrial design discipline at QUT. The pedagogical approach for this series of units was a constructive learning model, where students grasp concepts of CAID through embedding the technology in actual practice (design projects and exercises). As an extension to this set of units I established a new optional unit (elective) which introduced the concept of virtual reality as a design development and evaluation tool. As part of this unit (the unit program has been included in Appendix B), students were provided with access to state of the art virtual reality facilities, such a haptics and tracked active stereo immersive projection, to review their design solutions. The unit was delivered in an innovative way which allowed students to build on their knowledge of design and CAD and apply this to their understanding of virtual reality, without having to understand the technical aspects (such as computer coding) of computer science and virtual reality.

Having responsibility for both the design and technology based units I was able to provide students with a foundation to explore emerging design tools (virtual artifacts) grounded in their design practice. This provided me with an opportunity to observe the students' use of these emerging tools within a design setting which closely related to design practice. As part of this research I provided students with an opportunity to supplement their design review as part of the design program, by undertaking a review using the virtual artifacts.

A second case study was developed to compare and contrast the traditional setting. Students were offered an additional design review session during the week 11 period (outside of their allocated studio time) to undertake a critique of their work to date. Students were informed at the start of the semester that this additional time would be made available during week 11 of the program but would require them to undertake some minor additional work to transfer their design concepts into a Virtual 3D Sketch Models. Students undertaking this design unit were also required to undertake a Computer Aided Industrial Design unit, where the concept of immersive virtual reality as an early stage design tool was demonstrated, but not applied as part of their design project. Therefore all students who were undertaking the design unit also had the skills to develop and interact with a Virtual 3D Sketch Model.

The students were encouraged to develop initial 3D CAD surface models of their concepts during the project. Creating a 3D Sketch Virtual model required little effort (as the same file structure and level of detail is used). The process required them to export their native 3D CAD Surface model to a polygonal based model and import it into the Immersive 3D environment using a script file template. When this was completed (which generally takes a couple of minutes), students could interact with the virtual representation of their concept which was presented as an active stereo projection. Figure 5 illustrates the translation from a native 3D CAD model into a a Virtual 3D Sketch Model. It should be highlighted that the coarse resolution of these models was encouraged, as the students were not 'presenting' their final design but exploring design options.

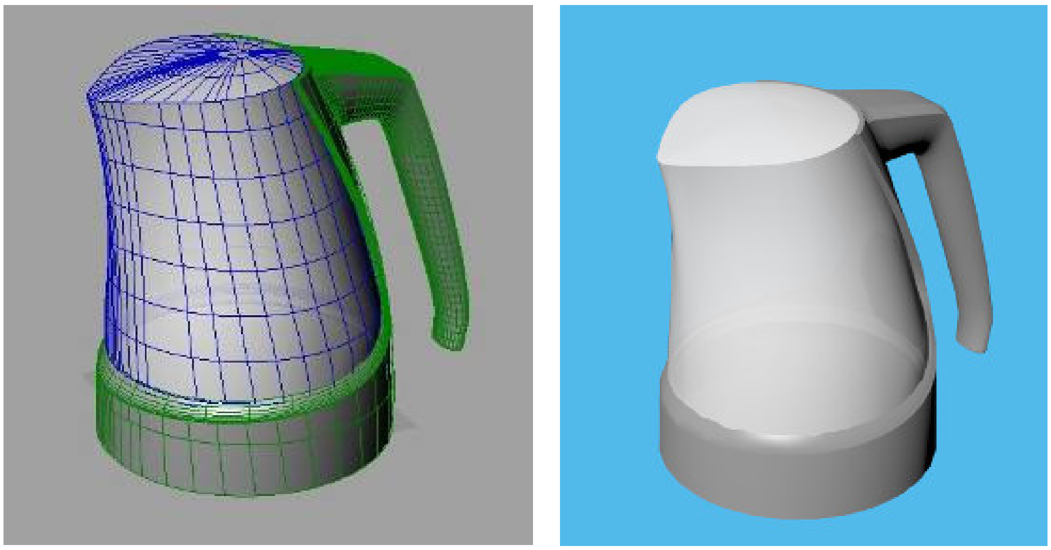


Figure 5 – 3D CAD to Virtual Model

The interaction consisted of head tracking, which provided an infinite 'real time' perspective view of the project model based on the position of a viewers eye position (if a user looked left, the model would appear to be seen from the left hand side, if the viewer looked down on the model, a view would be generated which would appear to be looking on top of the product); 'hand tracking' using the dedicated 'wand' input device allowed the users to grab the virtual object through a virtual avatar of their hand, allowing them to bring the object closer or place it further away or rotate it around their hand to inspect the object (Figure 6).

Figure 6 – Interaction within the Immersive Virtual Environment

Ethical clearance for this aspect of the study was granted. As with the first study, students were informed that their participation in the project was entirely voluntary. If they decided to withdraw from the study, they would not be penalised or judged in any way and could discontinue participation at any time without comment. In addition to being video recorded during their interactions with the virtual artifact during a design review, students were asked to reflect on their experience of using the immersive environment.

Additional cohorts of students were also invited to voluntarily participate in this phase of the study. As part of the unit title Fundamentals of Synthetic Environments - Post Graduate Industrial Design students who were acquiring the knowledge of developing Virtual 3D Sketch Models were encouraged to apply this knowledge to their final year project. As part of this unit I integrated a design review session (in addition to the reviews being undertaken in their Post Graduate Design Unit which I was not involved with) allowing them to apply these tools to their design project. In total 16 students elected to participate in this second study.

3.2 Data Capture

There are many approaches that could be applied to capture and analyse user interaction and experiences. However, as I was interested in understanding the moment-to-moment interactions with media, video was chosen to capture the interactions. During the course of designing, one is focused on the design discussion, which precludes paying attention to exactly how you are using and manipulating the media, so detailed interactions are not available for reflection. A video camera can capture the dynamics of the work setting and the complexity of interaction, albeit from a single viewpoint, rendering human activities such as talk, nonverbal interaction, the use of artifacts and technologies and the immediate workplace context available for repeated viewing and analysis, so that researchers can examine the consistency and generality of their observations.

In viewing videotape it is easy to become captivated by interesting interactions. However it is necessary to understand which of these interesting interactions are representative and to get a broad characterization of the data. This requires extensive viewing of data. It also helps to represent data in different ways, moving from descriptive themes and storylines to dimensions or categories (Strauss 1987).

In the spirit of Situational Analysis, the use of video data would allow me to see the moment to moment interaction between designers and their artifacts within different settings. Two specific methods were adopted for this study - Video Interaction Analysis and the Video Card Game, to standardise the data collection process. These are described in greater detail in the following section.

3.2.1 Video Interaction Analysis and the Video Card Game

Interaction Analysis (IA), as described by Jordan and Henderson (1995) is an interdisciplinary method for the empirical investigation of the interaction of human beings with each other and with objects in their environment. Human activities (e.g., talk, nonverbal interaction, the use of artifacts and technologies) are investigated, identifying routine practices and problems and the resources for their solution. Only videotape recording produces the kind of data corpus that allows the close interrogation required for IA. Video provides access to conversation, gestures, expressions, actions and the immediate workplace context. It allows repeated viewing of the original data to examine consistency and generality of observations. It reveals the unanticipated. Textual accounts, ethnographic field notes, or interview responses, by themselves would be inadequate for communicating the dynamics of the work setting and the complexity of the interaction.

In Video Interaction Analysis (VIA), an interdisciplinary team view segments of tapes selected by the primary investigator and identify routine practices, routine problems and resources for their solution. Only those practices confirmed by the raw data that occur repeatedly in different parts of the tape are considered admissible in the analysis.

Some fundamental assumptions of the Interaction Analysis method are that:

- Knowledge and action are fundamentally social in origin - knowledge and information lies within the social milieu of people, artifacts, books, the world etc., and people access and construct this information into personal knowledge through interaction with the social milieu. This epistemological stance does not downplay the mind as a manipulator of internal representations, but it puts the focus on the interaction between the person and the social milieu. One can understand this perspective on knowledge construction by considering how much a person could learn in life if isolated from the social milieu.

- Theories of knowledge and action should be grounded in verifiable observable empirical evidence.

- Theorizing should be responsive to the phenomenon itself rather than to the characteristics of the representational systems that reconstruct it. Analysis is done directly on videotape data, rather than on transcripts, or other reduced forms of data. It is acknowledged that video does not capture the broader context of events in the videotape and that the view from the camera is only the view available (Brereton 2002).

This method was considered as it supports the formulation of my understanding of natural activity. It is through an understanding of the social interactions with physical and virtual objects that I aim to develop my understanding of the impact of these artifacts on the design activity.

A complimentary approach to Video Interaction Analysis is the Video Card Game developed by Buur and Soendergaard (2000). They note that the Video Card Game helps to build a shared understanding of what a video recording tells. The Video Card Game was developed in an attempt to allow video data to be used as a resource within design discussions, used by the members of the team and not considered a specialist task. “The basic idea of the Video Card Game is to turn video segments into artifacts (cards), which the developers can refer to and handle in a design discussion. With the cards the developers create new understandings of the design directly in the video media. To make it succeed the developers need to work sufficiently with the artefacts to appropriate them for their design practice" (Buur and Soendergaard 2000 , p.64).

In order to undertake a Video Card Game, video data must be collected, which is then segmented into sequences which seem of significance by the researcher. Each segment is short and should be no more than a few minutes in duration (30 seconds to 3 minutes is ideal). Cards are then created which represent that particular segment. The card which is a tangible representation of the digital video clip is given a title, number and a space for writing annotations during the game. The number of cards to create is dependant on the reviewer of the video and relates to elements which they believe have significance.

To play the game participants are assembled and informed of the game rules (five steps in the methods). The participants are grouped into pairs and the cards are divided into stacks with duplicate cards within each stack and handed to the groups. This duplication of cards between groups allows for different interpretation of any video sequence at a later stage. The groups are then allowed to watch the video sequences which relate to the cards they were provided with. While watching each segment, players within the group write notes on the cards of what they have observed. As duplicate cards have been provided to the teams, each team member is encouraged to review all of the video and make notes individually on their cards. Annotating the cards in the participant's own hand writing adds a dimension of ownership to the artifact. Players are then asked to group their cards and create themes openly in front of all participants. They are asked to present their themes to the group. Players are then asked to select one theme from their stack and then invite other players to contribute to their theme by handing over their cards and interpretations. Within the workshop a family of themes emerge which have been contributed to by the entire group. The cards from each theme are placed on a separate poster and a title is provided for the theme. The remainder of the workshop allows for all of the members of the group to discuss each major theme by reviewing the video sequences and understanding what this theme means to the design.

McGarry (2005) notes that while the Video Card Game was intended primarily as a means to engage users within the design process, it has also been used as a means to develop an understanding of a particular domain, or as a means to study interactions across domains" (p.95). Unlike Video Interaction Analysis, the original intention for the Video Card Game use was as a stimulus for designing or re-designing a particular problem. Therefore the groups, who reviewed the video material, draw on their own experiences for interpretation. This acts as a way of providing a collective insight of the activity seen within the data.

3.2.2 Data Capture Justification

I have utilised Video Interaction Analysis and the Video Card games as complementary methods to analyse the video field data. Video Interaction Analysis has allowed me to focus on detailed interactions with the artifacts, whereas the Video Card Game has allowed be to develop general categories of interactions.

However, as noted by Mackay (1995), "researchers often treat videotaped records of human behaviour as objective scientific data: they can be viewed repeatedly, individual events can be counted and findings can be verified independently by other researchers. Unfortunately the appearance of objectivity is just that: an appearance. Someone must choose a location and field of view for the camera, which must include some and exclude other information. The choice of when to press the 'record' button also includes and excludes information" (p.1).

As the focus of my study was the design review session which had a clear start and end point, I was able to capture the entire session for each group of students. Further, I ensured that the camera for each review was in a fixed location which focused on the interaction of the group with the artifacts during the design review.

The layout of the design review for this traditional environment is shown in Figure 7. It consisted of a number of tables joined together (referred to as a round table discussion) and the teams took turns in coming to the centre of the table and laying out their design materials. If members of the external group (a maximum of 16 peers and 2 staff were present for each review) wanted to make comment on the design material, they were encouraged to move to centre of the table and engage with the materials in whatever manner they felt comfortable in doing to comment on the design. Whereas in the virtual setting (also shown in Figure 7), the focus of the review was the Immersadesk screen where the design presenter stood in the middle with the other member of the team standing behind him or her. To ensure that the review group could accurately see the virtual model on screen the review group was required to stand as near as possible to the design presenter. Typically there were a maximum of 7 people in the virtual design review.

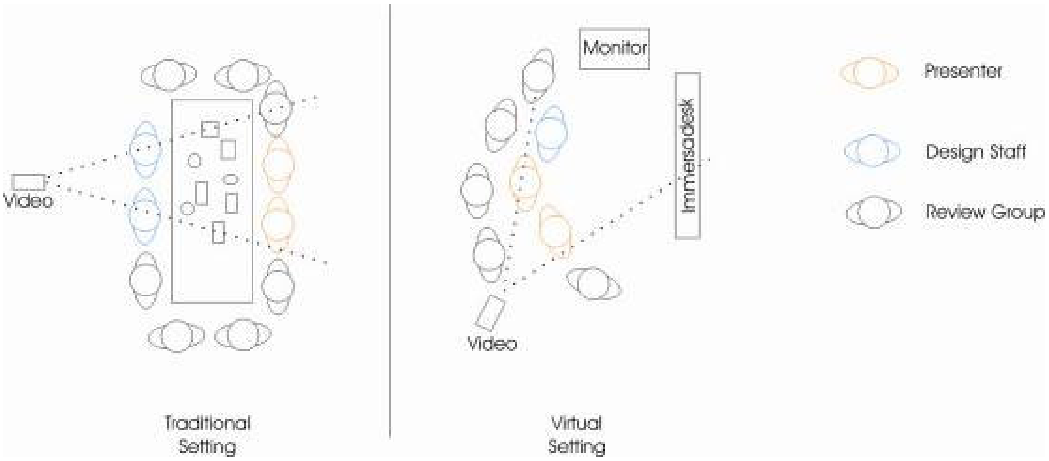


Figure 7 – Traditional and Virtual Design Environment Layout Schematic

Undertaking observations of the interaction of student designers with physical and virtual artifacts within the above contexts, has provided me with significantly rich data to undertake this research. I have recorded a total of 19 video sessions for the traditional setting and 17 sessions for the virtual setting as part of this study, with the raw data provided as an appendix in the attached DVD.

3.2.2 Additional Data Capture – Student Reflections

In addition to the video capture of the designer's interaction in the setting described, I had also undertaken a secondary data capture technique using interviews. I had asked the students to reflect on their experience after the virtual prototype study. Each student who participated in the study was asked to provide a written reflection on their use of the virtual environment for the design review, as compared to their experience in a traditional environment. Three questions were asked of the students:

- How has the environment assisted you in communicating your design details?
- How does it compare to a traditional design critique using sketches and models?
- Did the prior experience assist you in using the immersive environment to communicate your design?

The student comments collected have been used throughout the study to support the findings from the Video Interaction Analysis and Video Card Game. This dual approach also allowed me to apply the concept of Data Triangulation (Denzin 1989) to the study. According to Robson (2002), data triangulation can help to counter particular threats to the validity of the study because it allows the researchers to introduce a number of different channels to acquire and analyse the data. By analysing the data using three different approaches I hope to build a greater understanding of the interactions between the designers and the artifacts within the design process.

The above section outlines the field data collected for this study which captures authentic interactions between designers and their artifacts within design reviews. These are presented throughout this thesis as both transcripts and keyframe images of the interactions to allow the reader to make sense of the activity which was observed.

To ensure that the video data included as part of this thesis remains transparent to the reader and is presented in a way which allows the reader to make sense of the data, extracts of transcripts together with matching video key frames have been provided throughout the body of the thesis in the following sections. In undertaking the transcripts of the recorded video, I have best represented the activity observed during the design review, recording the conversation and interaction with the artifacts. However, I did not recorded every utterance as required by conversation analysis, as my interest was in the observed activity which matched the conversation, which allowed me to view the data at a more abstract level. This in turn has allowed me to present the data to the reader in a format which depicts the richness of the activity observed during each session.

Each transcript as shown through this thesis has a unique identifier. It describes:

- Being categorised as a Traditional or Virtual Environment – (T or V);
- The participant ID (two digit number for traditional and three for virtual); and
- Time stamp from the beginning of the design review (mmss).

Therefore a transcript with the unique identifier of T-003-1220, relates to a traditional study environment, participant 003 and captures video 12 minutes and 20 seconds from the start of the session.

The following sections outline my attempts to develop an understanding of the in situ design activity.

3.3 Data Analysis

I have used the framework outlined by Miles and Huberman (1984) to analyse the data captured for this research. They note that data analysis consists of three concurrent flows of activity which consists of data reduction, data display and conclusion drawing. "Data reduction refers to the process of selecting, focusing, simplifying, abstracting and transforming the 'raw' data that appear in written up field notes" (p.21). Data reduction is not a discrete activity but occurs throughout the data collection and display stages of analysis.

Within this study the Video Interaction Analysis approach was used as part of the data reduction stage of the analysis. This technique allowed me to consider the large amount of data which was captured and begin to look at the emerging patterns which were being revealed.

The second stage of this analysis related to the Data Display. Miles and Huberman (1984) define 'display' as an "organised assembly of information that permits conclusion drawing and action taking" (p.21). Within this study the larger video files were broken down into smaller vignettes to allow me to 'display' the main areas of interest and present them in a way which could be reviewed and discussed. Representing the data in this manner allowed me to undertake the Video card game analysis to reinforce the patterns which were emerging from the case studies. The student reflections which were recorded were then overlaid on this data display to support or build upon the patterns being observed.

As mentioned this process was an iterative process of capturing the data, reducing it and then displaying it to assist in the building of the findings generated from this research. "From the beginning of data collection, the qualitative analyst is beginning to decide what things 'mean', is noting regularities, patterns, explanations, possible configurations, casual flows and propositions" (Miles and Huberman 1984, p.62).

This iterative cycle allowed me to constantly challenge my findings by looking deeper into the individual cases and then across the cases to look for generalisations and unique aspects to each context. Following this approach has led me to draw and verify the findings and conclusions made. However, before this is presented the data analysis stage will be discussed in detail in the following section.

3.3.1 Data Reduction

As mentioned, each design critique session was captured using video. Once all sessions were completed for both the traditional and virtual settings I then started the long task of viewing each tape to begin to identify areas of interest. To help with this approach, I developed a time based cataloguing system which was used to record potential areas of interest. This allowed me to return to this point quickly once I had viewed all the tapes and assisted in beginning to reveal the high level patterns I was observing.

After spending many days reviewing this video data, three main themes became apparent from this review. These related to Design Activity, Design Context and Interaction. I have provided examples of these observations, together with a transcript extract, which describes this activity in the section below.

Design Activity related to the nature of the design discussion observed during the review. The design students would:

- ‘Present’ information to the group, “here is the work undertaken this week”;
- The design group may ‘Query’ what has been presented or alternatively the design team may query the response from the design group, “what do you mean” or “I can not see that”;
- There would be periods of ‘Discussion’ where the team and group would have open discussion;
- There would be points of “Resolution” during the review, “I see what you mean”.

Design Context related to the context of the design discussion observed during the review. The design conversation would focus on the requirements of the design brief. This included:

- “Usability” – “Would that be comfortable for a person holding the kettle”;

- "Market" – "what price point is your product in";
- "Technical" – "How would that part be manufactured";
- "Aesthetics" – "the proportions of the form needs to be reconsidered".

Interaction with the Artifact referred to what interaction was observed during a particular moment. The design students would:

- "Refer" to an artifact – point to the sketch, model, virtual representation;
- Interact" with an artifact – picking up the artifact; pass to another group member;
- "Simulate" actions – gesture the actions of the intended use product (eg pouring water from a kettle), the actual artifact was often not required to be used;
- "Modify" the artifact - making a modification to the artifact – drawing over a sketch on the physical model.

This then led me to review the tapes again and re-catalogue the videos to identify areas of interest under these main themes. This helped reduce the data into meaningful sections which could be looked at in the next stage of the analysis. It is important to note that I was not trying to force these themes onto the video data, but rather this cataloguing was to make some initial sense of the data. A second point to note was that the themes I drew out were interdependent, design activity was dependent on a design context and form of interaction. It was the combination of these three factors rather than considering one in isolation which was of most interest in understanding the role of artifacts in the early stage design reviews. The video catalogue used at this stage of the analysis is shown in Figure 8.

Time		Design Activity				Design Context				Interaction				
mm	ss	Present	Query	Discussion	Resolution	Usability	Market	Technical	Aesthetics	Refer to Sketch	Refer to Model	Interact with Model	Simulate Action Only	Draw

Figure 8 – Catalogue of Video Data

3.3.2 Data Display

Short video vignettes were then extracted to be viewed using the Video Interaction Analysis and Video Card Game. An example of a video vignette is shown in the following transcript. In this example the vignette describes a traditional design setting which begins 8 minutes and 11 seconds into their design review session. The context of the discussion focuses on the design team discussing a detail relating to the base of the kettle which leads to a question of clarification from the review group.

As with all the transcripts presented within this research the students comments are in italics in the table below. Images are also used to support text.

 	Group ID T0307 Time 8:11 *To reduce this to get more cord on the base, the cord is the same, it just winds around (simulating cord action with finger).* Could you just please go over that again. *OK. This element is crimped onto the bottom (pointing to the sketch). And then this part is pushed up through there and this lip is locked up into there with an interference fit. It locks into there and then this part here is screwed into the bottom of it, which also has an interference fit around the bottom of it.* And that will support it? (Simulating holding motion). *We will also have brass pins as with the original (holding original product and pointing to sketch). It keeps it together. Like on this one, it is very, very stable (holding product again).* So you are locking it up that way (simulating action). And with the weight of the water, it will drive through. *(Pointing to the sketch). It shouldn't because you have these screws which screw into here and it will hold the weight of the water.* (Pointing to sketch). So this links to that and then to that. *(Pointing to sketch). This here will have to have an interference fit as well as the brass rings on top, so it will hold the weight when*

	you pick it up (simulating action of picking up). When it is down it sits flat on this (pointing to sketch).
	*That's how the existing works (holding original product). This bit snaps into here (pulling apart product). It is the only bit that holds the base in.* Does the back lock into it? (Pointing to product). *The back is mostly snap fitted along here (pointing to product) and the brass pins at the top.* OK. So you are locking it up like this (pointing to sketch) at the junction. So if I drop this part over the top, does it lock in? So if I lock this part onto the top bit does it lock over the elements? (Pointing to sketch). *No, it should already be locked on with the lip around the inside of that.* Will that slide up through? You may need something to lock it up (pointing to sketch). *Maybe a screw coming in from this angle (pointing to sketch). Yep, that would be easy.* How does the mould work? *(Simulating action) It is a four piece mould, two from the side, one on the bottom and the top, the top core comes down to the spout.* So where is the split line? *As with the original.* Doesn't that one have three? *No, it has four. You can see the split line.* I see.

The video vignettes which were created were initially analysed using the Video Interaction Analysis approach. They were viewed both individually and then in small groups to discuss the activity within the video clip and to relate these to the initial high level findings.

Following repeated viewing of these clips, it was noted that in both the traditional and virtual environment settings a number of similar activities and interaction styles were common to both approaches. Further significant querying and discussion of the design concept leading to a shared understanding by the group was observed in both environments. As a general observation it would appear that Schön's (1983) description of the Reflection in Action Paradigm was evident in both situations.

However a more detailed analysis of the video using this approach identified that although the groups did develop a shared understanding in both environments, the approaches to how this was achieved were significantly different. These differences relate to the level of abstraction between the virtual and physical artifacts and how the students compensate for this using a variety of interaction styles during the design review which are the basis of the study findings described in later sections.

Following this analysis and the reporting of these initial findings using the Video Interaction Analysis approach, I had undertaken further analysis of the video data using the Video Card Game approach. The study followed the Video Card Game Approach as described by Buur and Soendergaard (2000). Three groups of two researchers participated in the game (Figure 9).

Figure 9 – Video Card Game Environment

As per the Video Card Game approach, for each full length video, a number of smaller sections of approximately 30 seconds to 2 minutes were selected to be analysed within the game. Each section was captured as a separate video file and named according to its User ID and time stamp within the full length video section (e.g. File V-014-0658 relates to a Virtual Study of subject ID 014 and the 0658 refers to 6 minutes and 58 seconds into the full length video study). For each smaller clip, a card was developed which had an image from the clip, a representative title and space to write notes during the game. A total of 36 cards were made. Each group was given a random selection of 10 cards in duplicate. Each group was then required to watch the videos which related to their cards and note observations on the card (Figure 10). Initially this was undertaken individually and then the members of the groups could discuss their individual findings and begin to make themes from the data observed.

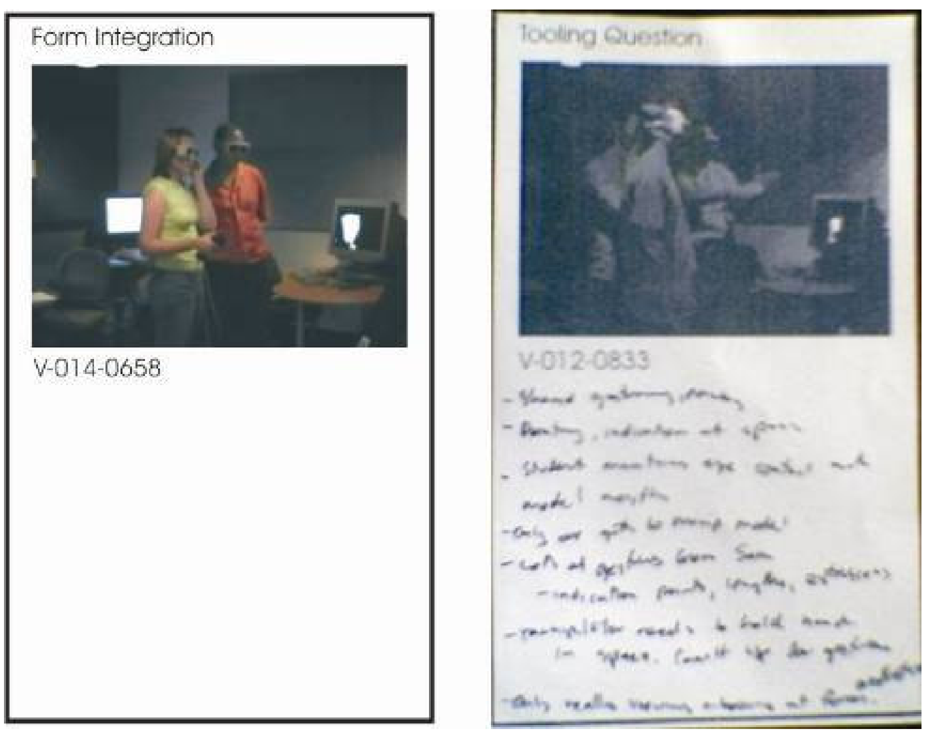


Figure 10 – Video Card Game Card Example

Once this was completed (within approximately one and a half hours) the groups then discussed their overall themes, together with the objective, to form collective themes. This involved groups presenting their individually developed themes and then discussing it with the wider group. If other groups agreed with this theme or developed similar themes, the groups traded cards to develop the unified theme.

The outcome from this discussion saw the development of four major themes which described the nature of the process. These included:

Overhead in the Virtual World - This theme explores the overhead required to interact in the virtual world. Not only is there extra effort required to drive the interface, but the interface limits natural interaction. The main presenter is the only manipulator and as such is the primary conduit to the design. This leaves their partner without much of a role. Also they tend to remain static due to gaze tracking and gesture interpretation. This also left them without the ability to point at the display. Negotiating the same level of understanding took longer than usual and normal cues such as eye contact are limited. Finally, even people with the interface found it difficult to perform the exact interaction they required.

Exploratory Language: "I'd like to see that" - Exploratory and tentative language was used to describe either the existing model or to suggest how the model could be modified. Language such as "I am liking this" … "I am thinking …" … "This could be red" … "The button would be…" .

Many Hand Many Views - In the traditional session the reviewers and students were able to interact with and manipulate the artifacts directly. Each participant was able to attain their own desired perspective and sharing. Whereas in the virtual setting, the interaction and perspective changes must be mediated through a single person.

Cooperating with Multiple Resources - The design students worked together to answer the questions from the audience. For example, one designer assembled the coffee maker while the group was still asking a question. The other students held up a drawing and began answering the question. The first designer joined in with some more information, referring to the product. The designers easily coordinated their turn taking and managing different resources to answer the question.

These themes from the Video Card Game identified broad categories of interaction with the artifacts, which related to the nature of the process being observed. As the groups undertaking the game were not looking specifically at one design review video file, this process allowed for common observation to be identified and considered with the data collected from the Video Interaction Analysis technique.

This combined approached allowed for the two sets of findings to be compared and contrasted to allow me to begin to build the theory which was emerging from the research.

3.3.2 Data Display – Student Reflections

As noted in section 3.2.2 in addition to the video data, student reflections were captured as an alternative data source. However, this was undertaken for the virtual setting only as the students were asked to compare their experience in the virtual setting to that of the traditional setting.

Although there was not a large amount of data from the questionaries completed, I still applied Miles and Huberman's (1984) approach of data reducing and data display to analyse the data. This involved reading the data, then short extracts were selected which began to form an emerging pattern, which was used to support or challenge the findings made from the video analysis.

From the student reflections, the majority of student comments focused on the usability issues associated with the virtual environment and how it impeded their ability to undertake a design review:

I believe physical models are a better aid for a design critique, it is something tactile and is excellent for looking at the form, scale, proportions, usability, semantics and ergonomics. I also personally feel a lot more comfortable talking about a design with a model. This is because I do not need to concentrate about holding glasses on, on trying to navigate my product with a user unfriendly hand control. With a foam model I can concentrate on what is important, communicating the design (V-002).

Usability issues are directly addressed in Section 6 and the impact this has on the design review activity. In addition to usability concerns, the design students did provide many interesting insights into the use of both environments from a design reflection perspective. The following is an example of one such comment:

The environment has assisted in communicating my design details by allowing the user to move, scale and manipulate the visual distance of the CD wallet. The user can then examine the design details by adjusting the options with simple functions using the joystick or viewpoint cards. Representation of materials can be limiting when using the immersadesk because of its sensitivity with textures and using 3D technology. In comparison with traditional methods of a design critique, immersive environments enable the user for more visual control, whereas sketches can be restrictive if only a small amount of detailed images are given. Tangible models are still more effective, especially with product design, because of a clear and realistic simulation of how the product may be used or held. Prior experience with any technology can be beneficial towards its usability. This increases the confidence of the user and reduces the guess work or insecurity of the technology. The communication was a little more effective because of an increase in comfort levels with the immersadesk. This may be an issue for novice users that have limited experience with any technology and it may be overwhelming for them to use an immersive environment. This technology has enabled me to receive feedback within a design critique more effectively than if it was to be done in front of a small PC (V-006).

The student comments were used to support the Video Interaction Analysis and Video Card Game observations and are presented throughout the findings sections.

3.4 Data Findings

By undertaking the analysis in the approach described above, I was able to begin to formulate and strengthen my findings which broadly related to how artifacts support design engagement, how the artifacts represented design knowledge and that there was a concept of an interaction overhead which impacted on the design engagement. These three findings were seen within and across the case study sites presented and were then further supported through the addition of the student reflection. As noted by Miles and Huberman (1984), “the researcher uses multiple comparison groups to find out the kinds of social structures to which a theory or sub theory may be applicable … by comparing sites or cases one can establish the range of generality of a finding or explanation and at the same time pin down the conditions under which that find will occur” (p.151). As I have gone back over the data and re-viewed the video vignettes using the iterative process I have described, these findings have been refined and strengthened adding to their validity. These findings are presented and discussed in greater detail in the final part of this thesis.

3.5 Summary of Section

This section has provided an insight into the field data and methods used within this study. This data focuses on design students' interactions with physical and virtual artifacts during a design review as part of a final year design review. An overview of the methods used to study this form of data has also been provided.

A review of the approaches found within the social sciences was provided focusing specifically on an Abductive research strategy. I have focused on ethnographic methods as I wanted to describe and explain the moment to moment activities of the nature of the interactions between the designers and artifacts.

An overview of the field data context and study design was then provided. Given my teaching responsibilities at the time of undertaking this thesis, I was able to situate myself in the domain of the study and undertake the study using an action research approach.

The framework used to undertake the analysis followed Miles and Huberman's (1984) approach of data reduction, data display and data findings / verification. I have used the approaches of Video Interaction Analysis and the Video Card game within this framework to review the data and draw out the findings from this research. Student reflections of the activity were also used to support the findings generated from the analysis using these methods.

General findings from the individual analyses were presented and have formed the major findings for this thesis. These major findings which are discussed in the following section include - artifacts supporting design engagement, artifacts representing knowledge and the overhead of the virtual environment.

These finding will be presented in the following section and extracts from the data analysis will be used extensively to support the findings.

4.0 ARTIFACTS SUPPORTING DESIGN ENGAGEMENT

This research aims to make a substantial contribution to our understanding of the early stages of the industrial design process. As noted in the review of the literature (Section 2) there are key knowledge gaps in understanding the nature of this process and the relationship to design artifacts. To address this knowledge gap and to develop new understandings, a study of in situ designer's interactions with different types of artifacts within the early stage of industrial design exploration has been undertaken. The findings gained from this study are presented in the following three sections which build upon our existing knowledge of the reflection in action process and the role of artifacts to support this.

Section 3 outlined the case study and study method to capture the interactions between the designers and their artifacts within a design review setting. It is the nature of the design review setting which has intensified both the role of the artifacts and the reflection in action process. Further, keeping constant the variables of both the traditional and virtual review settings and altering only the artifact type, has allowed for additional insight into the role of the artifact between both settings. In presenting the findings I initially look at what can be revealed from studying the traditional design review setting. I then build upon this foundation by focusing on the virtual setting to reveal new insights and additional knowledge.

The first of the three findings are presented in this section which focuses specifically on the role of artifacts in supporting design engagement. My starting point for this research was trying to identify what is the difference between physical and virtual prototypes in supporting design engagement. By design engagement I have used Schön's description of the design process where he refers to the designer's engagement in a reflective conversation with the problem continually asking questions to generate new possible solutions. As noted, Schön's (1983) reflection in action paradigm provides a useful framework to understand the role of the artifact on design thinking.

As mentioned in Section 3, it was expected that the students would reflect in action during the course of a design review as this is a process that they are familiar with. However, where this research extends our existing knowledge is providing greater understanding of the role of the artifact to support this engagement within this unique setting. What is of particular interest is when changing the type of artifact, how does this impact on the design process?

This understanding is then extended by exploring the nature of the process in greater detail. Using Suchman's Situated Plans and Actions framework, the nature of the interaction between the designers and the different types of artifacts is revealed. As is shown later in this section, the design students come to the design review setting with a plan to communicate their design concepts with their design peers. These plans are situated within the given context, however they do get altered during the design review. It is how the students make use of the different environments to reassess the situation which reveals new understandings on the nature of the design process.

Section 5 presents the second finding of this thesis. It contributes further to addressing the identified gaps in the knowledge by focusing not only on the artifact as a resource within the design review, but also looking at the dynamic relationship between it and all other resources which are used. The comparative analysis identifies how the design students make use of the resources and also compensate for them within the design review setting. Further, it is the temporal dimension of these additional resources which highlights differences in the nature of the traditional and virtual design review session.

Section 6 presents the final finding of the thesis. This section makes comment on the impact on the nature of the physical setting and how this impacts on design engagement within the review. The constraints of the setting have been shown to have a significant impact on the nature of the design review activity. It is how the students compensate for this in the different settings which can reveal information about the nature of the design engagement.

Section 7 then summaries these three main findings as a comparative framework which highlights new understandings of designer's interactions with physical and virtual artifacts within a design review environment. Through these findings new understanding of design engagement within the early stages industrial design activity has been made. Further, insights into adopting new technology based artifacts and the impact on design engagement has been revealed.

4.1 Artifacts, Design Engagement and Early Stage Design Activity

The following section presents the first of the three findings from this thesis which relates to the role of artifacts in supporting design engagement. In section 2.3 Schön's Reflection in Action process is outlined which has been used as the basis for defining design engagement. Schön describes the design process as an interactive process of framing the design problem, discovery mediated by the materials and subsequent reframing of the problem in the light of the discoveries made during designing. In his initial description of the reflection in action paradigm (Schön 1983) he describes the sketch as talking back and revealing issues to the designer. He notes that the evolving physical prototype is a yet more active and evocative participant than the sketch as it responds through physical behaviour allowing the designer to obtain feedback through seeing, smelling and hearing the prototype. The work of Polanyi (1998) and Ehn (1988) furthers this understanding of design activity and the role of the artifact. They note that the artifact allows us to make new discoveries by bridging existing and new knowledge.

As noted throughout this thesis, much has been written on the role of artifacts for design. However, the contribution this thesis aims to make relates specifically to the early stages of industrial design activity and the role of different types of artifacts in supporting the design engagement during this activity.

As outlined in detail in Section 3, the case study used for this research was a final year design review session. The design project related to the redesign of a consumer product, where students were required to select a product, analyse it in terms of manufacturing, usability and aesthetics and then redesign it to address the product's shortcomings found in their analysis. The final year students were working in groups of 2 and this was a major part of their design unit. The overall goal of the review was to obtain a shared understanding of the concept among the team presenting and the group (staff and students) whilst determining the suitability of the concept to meeting the original design brief.

The design unit was undertaken within the context of a 13 week design studio environment (Figure 11). The studio was conducted once a week for 6 hours where the students were required to discuss their progress with staff and their peers. A major part of this day was to participate in a "round table discussion" where work in progress would be discussed and reflected upon. Students would be required to highlight particular “issues” which may have related to manufacturing, aesthetics or usability and to seek assistance to resolve this to progress their design development. Accordingly, the students would bring to the studio and the “round table discussion” a range of artifacts which may have included: design sketches; rendering; form studies; mock ups of functioning elements of their design; reference products; and CAD models. As the students did not have access to this studio throughout the week they were required to bring and then remove all material each session.

Figure 11 – Design Studio Environment

As mentioned, the focus for this case study was a particular review session which occurred in Week 11 of the project. During this round table discussion, the students were required to select one concept from a number of ‘frozen’ design concepts. They were to present their rationale for this decision on the selected concept to the group and then through an intense discussion with their peers select the concept which would be developed further during in the final weeks of the project. This particular round table discussion was selected as it intensified the nature of the design engagement. During this session students would come to the review with a spectrum of issues spanning manufacturing, usability and aesthetics which they needed to highlight and seek resolution and consensus on before they could proceed with confidence to a final design solution.

As this was a final year studio, the students were familiar with this type of environment and review procedure. They were aware that the time frame for their particular review was quite short (averaging 20 minutes) and they needed to come to the session with set questions or problems on particular issues to initially seek a shared understanding of their problem and then seek a shared resolution by the group. The design teams who were presenting were actively to seek out, or frame problems dealing with issues of manufacturing, usability, aesthetics during the design review which allowed the wider group to contribute to create new discoveries. Alternatively, if the review group was unclear of particular issues of manufacturing, usability and aesthetics they would seek to develop a shared understanding, by framing a question and allowing the design team to respond, which often resulted in new discoveries being made. This process aligns closely with the reflection in action paradigm as described by Schön.

The entire round table session would last up to 4 hours with each of the 8 student teams having a turn in presenting their concepts. There were a maximum of 8 groups of two students which made up the round table review and two staff members. Once the team who had presented their design had completed their session they would then participate in the group discussion as a participant of the "Round Table" discussion. The elements of the review can be summarised as follows:

- Design Presenters (group of two design students);
- Design Artifacts (sketches, 3D renderings, foam models, original product);
- Review Peers (7 remaining groups and two staff members).

To present the first of the three findings, the following section provides extracts of activity of how the groups became engaged with the design problem during a traditional design review to demonstrate how the students followed Schön's Reflection in Action paradigm within such a situation. This section highlights the role of the artifacts within these situations.

Rather than provide complete transcripts, small clips are provided which highlight exemplars of interaction found during the analysis. 'Design Presenter' comments are indicated in italics, where as the 'Review Peers' are indicated in normal text. Description of the interactions between the designers and the artifacts are shown in brackets. Time from the start of the review is also shown to contextualise where in the review the activity takes place. A reference image is also included to help contextualise the vignette. Full videos can be found in the attached DVD.

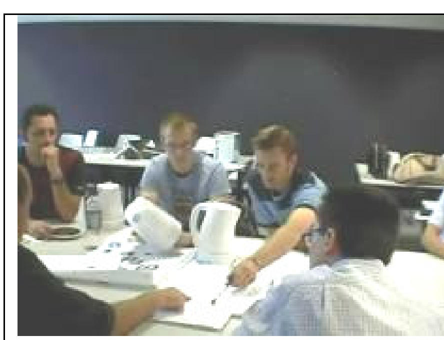
As noted previously, I will use the findings from the traditional design environment which are presented first as a foundation to bridge the knowledge gap between traditional and virtual artifacts within such settings.

4.2 Design Engagement - Traditional Design Review Environments

As expected, it became clear from the analysis undertaken that Schön's reflection in action paradigm was evident within the design reviews. Significant questioning and discussion around the areas of manufacturing resolution, usability and aesthetics occurred during each of the design reviews observed. Although this was expected, this analysis provides a unique account of how industrial designers engaged in a reflective process during a design review.

To highlight how the students undertook the design review activity, four exemplars of interaction have been selected which demonstrate how the students resolved their design decisions relating to manufacturing, usability and aesthetics during this particular design review. They are presented as video vignettes below.

In the first example, the group seeks to get clarification on a particular manufacturing detail.   The group is about halfway through their review of their design of a new domestic kettle. The point at which the transcript begins is with the design team presenting a detail related to the base of the kettle which leads to a question of clarification from the review group. This transcript is expanded from that shown on page 67.

	Group ID T0307 Time 8:11 *To reduce this to get more cord on the base, the cord is the same, it just winds around (simulating cord action with finger).* Could you just please go over that again. *OK. This element is crimped onto the bottom (pointing to the sketch). And then this part is pushed up through there and this lip is*

	*locked up into there with an interference fit. It locks into there and then this part here is screwed into the bottom of it, which also has an interference fit around the bottom of it.* And that will support it? (Simulating holding motion). *We will also have brass pins as with the original (holding original product and pointing to sketch). It keeps it together. Like on this one, it is very, very stable (holding product again).* So you are locking it up that way (simulating action). And with the weight of the water, it will drive through. *(Pointing to the sketch). It shouldn't because you have these screws which screw into here and it will hold the weight of the water.* (Pointing to sketch). So this links to that and then to that. *(Pointing to sketch). This here will have to have an interference fit as well as the brass rings on top, so it will hold the weight when you pick it up (simulating action of picking up). When it is down it sits flat on this (pointing to sketch).*
	*That's how the existing works (holding original product). This bit snaps into here (pulling apart product). It is the only bit that holds the base in.* Does the back lock into it? (Pointing to product). *The back is mostly snap fitted along here (pointing to product) and the brass pins at the top.* OK. So you are locking it up like this (pointing to sketch) at the junction. So if I drop this part over the top, does it lock in? So if I lock this part onto the top bit does it lock over the elements? (Pointing to sketch). *No, it should already be locked on with the lip around the inside of that.* Will that slide up through? You may need something to lock it up (pointing to sketch). *Maybe a screw coming in from this angle (pointing to sketch). Yep, that would be*

	easy. How does the mould work? *(Simulating action) It is a four piece mould, two from the side, one on the bottom and the top, the top core comes down to the spout.* So where is the split line? *As with the original.* Doesn't that one have three? *No, it has four. You can see the split line.* I see.
	With this do you have an undercut? (Pointing to model). *Um, on the inside?* No, on this part here. You will have a core on the inside (simulating action). *The tool will come from two sides and one underneath (simulating action), and another one from the back.* Will you be able to pull it out? Does it wrap around on its side? *The one from underneath.* So it comes in halfway (pointing to model). So you say it is coming halfway up here (pointing to sketch). *Well as far as it could come up to meet this part (pointing to model and sketch). This one comes in as far as it can (holding model). Yeah, you might be right. Might have to change that to narrow it (holding model and looking at detail).*

In this vignette the designers begin by presenting their solution for their base detail which has come from an aesthetic solution to reduce the base form of the product. However as they do this a question of clarification is asked of the designers relating to the base detail and how the storage chord would be integrated into it. A question has been framed by the review group which then needs to be resolved. The design presenters then respond to the question by using a series of artifacts including technical sketches, form study and the original product. This in turn leads to another question (re-framing of the problem) being made by the review group related to the weight of the unit and whether the proposed base detail will support it. Again the design presenters make use of a series of artifacts to respond to the question. This then leads to a third question (re-framing in light of the discovery just made) being raised in relation to the manufacturing of the product and whether a complex manufacturing process has been introduced inadvertently through their proposed design solution. After some discussion using a range of artifacts, the design presenters agree this is now the case and will need to change their design – “Maybe a screw coming in from this angle – Yep that would be easy”.

This first example demonstrates that through the course of this short discussion a new discovery has been made based on the conversation and use of the artifacts brought to the review. By framing a series of related questions, this discovery has been made. Further, that a shared understanding on this particular design detail between all members of the review group has been made.

In the next example, the design presenters discuss their concept to access the contents of a kitchen blender jug. This discussion begins with aspects related to usability and then turns to functionality and then manufacturing concerns with their proposed solution.

 	Group ID T0316 Time 4:20 *(Holding sketch) I was thinking about the usability of the actual plunger itself. Maybe you have it full of ice and fruit and you don’t want something in there, such as the blender mechanism, so making it that you have an attachable body that you can pull the body off, or just use the handle and the lid as a plug to block off the port hole. That is another feature, you can just pull it right out of the lid and there will be a hole there that you can screw onto it.* Sorry, just to go back to the usability on this one, just that top left hand picture there, is that the actual scale of the blade to the bowl? It looks like it is a lot bigger – are you going to get all of the stuff inside and mixing well with this design? *The idea with this design was (putting down sketch and simulating with hands) was to have the base wide and tapering down to a blade as a sort of funnel shape so it is a funnel moving into a cylinder. On the side sections where the blades are, it is like a cone shape (simulating funnel shape with hands).* Is that an internal feature? *Yes, that’s an internal feature.* Is that part of the same mould? (*Finding correct sketch) Yes, that is part of the same mould. I will show you how it will be (holding up sketch).*

	The blue section here is the actual jug, so you would have the jug wall that is actually tapered (pointing to sketch) which will help you with the actual mould. That sliding core will then come out easily. There will also be this conical shape around the blades. The only area for a problem might be around this flat area here, but this area here (pointing to sketch) will have ribs on it to help with the mixing and there is also another piece that comes down here which has a screw thread on it which attaches the bottom section. So the bottom section screws on and it forms a seal with this shape here (pointing to sketch). So there will be the blade assembly and seal in one. That's actually what clamps down onto the blades. This section is hollow in here (pointing to sketch). Yep, OK (nodding).

The design presenters start with a verbal description of a new feature of their blender design which they present as a solution to address a usability concern. They make use of a 2 Dimensional design sketch to assist in clarifying their concept. However in the course of them presenting the review group frames a question around this concept. Initially this starts with clarification if the sketch is accurate. Rather than use the sketch further the student elaborates the concepts through the use of gesture to describe the particular detail. A further question is then framed, which relates to a manufacturing concern "is that an internal feature". The student reverts back to another sketch to further communicate the concept, from which a shared understanding is then acknowledged by the review group.

The group had framed the question as they were unsure if their design solution was able to achieve what was being claimed by the design team. Although there was no new discovery made, a shared understanding of what was being presented was achieved through the design team's clarification (through sketches and simulation) of their design concept.

In a related example, it is the review group who again frames the question based on what is being discussed. The context for the vignette relates to usability of the water level of their proposed design.

	Group ID T0307 Time 16:00 *(Pointing to sketch). Also, this one, the surface finish is translucent. It is spark eroded on the outside so you almost cannot see the water level. Then you will have these polished areas on the sides (pointing to model). Where you can see like this (pointing to original product). So you can see the water level in there. And therefore we save on parts and assembly.* Do you think you need it? I mean, just that form by itself (pointing to the model) looks fine. Or do you need another detail? What do others think? In the sketch there (holding sketch) I reckon if it is going to be hard to see the water level without it, then it is appropriate. *Yeah*. Looking at that form it is making the part look very busy (pointing to sketch). You have lots of lines going. What you have got on the model is more like what you have got here (pointing to original product). It is a quite simple form. It is worth considering if you really need something there. You had that line idea (nodding).

In this vignette, the design presenters begin by presenting their proposed concept for a water level indicator, which avoids the need for additional parts and therefore has a minimal impact on manufacturing. However, a question by the review group is framed to determine if what they have proposed is still too complex from a form and usability perspective. To ask this question a range of artifacts are used including sketch rendering, the form model and the original product. Although no resolution is made, the design presenters acknowledge that their solution may be visually complex and they will look into it further. The design group then verbally refers back to a previous concept the design presenter had come up with as a starting point to re-consider their design solution.

In the final example of demonstrating the presence of Schön’s Reflection in Action paradigm, a vignette has been selected focusing on the resolution of an aesthetic design detail. The product concept is an electric water kettle.

Group ID T0304 Time 7:10

(Pointing to sketch) This switch is pretty much like the original. This switch placement at the top, people said they really liked that, so we are keeping that there. Switch also has a backlight on it as well. We kept it all the same because people really liked that.

Where is the part line? Can I see the model next to the original (students put the two models together).

It won't be a part line, as such. It will just be where the two tools come together (student holding the model and simulating action of tool). It will have to be moulded like that and that so we can get this handle in here and we will need a core from underneath and there will be one from the top coming in here to get the spout (simulating actions of tool). And the bosses and positioning pins we need in here (pointing to sketch).

Can I have a look at that? (Model being passed through and compared with original product). Maybe I am not seeing it, but does this have an angle on this face here (pointing to model). Do you need an angle on here or can you make is narrower?

Yep – (pointing to original design) – I was trying to follow this curve but it is different when it is in a side view as compared to a perspective view.

This is what I was thinking – see that detail you have on top of the handle, is there any way you can get that detail to marry into the top of the body?

Last night I was resolving to get rid of that detail (trying to find sketch). Well this is what I was actually trying to aim for last night (holding up sketch) but still that type of thing but a lot more softer (pointing to model). It is less angled.

This is what is keeping it in the high range, this angled look. And it is that point of difference and you have definitely got that in yours (pointing to model).

(Holding the model) I was thinking if I have this handle curved, maybe move this out slightly.

	You will have to thicken that base now. *Here (pointing to the base).* No, no, where the base comes down. *Oh, yeah. That is what I have been working with here, I have widened it by 10mm (pointing to sketch). That makes it a little flange that goes like that (simulating form on the model).*

The design presenters initially outline their justification of the button placement for the kettle design. This placement is based on their initial usability studies which they verbally refer to. This then leads to clarification (framing a question) about a manufacturing detail of their overall form. The review group questions what type of tooling will be used and the design presenters respond by simulating the action of the tool direction with their hands on the foam model. Following this an additional question is framed, this time relating to the overall aesthetics of the product. Their concept model was used in conjunction with the original product as a reference. This leads to a new discovery related to the integration of the handle into the top of the body with the design presenter adding additional information with the inclusion of a new sketch. Both the presenters and the review group then start to 'design in action' based on this recent discovery of the handle integration.

> *(Holding the model) I was thinking if I have this handle curved, maybe move this out slightly.* You will have to thicken that base now.
>
> *Here (pointing to the base).* No, no, where the base comes down.
>
> *Oh, yeah. That is what I have been working with here, I have widened it by 10mm (pointing to sketch). That makes it a little flange that goes like that (simulating form on the model).*

The final outcome from this dynamic discussion is a shared understanding of the direction of the overall form for their proposed design.

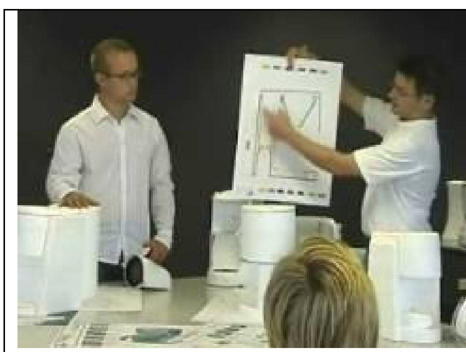
4.2.1 Reflection in Action – Traditional Design Review Environments

In the above examples, Schön's reflection in action paradigm is evident. Problems were framed within the design review session, and new discoveries were made which were mediated through interaction with the artifacts. Further, the design conversation is either started with or altered through an artifact. Examples of this include:

- a sketch is shown which makes explicit a particular concern, another artifact is then used to provide additional detail;
- the artifact is passed around and manipulated;
- the artifact is cross referenced to the sketch and the original product.

This fluid process of interaction with the many artifacts within the design review leads to new discoveries and reframing of the original problem. Although the artifact is critical to frame both questions and make new discoveries, it is the seamless integration of the artifact within the design review session which is of interest. This observation aligns with Harrison and Minneman's (1996) description of artifacts (objects) as being "more than a source of information, that they are constituents of the activity … that they are constituents of and frames of the communication (and) …they alter the dynamics of interaction especially in multi designer setting" (p.432).

In the following transcript, Harrison and Minneman's description is further illustrated. The spectrum of artifacts and resources are highlighted in bold to illustrate the point further. The context of the review is the redesign of a drip fed coffee maker.



Group ID T0313 Time 12:19

You were saying in your original usability studies and market studies (**prior knowledge**), that when you took the jug out, it was quite difficult to remove. From the cross sections you showed, it does not look like there is much clearance for the jug to be removed from the cavity, especially in the cylinder design (referring to one of the concepts just described). Can you show me that cross section again (**sketch**)?

*(Working with **original product** while the other student gets the cross section) The difficulty of the existing design was that this section pulls open because the snap fit did not actually work (showing where the problem was on the original product). It has to be a reasonably tight fit because you have got a shut off valve in there which is on the bottom of the filter, to stop it from dripping all over the hot plate, so it has to be located in*

	*exactly the right place (holding the actual product). I guess an angled approach virtually renders that approach impossible. The last insert of the jug has to be straight in (**gesture**). We thought about a lead in.* Yeah. For instance, on that design (referring to the **sketch** the student is holding up), you have to lift it up and then back out again. *In which design?* The one you are holding up. *No, basically it will just pull it back (**simulating action**).* *As Sam (first design student) said, it needs a tight fit. As I said (second design student), the main problem here was this section just popping out (pointing to **original product**).* So when you slide the jug into the cavity it drops down into a small section. *Yeah, yeah (actions to **draw** something, but **comments**).* *It has a thermostat lip at the top of the product. I can see what you mean but I think minor dimensional changes are possible after this point but, yeah, it does need a tight fit.* Yep. I was thinking, is it possible to slide it straight in and not drop out. *Well probably not as we have the thermostat ring which is a standard component which has an angle on it. We can't change that. The bottom of the jug also has a section which drops into the thermostat and this is actually holding the actual product.* OK, yep, yep.

In this example, the conversation starts by questioning a comment the design presenter had made, which related to their usability testing of the original product. This quickly leads to issues surrounding manufacturing, where multiple resources are used in the discussion. Both manufacturing and usability are discussed simultaneously, using a variety of resources to help build the shared understanding. The artifact is not used solely to respond to questions (sources of information) but is also the source of framing the discussion based on what is being said or is being represented.

A key aspect of this observation is that the artifacts can be used and manipulated by all members of the design review group. As shown, often the artifacts would complement each other to assist in both providing additional information and revealing new discoveries. Further it is the seamless dynamic relationship between the design presenters, artifacts and the review group which allows for such a process to occur. As demonstrated in the above vignette, all participants within the group could manage the use of the artifacts to ensure that the original question of usability was resolved, whilst considering the issues which surrounded this problem.

As noted previously, it was expected that the students would engage in a process following Schön's Reflection in Action Paradigm, as the nature of the design review activity follows this approach. The design presenters needed to seek clarification of their design by framing questions to seek appropriate feedback which in turn allowed for additional questioning from the review group during each of the sessions. The role of the artifact was integral to this process, which follows the process Schön has outlined. However what was not expected was the seamless and dynamic use of resources used throughout the review process.

Schön (1983) makes a distinction between the sketch and prototype, describing the prototype as a "more active and evocative participant within this process"(p.84). However, this distinction was not evident in the studies observed, but rather, the designers were opportunistic in seeking out the most appropriate artifact during the design review session. In the above vignettes, the artifacts used during the design review included:

- 2D Technical Sketches;
- 3D Renderings;
- 3D Foam Models;
- The Original Product.

Further, the students augmented these artifacts with:

- Verbal Description / Rich Design Language;
- Gesture or Simulation of Action;
- Prior Knowledge.

What was observed was that there was no hierarchy in the role a particular artifact had during a review session. Students did not prefer one type of artifact over another. Sketches appeared to be used equally to 3D foam form studies. The choice of artifact related to how it contributed to the nature of the design discussion and therefore overall engagement. Often multiple artifacts needed to be used to assist in communicating or resolving a detail.

Within a traditional design environment, traditional artifacts support design engagement by allowing the designers to seamlessly incorporate them into the early stages of an industrial design review process. It is the dynamic integration of the artifacts into the design review activity which is critical in enabling this reflection in action to occur.

4.3 Plans and Situated Actions – Traditional Design Review Environments

The above section provides an insight into the nature of interaction between the designers and their artifacts during a design review setting. The following section extends this understanding by outlining the role of the artifact during a review using Suchman's (1987) Plans and Situated Actions framework. This framework has been selected to review the role of the artifact within a design review as it allows a deeper exploration of how the design engagement is occurring. Suchman's work contextualises design activity beyond the direct engagement between the artifact and the designers and provides a framework for exploring the relationship between activity, the situation and the mind.

Schuman notes "that the significance of artifacts and actions and the methods by which their significance is conveyed, have an essential relationship to the particular concrete circumstance" (p.50). Therefore, the following section aims to build upon this understanding by outlining the moment to moment activity within a design review and determining the significance of the artifact during this activity.

To demonstrate how a designer may change their plans during a design review, you need to consider how the designer prepared for the review. This involves the designer mapping out the structure of the presentation to ensure that the issues to be covered are addressed. They ensure they have the appropriate details drawn, form models available, historical data (such as a market study) available and in a form which is appropriate to the review setting. As noted in the above vignettes the design presenters all had available a selection of artifacts at various levels of completion which were brought to the design review session. Often the starting point for the design review was the students 'presenting' particular issues they wanted to discuss and these issues were related to a particular artifact. A specific sketch would relate to a particular detail. A foam model may be planned to be used to discuss a particular aspect of their proposed solution.

This description of the design review process parallels the example Suchman provides to demonstrated her Plans and Situated actions framework.

… in planning to run a series of rapids in a canoe, one is very likely to sit for a while above the falls and plan one's descent. The plan might go something like "I'll get as far over to the left as possible, try to make it between those two large rocks, then backferry hard to the right to make it around the next bunch." A great deal of deliberation, discussion, simulation, and reconstruction may go into to such a plan. But however detailed, the plan stops short of the actual business of getting your canoe through the falls. When it really comes down to the details of responding to currents and handling a canoe, you effectively abandon the plan and fall back on whatever embodied skills are available to you. The purpose of the plan in this case is not to get your canoe through the rapids, but rather to orient you in such a way that you can obtain the best possible position from which to use those embodied skills on which, in the final analysis, your success depends (Suchman 1987, p.52).

Within a design review (as demonstrated in the transcripts above), once the review occurs, the original plan of discussion may be abandoned, as the artifacts will reveal new information. The design presenters will need to bring in new artifacts and knowledge to respond to queries, or to frame additional questions. The outcome may be new discoveries which the students had not originally considered.

This is clearly demonstrated in the first vignette (T0307) where the students begin by presenting their solution for their 'base detail' however as they do this a question of clarification is asked. They respond to the question by using a series of artifacts including technical sketches, form study and the original product which have previously been used throughout the review, but now for a different purpose. This in turn leads to another question (re-framing of the problem) being made relating to the weight of the unit and whether this detail will support it. Again the design presenters make use of a series of artifacts to respond to the question. This then leads to a third question (re-framing in light of the discovery just made) being raised in relation to the manufacturing of the product and a new discovery by the design presenters is made.

The designer presenters and the review group are able to substitute resources (on the fly) to help frame, discover and resolve the problem and often use more than one resource to achieve this. This approach to artifacts supporting design engagement is illustrated in the following diagram.

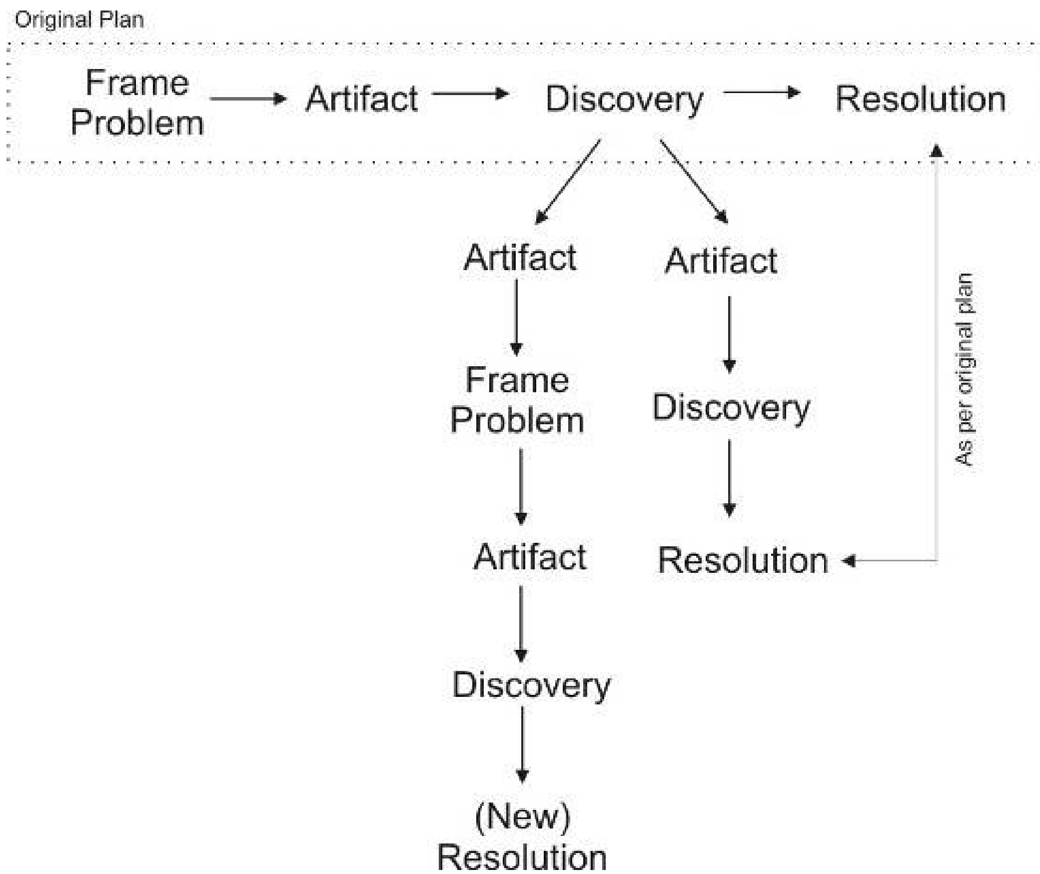


Figure 12 – Nature of Interaction with Traditional Design Artifacts

The design presenters come to the design review with a set plan where they have pre-framed their problems and have constructed artifacts to communicate this. This could be as simple as a rough sketch to help clarify a particular detail or mechanism. Alternatively it could be a complex 3D form model with many elements integrated into it to communicate the overall look and feel of the concept. In constructing the artifacts and pre-framing the problems the designers have a plan to make new discoveries through the group discussion. However, as the review begins and one discovery is made this in turns leads to new problems being framed as the original problem is often interrelated to other aspects of the design concept. Alternatively, to make a new discovery, additional artifacts need to be brought to the discussions which were not originally intended for this purpose, however can be easily used in this role. The final outcome is both further clarification of the original problem or a new discovery which was not originally considered.

This observation extends Suchman's Plans and Situated Action framework which was conceived originally as a framework to describe human interaction with physical artifacts. Through the study of an in situ design review session this study has demonstrated how a designer's original plans and their intended use of their artifacts are modified based on a moment to moment basis based on situations presented within a particular circumstance.

This sub section has presented the finding of the role of the design artifact supports design engagement within a traditional design review environment. It was observed that the design reviews followed that of Schön's reflection in action paradigm. The students were able to develop a shared understanding using a combination of artifacts available within the design review setting. However, it also demonstrated that the role of the artifacts altered the path design review and that the artifact directly led to new discoveries during the design review. This follows the notion of Suchman's (1987) Plans and Situated actions.

In the next section, the findings described above are compared to the observations made during the analysis between designers and their artifacts within the virtual setting.

4.4 Virtual Design Environments

In order to compare the findings from the previous section and to determine the impact of a virtual setting on design engagement, the variables within the case study of the virtual design environment had to remain consistent with that of the traditional setting. As noted in detail in Section 3.1.3, the virtual design review exercise was an optional studio session which was offered to the students who were undertaking the consumer re-design project. By undertaking this session they would be provided with additional feedback on their design progress, however, they were required to undertake the review using the virtual design setting.

Therefore the context of the design review session remained identical to that traditional design review. The design students were required to present their progress of the re-design exercise within a virtual ‘round table discussion’ while the review group were required to seek clarification of the ideas put forward and seek a shared understanding and resolution of the concept.

The review was undertaken in the same week as the traditional design review. Students could make use of any of the artifacts such as sketches, models or the original product within the review session. The virtual design review lasted up to 15 minutes in duration.

A major point of differentiation was the requirement for the designers to create a 3D Virtual Sketch of their proposed design concepts. As noted previously, these virtual artifacts are relatively quick to produce (typically less than 1 hour creation time) and provide a similar level of detail to a 3D foam model (see Figure 5 p.53)

In addition to the type of artifact which was introduced into the design review session, the nature of the design review environment was also significantly different. The virtual design environment alters the interactions within the setting due to the constraints of the technology being deployed.

The group must wear special eye wear to activate the stereoscopic display. Although the glasses do not affect your normal vision if you look away from the screen, they do block peripheral vision and if you take off the glasses you may not be able to clearly see what is being displayed (due to the projection of the stereoscopic images which is seen as two images overlayed slightly apart from each other).

The interaction with the virtual model is also mediated through one person, who has ‘tracked’ glasses and a wand interaction device which controls a virtual avatar on the screen. This ‘tracked’ interaction allows for an infinite number of perspective views to be displayed on the screen based on the viewer’s head position and their hand orientation. The wand device allows the user to to interact with the virtual artifact through natural wrist movements. This ‘tracked’ interaction allows for immersive viewing for the one ‘viewer’. All others in the group see a slightly distorted image being displayed with the level of distortion being relative to their physical location to the person with the ‘tracked’ glasses (Figure 13).

Figure 13 – Stereo Glasses and Wand Virtual Interface

The environment to view the virtual world must also be kept dark, which limits the use of other artifacts (such as sketches) within the environment while a review is being undertaken. However, despite these short comings, the virtual design environment provides an opportunity to explore a design concepts in a manner similar to that described in the traditional setting.

The following section provides examples of how the groups became engaged with the design problem during a virtual design review to determine if indeed the students followed Schön's Reflection in Action paradigm within such a situation. As with the traditional review description, this section highlights the role of the artifacts within these situations. Rather than present these new findings in isolation, they are referenced to the findings made in the traditional setting as they build upon the knowledge gained from this initial section.

To demonstrate these findings, small clips are provided which highlight exemplars of interaction found during the analysis. 'Design Presenter' comments are indicated in italics, where as the 'Review Peers' are indicated in normal text. Description of the interactions between the designers and the artifacts are shown in brackets. Time from the start of the review is also shown to contextualise where in the review the activity takes place. A reference image is also included to help contextualise the vignette. Full videos can be found in the attached DVD.

4.6 Design Engagement - Virtual Design Review Environments

As with the traditional design environment, it became clear that Schön's reflection in action paradigm was evident within the virtual design reviews. Once again this was expected as the designers had the same motivation to participate within this review as they did with the traditional review setting. Significant questioning and discussion around the areas of manufacturing resolution, usability and aesthetics were also frequently observed. However, what was also apparent and where this research contributes to filling in the identified knowledge gaps, relates to the nature of the interaction between the designer presenters, virtual artifact and review group within the virtual setting.

As identified in the literature review, very little is known about the nature of the interaction between designers and virtual artifacts for early stage design review. To highlight these differences four vignettes from the virtual review sessions have been selected which demonstrate how the students resolved their design decisions within the virtual design environment setting.

In the examples below the presenter begins the review while wearing the tracked head set and is in control of the wand interface to allow them to manipulate the virtual model. The design review group stands behind the design presenter and have stereo glasses on allowing them to see the image as an active stereoscopic projection. Therefore, they are all facing the screen and listening to the discussion. Typically no other artifacts have been brought into the design review (even though the students did have this option available to them).

In the first exemplar the designer is having trouble resolving the form of a handle for the concept of his kettle redesign. The review begins with the selected concept being projected onto the immersive display.

	Group ID V004a Time 6:23 *(Student rotating virtual object) I wasn't very happy with this handle. But from the other ones I did, this was the better one (continuing to rotate the object).* Is there some way you can… that critical component looks very wide. *No, you can't reduce it.* I realise you can't reduce it but can you make it look less fat. You can put vertical lines on the form (simulating vertical hand action). Making it look upwards rather than outwards. *Yeah, or maybe if I … the height of it looks OK.* Maybe if you taper it in. *Yeah, from the base tapered to the top. Yep I can change that.* Yes you really need to look at that because the form at the moment is making it look really big.
	Could you incorporate the handle into the natural form? (simulating desired shape). It might actually look OK. *Yeah I actually had one (sketch not shown) that sort of arched through there (pointing to the virtual model) and that one looked OK as well. And I had this sort of curved shape as well. But now the more I think about it, the more I have to move away from this shape.*

The student begins with a problem and appears stuck as to how to move forward to resolve the handle design. From his opening comments it appears that he does not frame a problem directly but rather becomes critical of his past attempts to resolve this detail. As he does not have any additional material to show, the design presenter constantly rotates the virtual model on screen in attempt to engage the review group by looking at the design from a continually changing perspective view of the product. This action which is discussed in detail in a later section is typical of the interaction with the virtual environment.

The review group provides a suggestion to help reduce the visual bulk of the handle, from which the design presenter can see a possible solution and begins to become engaged by providing a design solution (designing in action). As there is not the option to make the change on the virtual model (such as sketching on the virtual model), as the technology does not allow for this, the review group indicates that this option needs to be explored outside of the review. The review then continues but still focuses on the form of the handle detail. The design presenter then makes reference to a sketch which is not brought to the design review and begins to verbally describe this concept using rich design language and compares it with the virtual model being displayed. A final question was then asked by the review group, seeking clarification on a design detail represented on the virtual model. The design presenter then clarifies his response with a verbal discussion.

In this example the design review group had put forward a suggested solution in an attempt to frame a problem for the designer to consider. From this, a new discovery was made by reflecting on the impact of this suggested approach to his design concept. The designer had moved his design forwards through this discussion, following a reflection in action paradigm. Although there was no actual resolution, the designer was provided with new information, which could be considered outside of this review.

In the following example, the design presenter again seems stuck as to how to move forward with her redesign of a CD carrying case. The transcript begins after the students had spent considerable time rotating the virtual model on screen which then prompted a question from the design review group.

	Group ID V-006a Time 3:03 (*After a rotation of the object*). It looks quite good from there, to me. If you actually did that as your front, and you made an extra cut in there. *OK.* When you rotated it (casing), then you would have a matching design (pointing to the virtual object). *OK, yep. So, actually, modify this part here (rotating the object).* Yep. (While student is rotating the object). I like that top detail. *I wanted to show that as I will eventually make this grey plastic component transparent.* But if you wanted to have a look at it from this direction (pointing to the side to be looked at).

	Ah, I see what you mean. That cut will be on the front of the face, then you can rotate it and just get the CDs out (simulating rotation action with hands only). *Yeah, yeah, so you are saying from there.* Yeah.

This shared understanding arose from the student continuously rotating the virtual object during the design review (while the discussion was ongoing). This prompted the group to comment on a particular view which was being displayed, which related to usability issues (inserting a CD in a Carry Case). The review group proposed a design solution from which the student responded by reflecting on this in the context of her design. The student commented on her design direction and how this proposed solution fits in with this. The final resolution as shown from the transcript is that the design presenter has a clear direction to consider outside of this design review. This same design review is explored further within the review in the following example.

 	Group ID V006a Time 9:10 *The reason I created this detail as well was to guide the eye to rotate it in that direction.* So how would you put your hand on it? (Putting hand in front of the virtual object). So would you put it in your hand and spin it (simulating two handed action). *No, you would clasp this area (pointing to the virtual object) and then you would use this white area to rotate it.* (Simulating rotation of what was explained) Like this, or would it be a rotating action? *Yes, definitely two handed. One hand grasping here and one grasping there (pointing to the virtual object). So, basically doing this pulling action (student showing the movement).* If you can manage to get a button on top of that, (pointing to the virtual object), you might be able to make it a living hinge which actually locks it in. *Oh, OK.* Then you could just push it in and rotate it and push it back and lock it (simulating action). *Oh, OK, yep I see what you mean.* You would give people a lot better feel for the

	product. Then you would not get people's fingers in the way (pointing to the object). *So you need a little button in here so as you rotate it you move it like this (simulating the action).*

In the above example a problem was framed around the opening of the device once the designers had presented this detail. To frame the question, the review group made use of not only the virtual model, but gesture and simulation to outline their question. The design presenter went on to clarify the proposed design detail using the original view of the artifact.   This was further questioned and the response was made by simulating the action of the operation rather than using the virtual artifact. The design group who asked the original question then asked for further clarification by doing a similar action. This then leads to a new discovery, a manufacturing discovery which also addressed the original usability problem.

In the following review, a question is posed relating to the overall rationale of the form of the product. The review group had raised this based on the images of the artifact being presented. The context is the redesign of a kettle.

 	Group ID V012 Time 10:56 My main concern is … I think the form is quite nice. It has got a nice bend in the form to it but it does look like it wants to actually spring back. Just looking at it here it looks like it is trying to actually bend further (simulating bending action with hands). It is wanting to actually bend back (simulating rocking motion with hands). *Yeah, yeah (heads nodding). I can see it now.* Maybe the form is just a bit too much. Are you going to work on it a bit more? *It did come from a concept similar to the geometric form of the original.* Because what you want is this curve coming up (simulating curved action on screen) and for this curve to come down. So do you think you can play with this top form a bit more? That spout needs to be further down (again pointing to the screen). *Oh yeah.* It is going to be like you pick this thing up and just automatically pour it (simulating the pouring

	action). *Yep (heads nodding).*

In this example the group questions the form, indicating the shape may be too pronounced, but wants to get clarification. The designer did not originally view the product in the way the group had described this and therefore made a new discovery about his design. From this, an additional question was framed as to the rationale of the form and whether this would lead to additional problems. The designers then justified their decision based on their analysis of the original design and describing that they wanted the form to match the action of the user pouring the kettle. This discussion helps the review group develop a shared understanding of the concept, however it also raises an additional question related to the usability of the product.

In the final example to demonstrate the role of virtual artifacts, a discussion of a technical nature within the group is provided.

 	Group ID V-012 Time 5:01 *There are still a lot of details to be resolved. It is still a fairly loose concept.* What about that connection from here to the base (pointing at screen). *That again around where the joint is there will be a sort of a lip on the jug body with a snap fit into a detail.* Will there be other fixtures? *There are screws in the bottom and they connect the actual base to the element. (Student moves object and rotates head to look under the object). (The group changes their body position to view the correct perspective). There are three bosses in that section and three screws that come in from the bottom from there (pointing to the virtual model).* *So that sort of supports the weight. The element itself is crimped onto the jug body, so when it is flat a lot of the weight will be transferred directly onto the flat base. When you pick it up (student rotating object), it will be supported just by the snap fit around here (pointing to the object) and also the brass pins.* *Also, this helps in the assembly as you save a few parts. You don't need a separate handle.* So what do you now put your hand directly onto?

	(Simulating the grabbing motion of the virtual model). Are you putting your hand directly onto hot water? *Well it is possible as I made enough space there, anyone could easily get their hand into.* How many litres is it? *1.6 litres. Also with the wall section of the jug we have got, it really did not get that hot, so you would have to hold your hand on there for quite some time, a minute or thirty seconds, to notice any sort of heat. You would not be able to burn yourself. Your hand will get hot.*

In this example a question is framed by the review groups which relates to technical details of the concept. Initially defending the lack of detail in the concept, the designers provide a detailed verbal response, pointing to and rotating the model to contextualise their verbal description of the proposed solution. From this description provided, a further question is re-framed by the group related to usability (placing your hand on the kettle while it is boiling). Again a verbal response is provided, using the virtual model as a prompt to clarify their description.

The above examples demonstrate that the virtual artifact directly supports the design engagement during the design review as it follows Schön's reflection in action paradigm. The designers and the group were seen to be framing problems during the course of the review, there were new discoveries being mediated by the virtual model, and a shared understanding was being developed within the review. This was in line with the activity observed within the traditional setting.

It was not surprising that the virtual setting provided a similar level of design engagement to the traditional design setting. The design students and staff had the same objective in this review as with the traditional setting and therefore actively made use of the resources within the environment to ensure that the design review could proceed. To further illustrate this point the following student comment is provided.

This week we undertook design critiques of our current projects by only using immersive virtual environments. I found that the use of the Fakespace immersadesk was very helpful in discussing my design and evaluating it within the group. It was easy to show to the group the overall form of the blender and where the motor and blade were situated within the blender base and the blender jug. I did this by using *the skewer interaction function and turning and focusing in on the area I wanted to explain. Some of the questions and comments that came up during the critique related to the operation of the blender, the sizes of the blender base and jug, the use and appropriateness of the handle, the pouring action, the locking of the jug and lid and some manufacturing details. The discussion helped me to understand some of the areas in the design that I had not thought much about and problems with usability which I needed to resolve.*

I found that it was hard to convey the design in some aspects, firstly because the model was not accurate and detailed enough and secondly it was hard to navigate in the immersive environment. I also found it was hard to talk about the design because I would be trying to move a part of the blender while I was being asked questions. Because I was concentrating so hard in navigating the objects I wasn't answering the questions very well.

I think if I had a physical model it would have been a lot easier in explaining the usability of the jug handle and the pouring action. This was an aspect of the design that was talked about a lot in the critique and a foam model would have been a lot more effective. A physical form study would have also helped a great deal in creating a sense of scale and size especially on a bench top. I think that sketches would have only been useful if they were more detailed than the VR model. Sketches could show cross-sections and manufacturing details which would have greatly aided.

Overall I think the design critique was a very positive experience in gaining constructive feedback. I do feel however that a critique using a form study and sketches would have been just as effective, without the price tag! The area that the immersive environment has the edge is the speed in which an environment can be developed. (V-002)

4.6 Design Engagement – Comparative Analysis

The section has presented an insight into the interaction between designers and artifacts for early stage design review activities within two unique environments, a traditional and virtual setting. The objective of this section was to reveal new understandings of the early stage design review activity, by studying in situ interactions with designers and their artifacts.

Based on the transcripts provided and analysis undertaken, a reflection in action paradigm as defined by Schön could be seen in both environments. As mentioned, this was expected due to the nature of the design review activity which required designers to engage in the review by framing problems, making new discoveries and developing a shared understanding of the proposed new solution. However, although both environments enabled this design engagement to occur, the nature of the interaction with the artifacts was significantly different in both environments.

In the traditional setting, designers prepared and brought multiple artifacts to the design review activity. They had demonstrated a plan to guide the review discussion to enable them to frame questions and seek resolution on specific design details. These plans were often altered based on the information brought to the design review, where discussion around one detail led to new discoveries or questions being raised. The designers would move seamlessly between the various artifacts in order to frame the questions or clarify detail. Further, the use of intangible resources such as language and gesture which were overlaid on the artifacts assisted this engagement process. Therefore, it was through the direct interaction with the artifacts where this design engagement was achieved.

However, in the virtual setting, the use of multiple artifacts was not observed. The designers did not come to the review with a plan to use different artifacts to highlight different aspects of their proposed design solution. Further, the review group did not seek clarification through the use of multiple artifacts. Rather the design engagement came primarily from the direct manipulation of the virtual artifact. It was through the constant rotating of the virtual model where questions were framed by both the students and review group. The affordance of the technology to generate an infinite number of perspective views of the product, often at an exaggerated scale, together with the low fidelity of the actual model, allowed the group to constantly question what they were being shown. To respond to these questions the designers were not able to refer to other artifacts as in the traditional setting and were required to rely on other resources such as language and gesture to assist with the design engagement. Therefore, it is the abstract qualities of the artifact which is of significance.

It is difficult to determine if the students come to the design review without a plan. It would appear that the designers did have an outline of issues they wanted resolved and they did have a set view (eg front view) or descriptions they brought to the review. However, it was the combination of the rotation of the virtual artifact and the abstract qualities which were presented and then referred to, that altered the design review and their original plan. This is outlined in the following schematic.

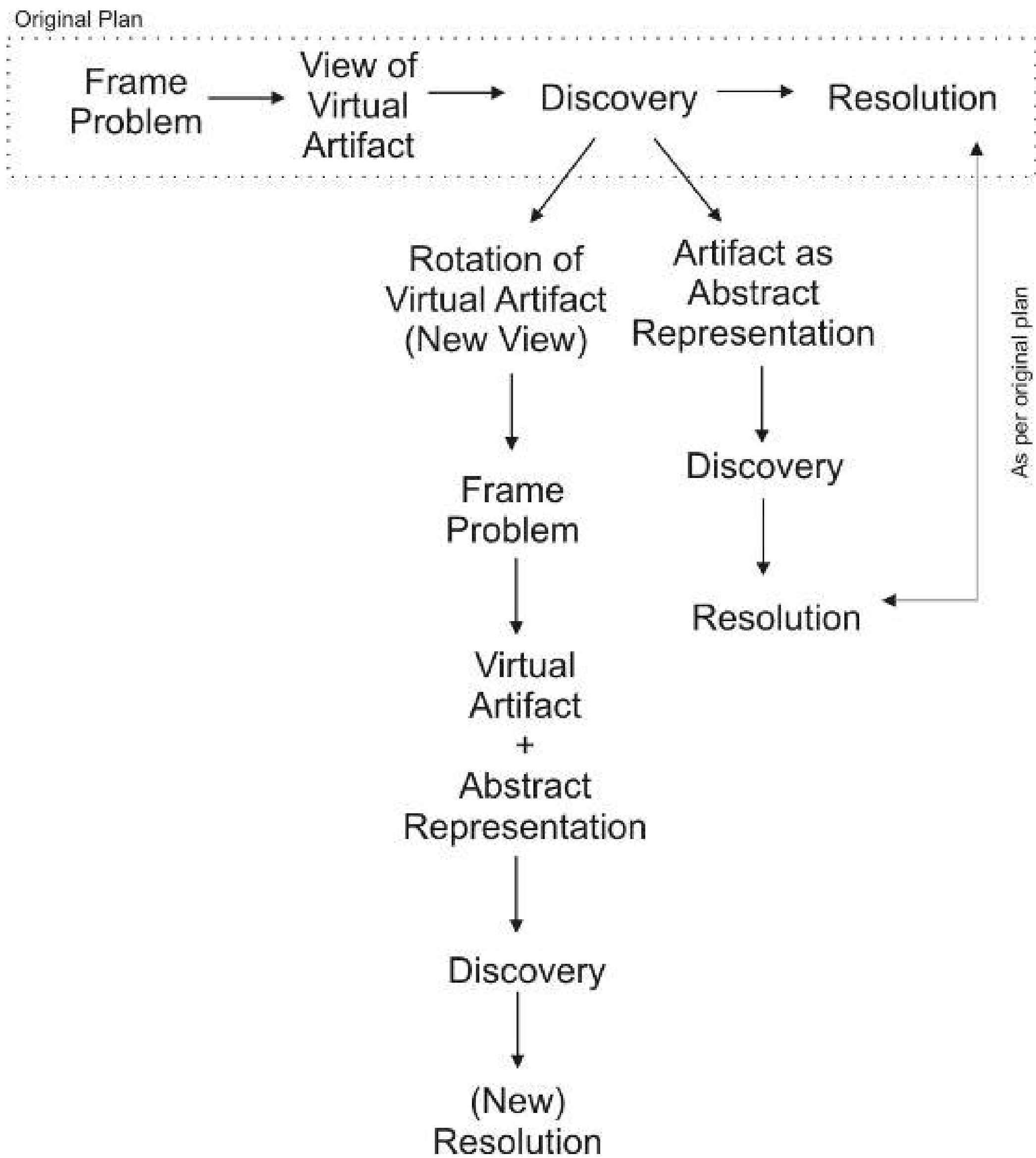


Figure 14 – Nature of Interaction with Virtual Design Artifacts

This finding builds upon Brereton's (2000) finding that: "design thinking is heavily dependent on physical objects; that designers are active and opportunistic in seeking out physical props; and that the interpretation of and use of an object depends heavily on the activity" (p.217). In the virtual context, it appears that the designers are opportunistic in using the resources available to them. This is shown in how the designers manipulated the virtual objects, pointed to the screen, simulated the intended user's action though the virtual avatar. However, they are opportunistic to supplement these virtual artifacts with abstract qualities, such as rich design language, use of prior knowledge and pantomime interaction used to describe the particular concept.

This notion of abstract qualities of a design artifact to support design engagement is discussed in greater detail in Section 5.

4.7 Summary of Section

This section has presented the first of three findings from this thesis. The finding focused on addressing the overarching research question from this thesis, namely what is the difference between physical and virtual prototypes in supporting design engagement, where Schön's reflection in action paradigm is used as a framework to define engagement. Through the analysis of the field data, it was shown that within the traditional environment, the design students followed Schön's paradigm. However, what was of interest was the designer's dynamic use of the resources used as part of their design review. New discoveries were shown to be made through the interaction with the artifacts available within the review; however multiple artifacts were used dynamically throughout the review rather than a single use of the artifact for a particular discovery.

Within the virtual setting, Schön's reflection in action paradigm was also evident and has been demonstrated through transcripts of the field data. However, given that the virtual setting did not allow for multiple resources to be included within the design review, the students supplemented the use of the virtual artifacts with abstract representations, which were embedded through rich verbal descriptions of the design concept and intended gestures of the product.

This finding makes a significant contribution to our existing knowledge of artifacts in supporting design engagement. It provides an in situ account of Schön's Reflection in Action paradigm and builds upon Suchman's Plans and Situated actions framework to reveal new understandings of artifacts within early stage design activity.

5.0 ARTIFACTS REPRESENTATING ABSTRACT KNOWLEDGE

This section presents the second of the three findings from this thesis. It builds upon the previous section which related to identifying the role of artifacts in supporting design engagement in both a traditional and virtual setting. This section will expand this finding to focus on the nature of the interaction in greater detail.

One of the goals of the design review session is for all of the designers involved within the review to develop a shared understanding of the design problem. It is acknowledged that there is a large body of work which aims to define what is meant by the term shared understanding. However as this thesis is interested in the moment to moment interaction with artifacts, it has used the definition provided by Henderson. Henderson (1995) notes that designers' interactions with artifacts act as a mechanism for interactively organising their shared understanding of their work. As shown in the previous section, the interaction between the designers and their artifacts within the design reviews observed, contributed to the shared understanding within the design team in both the traditional and virtual environments. However, it was also the dynamic use of the resources, of which the artifact is only one resource, within the design review setting which was also a critical factor in developing the shared understanding within the group. Gestures, design language and prior knowledge were all used to contribute to the development of this shared knowledge.

This dynamic use of resources within traditional design settings has been reported by others including Tang and Leifer (1991), Henderson (1995), Perry and Sanderson (1998), Logan and Radcliffe (1998) and Brereton (2000). The artifacts form part of a system which allows for abstract knowledge to be embedded into them and used explicitly throughout a design review.

However, as shown in the previous section, the use of dynamic resources is also evident within a virtual design setting, but is used to compensate rather than complement the other resources. The virtual design setting provided the designers with an impoverished communication medium and for the shared understanding to be gained, the virtual artifact acts as a prompt to enable the additional knowledge to be revealed.

It is the difference in how the designer's interactions with artifacts in the physical and virtual setting in revealing knowledge, which forms the second finding of this thesis.

This section explores this finding by presenting a comparison of the designer's interactions observed and relating it to their use of gestures and pantomimes, design language and use of prior knowledge.

5.1 Direct Manipulation versus Pantomimes

As noted in section 4.2, within a traditional design environment the designers were opportunistic in seeking out the most appropriate interaction with the artifact to ensure a shared understanding was achieved. This is consistent with Tang and Lefier's (1991) study of collaborative design activity which identified that hand gestures are used to demonstrate a certain action in conjunction with sketches and other objects to establish a shared reference for the design team. Perry and Sanderson (1998) identified that an artifact was a resource for discussion as well as the medium to generate change through discussion, with the communication channels including gesture, voice and gaze awareness to interact with the artifacts during a face to face environment. Logan and Radcliffe (1998) have used the term 'artefacting' to define the combination of utterances and physical interactions with artifacts to communicate complex messages within a design context. In their study of design activity, they identified that participants engaged in 'artefacting' because the combination of talk and action provided more detailed design information to other participants than solely oral presentation.

As noted in the review of the literature, these studies provide a strong foundation for this research. However, such studies do not relate to early stage design activity or provide insights into the use of virtual artifacts. Therefore, it is these two variables which provide a point of departure for this research and allows new insights to be revealed.

To present the second finding, a comparison between the traditional and virtual settings is made in the following section. The use of transcripts and students' comments are used to support this claim.

Within the traditional design review environment design students made use of a large variety of artifacts such as sketches (technical representations and rendered form perspectives) and foam form models. Although the design concept was not a final design solution, the artifacts contained an appropriate level of detail for the review to be undertaken. Students were able to refer to technical details such as wall sections and engineering components within the detailed sketches. Further, the tactile qualities of the foam model allowed students to directly interact with the model, furthering their understanding of the design concept.

It was observed that the students would focus their conversation on the actual artifacts and dynamically manipulate the many artifacts present to ensure they were able to communicate effectively. They touched, pointed at, manipulated and gestured with the artifacts.

The following transcript has been repeated from Section 4.2 and enhanced with the inclusion of additional images to demonstrate this activity.

	(Group ID T0304 Time 7:10) *(Pointing to sketch) This switch is pretty much like the original. This switch placement at the top, people said they really liked that, so we are keeping that there. Switch also has a backlight on it as well. We kept it all the same because people really liked that.* Where is the part line?
	Can I see the model next to the original (students put the two models together).
	*It won't be a part line, as such. It will just be where the two tools come together (student holding the model and simulating action of tool).*

	*It will have to be moulded like that and that so we can get this handle in here and we will need a core from underneath and there will be one from the top coming in here to get the spout (simulating actions of tool).*
	*And the bosses and positioning pins we need in here (pointing to sketch).* Can I have a look at that?
	(Model being passed through and compared with original product). Maybe I am not seeing it, but does this have an angle on this face here (pointing to model).
	Do you need an angle on here or can you make is narrower? *Yep – (pointing to original design) – I was trying to follow this curve but it is different when it is in a side view as compared to a perspective view.* This is what I was thinking – see that detail you have on top of the handle, is there any way you can get that detail to marry into the top of the body?
	*Last night I was resolving to get rid of that detail (trying to find sketch).*

	*Well this is what I was actually trying to aim for last night (holding up sketch)*
	*but still that type of thing but a lot more softer (pointing to model). It is less angled.* This is what is keeping it in the high range, this angled look. And it is that point of difference and you have definitely got that in yours (pointing to model).
	*(Holding the model) I was thinking if I have this handle curved, maybe move this out slightly.*
	You will have to thicken that base now. *Here (pointing to the base).* No, no, where the base comes down. *Oh, yeah.*
	*That is what I have been working with here, I have widened it by 10mm (pointing to sketch).*

	*That makes it a little flange that goes like that (simulating form on the model).*

In the above example the sketch is used to explain the details of the proposed concept. The designer refers to known details which they have produced in the weeks leading up to the review to best communicate the concept. The foam model is used to simulate assembly and component details. The model is also commonly used to describe the intended user activity.

Further, the group uses the artifact directly to query the design with ongoing discussion being made using the artifact. When a question was asked, direct reference to a variety of resources was used to help in communication. For example, when the designers were asked about a possible part line and the students' response consisted of them referencing to the model and interacting directly with the model and then making reference to a sketch.

When the students were asked to justify their placement of a particular feature, the switch in this case, they responded by indicating that this decision was part of an earlier design decision. They were able to find the sketch which was used to make this decision, bring it to the group's attention and they were also able to reference the original product as they were basing their new design on this placement. When asked if a design decision will lead to a modification in tooling (the base section) the students responded by using the model, sketch and referring to an exact dimension to clarify their response.

The design students ensured that by making use of the multiple artifacts, which varied in the level of abstraction and complementing these resources with gestures and language, the shared understanding within the design review was made. When this is compared to the interaction within a virtual setting a different pattern of activity was observed.

As noted within the virtual environment, the designer only had the virtual representation to assist in communicating their design. Unlike a typical detailed 3D CAD representation, which contains significant design detail, the virtual representation used during this review was similar in detail to an early stage physical foam model (see Figure 5 p.53). As this was the only artifact which they had available to them during the review, the designer could not rely on the variety of artifacts to prompt discussion as in a traditional setting and was required to rely on external resources such as metaphors, hand simulations and detailed verbal descriptions to assist them in communicating their concept. Further, they were able to make use of the multiple viewpoints which could be generated by rotating the virtual model.

However, it has been shown in Section 4.0 that the design students were able to develop a shared understanding in both the traditional and virtual setting, therefore the importance of how they compensate for this impoverished communication channel is of significance. The following transcript and visual narrative demonstrates the interaction styles and role of the medium within the virtual setting.

	Group ID V-013 Time 5:00 *(Justifying why the presentation starts with a side view) The reason I have gone quite close to the handle to begin with – if you view it from the side view the lines end up in the same point - it looks like an orbit – it was (my) attempt to see if I could get the form forward.*
	I like the curve but I am not to sure about how the form flips out (simulating form with hands away from the screen). I think you end up with dust in that part – you will get grime on it as you have steam coming out it will cause moist dust and it will stick on that ledge (pointing to the location on the screen) because there is a gap in the material (showing the distance of the perceived gap with hands away from the screen). Things will want to live in there making it less functional. *I do not think there is a sufficient gap*

	What about over here on the button as it steps down (pointing to the location on the virtual model) *Oh Yeah, well it shouldn't, it should be flush (simulating what the form should look like using his hands away from the screen)* Would this still form an undercut? *This is sheer and the base snaps into the bottom (again simulating the form with his hands)* Does your form sit flush on top (pointing to the virtual model) – *No it goes inside – it is like their jug (simulating how the moulds would come together)* So it will sit on top and come in here and then pop out (simulating the intended action)? *Oh OK – No it will sit inside it like this* (further simulating the action) (all then nod as they have reached a shared understanding)

In the above example a query was made about a feature in the form, the lip created at the joining of two parts. A question was raised about this feature and that it may present an issue in terms of usability and maintenance. This was prompted initially by the design conversation centred on the virtual model, but was then augmented through the use of gestures and rich design language which provided an insight into the designers' thought process and assisted in clarifying their decision.

Although the group had an immersive view of the virtual artifact which allowed for an infinite number of views to be generated in real time, they did not make direct reference to this artifact. In a traditional environment they would most likely have additional sketches or cross reference the original product to assist in communicating their decision. As this was not available, they were required to compensate for this lack of detail, by making use of the resources which were available to them, namely gestures and design language to assist in communicating these abstract details.

This is further illustrated in the following transcript.

	Group ID V016 Time 04:00 It still looks too harsh (referring to the overall form of the product) – just follow the form down (simulating the outline of the form while pointing to the virtual model on screen)
	*Yeah Yeah – it is actually – if we spin it this way (rotating the virtual model on screen) it will be half a cylinder (simulating the cross section on the virtual model with the wand device) with a nice flat back*
	*Because they have to rest the back of their thumb (simulating where product would sit in the palm of their hand) and then against the top –then there are their two fingers - they would then hold it in this direction (simulating action of how the product is intended to be held), making a nice flat surface on their hand.* Would their hand be at right angles? *It does not really matter – everybody uses it this way* Then would it make it (the grip of the product) off centre? *No No No – there are buttons on this centre panel (pointing to button placement on the screen) – they hold it this way from the front (simulating how the product is intended to be held and then rotating the virtual model to get to the correct side view of how it would look being held) This is pretty much the position they use it in most of the time (using the and to control the virtual model to show the movement of the product in use)*

	*They are blow drying away like this, they will then sweep under use it like a brush, extend the hair out and brush back in underneath (while simulating the action of the users hand while controlling the virtual model with the wand device)*

In this second example the design students were asked to clarify a manufacturing decision which then led into a usability issue. The students overlayed onto the virtual model a design language ("it will have half a cylinder and a flat back") to assist in communicating their vision of the form. This information could have been included in the virtual model, by modelling these details at the CAD stage, however would have added significant time to this stage of the design process. Therefore, it was easier for them to describe their vision of the form using a common design language among the group.

They then describe the particular action an end user would make to interact with the product. Their understanding of the end user would have been developed through initial observations with the actual product and they have brought this knowledge into the design review through the use of a pantomime to describe how they would envisage an end user interacting with their design. This could have been achieved through a simple sketch showing the placement of the hand and the user in a particular context. However given that this information was not available to them, they could complement the abstract representation of the virtual model with detail in the form of pantomimes and verbal descriptions to assist in clarifying their design decisions.

A point to note with this observation is that the design language and the understanding of the pantomimes used by the design team must be understood by all the participants of the design team. Given the reliance on this abstract nature of the artifact, it is critical that all members of the review team are able to communicate using this abstract design language. Given that the design group is of a similar education level this assumption would seem valid. However, if this same study was taken with a less experienced cohort of design students (for example first year students) who may not have the same level of expertise in the use of abstract design language, a different outcome may be observed. Further, in instances where there may be a client who may be a lay person and does not have the ability to discuss artifacts using an abstract design language, the use of such an environment to undertake early stage design reviews may not be suitable.

Within the virtual review setting, as the designer is unable to directly interact with the model, they are often required to simulate the user action and provide a rich verbal description to describe their design approach and decisions. Often a richer discussion occurred away from the virtual environment, when the designers could remove their stereo glasses and discuss the details using a combination of rich language, simulating action through pantomimes and metaphors to communicate the concept and resolve a particular design detail. It is this overlay of additional information rather than the virtual artifact in isolation, which contributes to the design engagement and shared understanding within the design group.

This is a significant contribution to the knowledge gap identified in Sections 2 and 3. It reveals new insights into the role of the artifact in a traditional setting. However, more importantly, it provides a new understanding related to the qualities of a virtual design artifact to ensure that design engagement within the virtual design review can be maintained.

This finding is further elaborated in the designer's reflection on the experience of using the virtual environment:

…I had quite a few unresolved areas, which I tried to explain what I intended to do to the group. These included the base section and power activation area that would have a foot-button. However this was very difficult to explain with the use of the model on screen, I felt like I needed to draw interactively on screen to get my point across. In the end, I found I didn't really use the model so much as I explained to the group about my future intentions. (V-003)

The technology is such that everyone has the same view of the product and a person pointing at one item he sees, appears to be indicating something completely different or even not in the scene to other participants. This forces you to fall back on verbal communication during the interaction or conventional methods thereafter. The technology has its benefits in the interaction and manipulation of the product by the *individual to create a feeling of ownership (not fiscal, but in terms of interaction) (V-007)*

A further point which needs to be highlighted is the relationship between the level of abstraction of the artifacts and the design context and how the design students modify their interaction to ensure they engage with the design conversation, is significant. Given that the artifacts lack significant detail they have little meaning outside of the design review context. As noted by Winograd and Flores (1986) on their analysis of Heidegger "note that it is meaningless to talk about the existence of objects and their properties in the absence of concernful activity with it potential for breaking down. What really *is*, is not defined by an objective omniscient observer, nor is it defined by an individual … but rather a space of potential for human concern and action" (p.37). The use of low fidelity mock-ups and artifacts are cautioned outside of the design review setting described. It is the design review setting which provides the additional resources which are required to augment the low fidelity artifacts to provide the necessary meaning. As shown in Section 4, the designers are opportunistic in using the resources available to them and altering their use depending on the environment. When considered in isolation or in a different environment the same finding may not be made.

To contrast how the two types of settings and their related artifacts differ, the following summary is provided.

Within the traditional setting, the artifact affords direct interaction by the design group. This interaction includes:

- pointing to the sketch or model;
- gesturing with the model;
- simulating the action of the end user with the model;
- overlaying rich description directly on the artifacts.

Information is overlayed on the artifacts within the design review which assists in developing a shared understanding of the design review. It is through this direct manipulation with the artifacts, which is only possible in a physical environment, that this additional information is shared within the group.

This is in contrast to the virtual setting, whereby the physical affordances of the environment does not allow for direct manipulation with the artifact but only simulated interaction, facilitated by the 'tracked wand' interface. In this environment, the interaction with the virtual artifact prompts the designers to overlay abstract knowledge through gestures, pantomimes and rich design language.

It is the impoverished nature of the virtual environment which demands the designer compensate their interaction with this additional abstract information. Unlike the traditional environment where the information can be overlayed seamlessly onto the artifacts, the virtual setting often required the designers to move between the interaction with the virtual representation and their interaction focusing on their verbal descriptions and actions.

5.2 Prior Knowledge – Creating Physical and Virtual Artifacts

Henderson (1995) notes that the role of the prototype can be seen as both a source of old knowledge and a mechanism enabling the creation of new knowledge" and interaction with the prototype helps to elicit and construct individual observations and knowledge whilst also serving to build communal knowledge through the interplay between individual contributions. Sections 4.0 and 5.1, have identified the differences and significance of the interactions between physical and virtual artifacts within a design review. This sub section furthers these findings and follows Henderson's argument that in addition to the significance of the interaction with the prototypes, considering the prototype as a source of old and new knowledge is also of importance.

As described in Section 3, this study has focused on the observation of student designers within a design review session. This focus of the design review was part of a larger project which required the students to undertake an analysis of an existing product and propose a new design concept based on the constraints provided by the original design. As part of the design project, students were required to generate design concepts which were presented as sketches, models and / or computer representations. These representations were brought to the weekly design studio session where they were discussed and developed. The video data collected as part of this thesis was for a fixed aspect of this project – a scheduled design review, a critical aspect of the design process where the design concept is frozen and the project moves from a design exploration stage to one of design development.

The information not explicitly presented to the reader is the student's progressive understanding of the design problem over an eleven week period. Although this has not been captured in the video transcripts, it is implicit in the discussions which have occurred during the design reviews. Captured within the transcripts that are presented throughout this thesis is evidence of the students continually referencing their prior knowledge in the exploration phase of the project. Examples of this for both settings include:

- Making reference to the findings of the usability studies undertaken during the initial phase of the project. "People were happy with the placement of this button" or "They definitely said they did not want buttons on this side";

- Indicating that a design detail is similar or identical to that of the original product. "The switch is pretty much like the original" or "That's how the existing product works".

However, what has not been made explicit is the role of the artifact creation process and how the properties of the artifact and its environment allow for this evolution to be represented within a design review. Knowledge gained through creation of artifacts is an essential element of the design process. As Erickson (1995) notes, artefacts are a "medium through which the design team can interact, collectively advancing the design" (p.56). Buur and Andreasen (1989) further this comment by noting that product development is a modelling activity where the designer's work progresses between models with different purposes throughout the development process spectrum. They describe modelling as an important tool for the designer to describe, visualise and sculpture thoughts both at a time when the designer is alone or when in the process of designing or communicating with others. So how do the different environments allow for this knowledge to be included within the design review?

Within the traditional setting, representing the knowledge gained during the artifact creating process is evident through the inclusion of chronological sketches and 3D form studies physically brought to the design review (Figure 15).

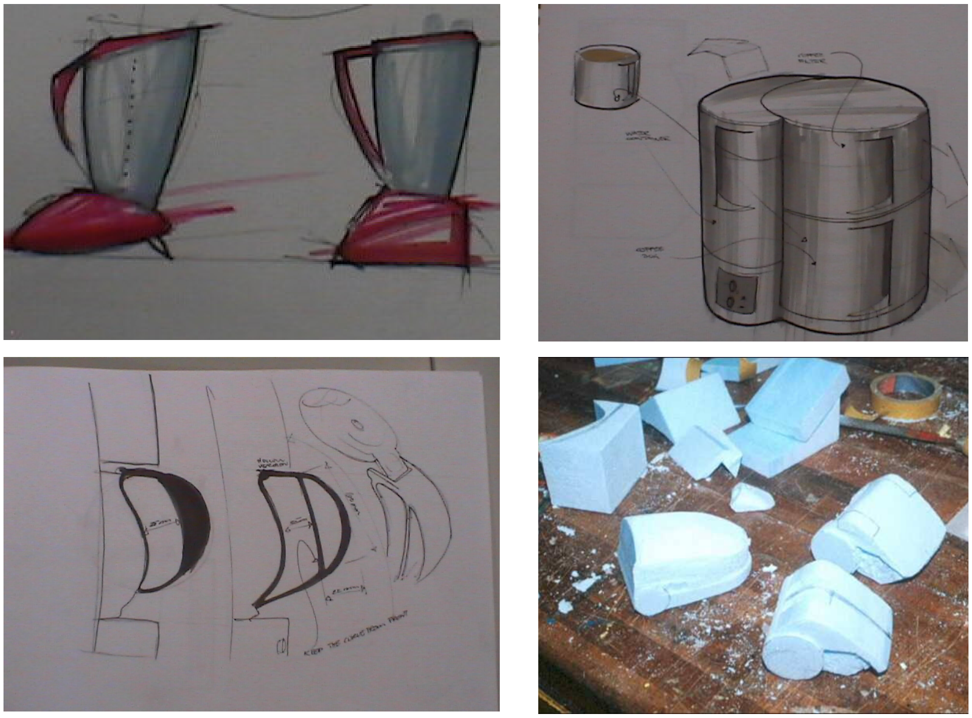


Figure 15 – Examples of Artifacts used within the Single Review Sessions

During the design reviews the design students were often seen to be searching for a specific sketch or model to assist in communicating their design concept. Where it may be practical to only keep a limited number of 3D model variations (due to space constraints), often the students captured each version by photographing the model and including it within their sketchbooks. Although there was no technology available within the traditional review session, the use of CAD information was also brought to the design review session with the students capturing the screen information and including it as a 2D image (Figure 16). Students would document the history of the CAD development and reference during their design reviews. The student's reference to specific sketches is evidence that they make explicit reference to this prior knowledge during the design reviews.

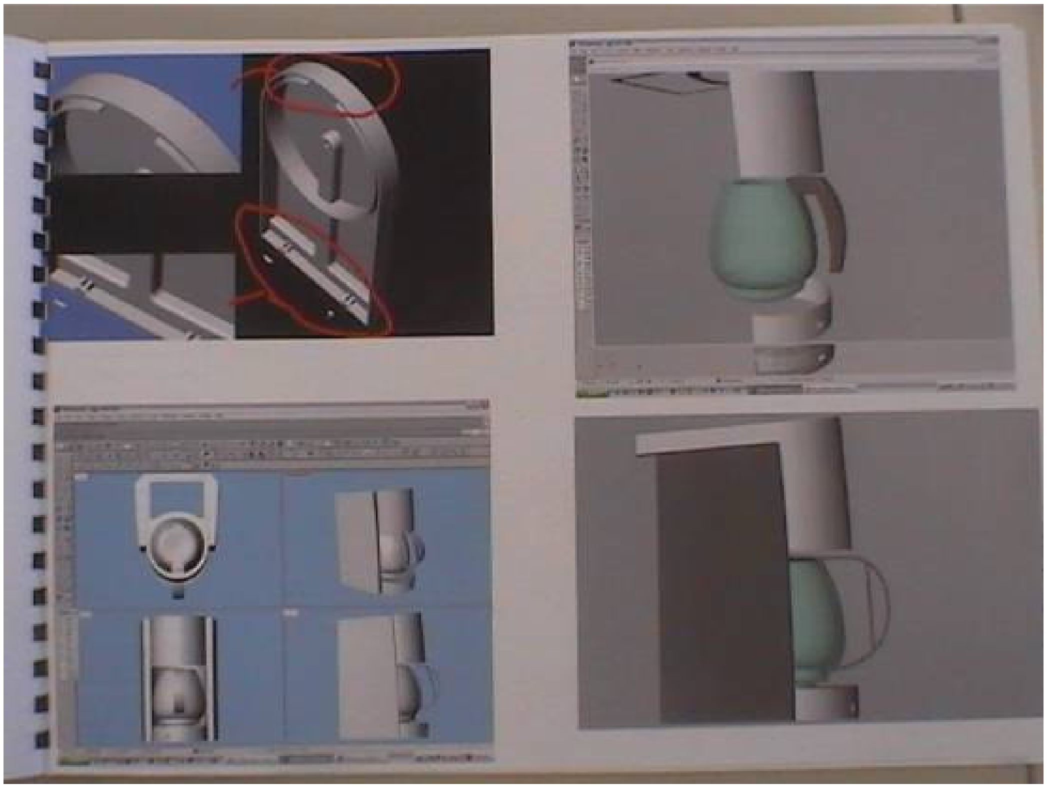


Figure 16 – Capturing 3D CAD as Images

As mentioned previously, within the virtual design setting the only artifact available during the review were the Virtual 3D Sketch models and the students' interactions surrounding this during the design discussion. Although the students were not able to reference specific sketches, they did cross reference their design rationale made during their development process, including earlier concepts, usability analysis and manufacturing analysis. However, what was of interest was the lack of reference to the creation of the actual virtual model.

As noted earlier, the virtual model was an additional requirement for the students who elected to participate in the study. The creation of the Virtual 3D Sketch model was to be based on information they had available and was not expected to take a significant amount of their time. Only the external information was required to be modelled which could communicate their design intent for manufacturing, form and usability directions. As with the traditional design setting, comments from the students in terms of them referencing the initial analysis phase of the design process and their continual reference to the original product was evident. Specific reference to actual sketches, for example "I wish I had that sketch available to explain what I mean" was less common. However, what was clear was the lack of the student's reference to the development of the 3D virtual model creation process. Although this was a minor process when compared to the overall project, no reference was made in any of the studies observed. The following student reflection furthers supports this observation.

Overall the virtual environment is relatively quick to prepare and is a great way of presenting a design concept onscreen. However, more traditional methods such as physical 3D models have always been an excellent communication tool because it is something that communicates straight away design issues that may not be so obvious onscreen, such as the size of the product. I think a combination of physical 3D models together with computer-generated images such as those created in VR is ideal for presenting a design concept. This is because both elements offer something unique which the other doesn't. So a combination of both traditional and new design tools such as a virtual environment would be ideal for a design presentation. (V-017)

In the past, the usefulness of VR has at best been questionable, due to the limitations of equipment and poor usability. This was in fact my view of VR coming into this course as having limited (if any) advantage over a physical form study (model). And I believed that it is less likely that an Industrial Designer would actually venture into 3D cad work early in the conceptualisation stage due to large amount of time that is required to create a digital model. Having said that, my views have somewhat altered over the period of this course. I now can see that exploring concepts digitally, even with crude simple forms, is becoming more popular – and can save time later down the track, as the model can evolve digitally as the design changes. However, the risk with delving into digital models so early in the 'process' is that it can limit the scope of a designer, pushing them towards using a design for the plain face that he has spent so much time on it, whereas there may be far better alternatives that could have been achieved with loose and broad conceptualisation with traditional means. (V-003)

The immersadesk has been an effective tool for communication and design awareness, which is also carried into sketches and models which are also effective tools within a design critique. Immersive environments can allow the designer and his or her colleagues to explore and manipulate the position of the product instantly. Sketches can be a little restrictive if the form has not been communicated correctly.

You are limited to the images that are shown, where your product on the immersadesk can be rotated and zoomed in/out immediately. Immersive environments may be challenged by the tangible advantage of foam or prototype model making, but in conjunction with these applications it can be a helpful tool. (V-006)

The significance of this finding is that it has been identified within the literature that the creation of the artifacts is an important aspect of the design process. Within this study the knowledge gained from this creation process is included within design review sessions through either the inclusion of the actual historical sketches created throughout the process, or through the referencing of knowledge made during the design process. The student's lack of reference to the creation of the Virtual 3D Sketch Model indicates that they did not see the value of this activity as a separate activity. It would appear that the students considered the process of creating the virtual model as copying – transferring the knowledge of their design artifact into a virtual representation.

As there are no findings to directly support this claim, this finding in isolation is cautioned. However, what can be extrapolated is that the students transferred their knowledge gained from the creation process of the physical artifacts into the virtual setting. It is the complimentary nature of the digital representation together with the analogue analysis within the design review which has contributed to the design engagement rather than one approach being superior to the other.

5.3 Section Summary

This section has presented the second of the three findings from this thesis. The finding has identified how designers ensure knowledge is brought to the design review when the artifacts they are working with are only abstract in nature.

Within the traditional design setting, the designers make use of gestures and rich design language dynamically with the many artifacts available with the design review to ensure that a shared understanding is obtained within the design review. This is in contrast to the virtual setting, which requires the designer to compensate for the impoverished setting with detailed pantomimes and language.

The difference between the two environments is that with the traditional setting the use of gestures and language used within the review are overlaid directly on the artifacts, however, within the virtual setting, the pantomime and language often occurs away from the virtual artifact which is used as a prompt to solicit this additional information. In both settings a shared understanding of the language used, both verbal and sensorial, is essential. Given that the design study focuses on design students of a similar year level, this assumption is valid.

A further finding within this section relates to the prior knowledge which was brought to the design review. This was expressed as a direct reference to the historical sketches and design representations within the traditional setting. Whereas within the virtual setting, it was observed that the students transferred their knowledge of the creation of the physical artifacts to the virtual setting. The designers did not reference the prior knowledge gained through the creation of the virtual artifact. Therefore the significance of this finding is the complimentary nature of both digital representation and traditional artifact creation process which support design engagement within a virtual design setting.

Abowd, Mynatt and Rodden (2002) note that the vision of ubiquitous computing assumes that "physical interactions between humans and computers will be less like the current keyboard, mouse and display paradigm and more like the way humans interact with the physical world. We speak, gesture and write to communicate with other humans and alter physical artifacts. The drive for the correct ubicomp experience has resulted in a variety of important changes to the input, output and interactions that define the human experience within computing" (p.48). In the following section, the usability of input, output and interactions between humans and computers specific to this study is presented. These observations are contextualised on how they impact on enhancing design engagement within a design review.

6.0 OVERHEAD OF THE VIRTUAL ENVIRONMENT

We humans are biological animals. We have evolved over million of years to function well in the environment, to survive. We are analogue devices following biological modes of operation. We are compliant, flexible, tolerant. Yet we have constructed a world of machines that requires us to be rigid, fixed, intolerant. We have devised a technology that requires considerable care and attention, that demands to be treated on its own terms, not ours. We live in a technology-centred world where the technology is not appropriate for people. No wonder we have such difficulties (Norman 1998).

This section presents the final finding from the research undertaken. The relationship between the usability of the technology infrastructure and its impact on the design engagement is presented. Although undertaking a usability evaluation of the Virtual Reality hardware was not a primary aim of the study (and indeed the thesis does not claim to have undertaken a formal usability evaluation of the hardware), it became evident throughout the analysis phase of the project that usability factors of the technology impacted on design engagement. Rather than present the identified usability issues of the Fakespace Immersadesk, these findings have been generalised to demonstrate the importance of appropriate interaction paradigms to support design engagement.

As noted in Section 3, the environment used as part of the study was a commercial system designed specifically as a tool primarily for small group discussions such as design reviews. The system included a 6DOF-tracked wand to allow for interaction of the model by using a “skewering” metaphor (VRSCAPE). Head tracking was also included. All other participants were required to wear LCD shutter glasses to be able to view the active stereo projection. Although such a system is considered state of the art, usability issues were observed in all groups studied. Further, student reflections on their experience within the virtual environment referred heavily to the usability difficulties that they had encountered.

Typical issues identified related to: the weight of the stereo glasses, which became uncomfortable after short periods of use; the skewer metaphor to rotate the object which required unnecessary hand and arm rotations to generate the desired view; and the need for team members to stand behind the person wearing tracked glasses in order to obtain the ‘one’ correct view generated due to the head tracking.

These issues have been categorised into three themes which relate to the usability overhead (or additional impediment) of interaction within a virtual environment and its impact on design engagement within a design review. The themes include: Limiting Natural Interaction, Passive Participants and Communication Breakdowns. These themes are explored in the following sub-sections and are supported through study images and student reflections.

6.1 Limiting Natural Interaction and Passive Participants

As noted in Section 5.1, the design students interacted with multiple artifacts within the traditional setting. They were able to move from artifacts which varied in their level of abstraction and overlay a rich design language and gestures to ensure that a shared design understanding was achieved throughout the design review. Further, the designers were able to interact naturally with the artifacts, easily passing them to each other and interacting with them. This consisted of the students either pointing to details which may be represented on a sketch or simulate their actual use when required within the design discussion. These interactions are further demonstrated in the visual narrative of a traditional design review below.

Figure 17 – Design Interactions with Artifacts (T0319)

As shown in the above example which represents a snapshot from a traditional design review, the students interact directly with the form models and original product. They make use of sketches to provide additional detail, often overlaying the sketches directly on top of the form model to communicate the additional detail. The students will pick up the form model or original product and interact with it to demonstrate how it would be used by an end user. Often the students would work together with the one artifact as part of the discussion. Finally the students would disassemble the actual product to assist in providing additional detail when required. The critical point is that the students would seamlessly move from one artifact to the next within the design review and that the interaction with the artifacts requires no additional learning or cognitive overhead.

This is in direct contrast to the interaction with the virtual artifacts where the direct interaction is mediated between the user and the technology through the ‘wand’ interface. This interface has been shown to enhance the keyboard and mouse paradigm for interacting with digital information, by allowing for the user to ‘pull’, ‘push’ and rotate the digital representation using their arm and hand muscles. The stereo interaction provides a sense of immersion for the viewer to allow them to ‘walk’ around the object. However, as shown in the following example, the interface isolates the ‘presenter from the rest of the group and a strategy was required by the students to adapt their interaction style to ensure a shared understanding of the design review was developed.

Figure 18 – Interaction within a Virtual Setting (V-016)

In the above example the main presenter (white shirt) both actively and passively ‘controls’ the design review session. He actively determines the view of what is being seen by rotating the virtual artifact with the wand interface. He also passively controls the perspective being generated by the direction he is viewing the screen (as noted in Section 3, the glassed were also tracked which resulted in the perspective being generated from the viewers head position – if the viewer looked left the view would be rotated to match their head rotation). If a member of the review group wanted to participate directly with the artifact they were required to be handed the wand interface. This presented a problem as the view being generated was only correct for the person wearing the ‘tracked’ glasses. A solution would be to share the tracked glasses, however, in the studies observed no groups had shared the glasses between the members of the design group. Rather than share the tracked glasses, an alternative strategy for the members of the group was to point directly to the virtual artifact. However as their view was slightly distorted from the viewers perspective, the group member was required to continually check that what they were pointing at was understood by all.

In the example below, the concept of achieving a shared view within this environment is further explored. In this example, the participants of the review are seen to physically move their body positions to ensure that the shared view is achieved. It was commonly observed that the group members would relocate their physical position during the review to stand directly behind the designer holding the wand interface to ensure that their perspective was correct.

Figure 19 - Achieving a Shared View in the Virtual Setting (V-016)

This point is highlighted again in the following student reflection … *another distracting feature to get used to was the way everybody had a different view of the product. When one points to a feature on the design, the other people see you pointing at either nothing or something completely different.* (V-007)

… I found describing and presenting my particular model quite a difficult task. I felt that there is a lot of potential for VR in helping in concept development, however due to issues with the interface and group interaction through the process I found myself quite frustrated with attempting to get my point across with the use of the VR model … when the VR user had to turn around and talk to the group or tried to refer to a section of the model (which would often take a lot of time to navigate to) we found problems (V-003)

A strategy from some of the groups to address this issue was to physically remove their glasses and view the screen without them. The advantage of the immersive 3D stereo display was outweighed by the limitations of the glasses and they were therefore removed. The impact on the discussion was that a blurred view was being presented to those not wearing the glasses. If the person with the tracked glasses removed them they were required to hold the glasses in a position which generated an appropriate view, thereby allowing them to make eye contact with the group. This is clearly demonstrated in the image below. The student has taken off their tracked glasses and holds them in a static position which would simulate the position of their head as if they were wearing the glasses.

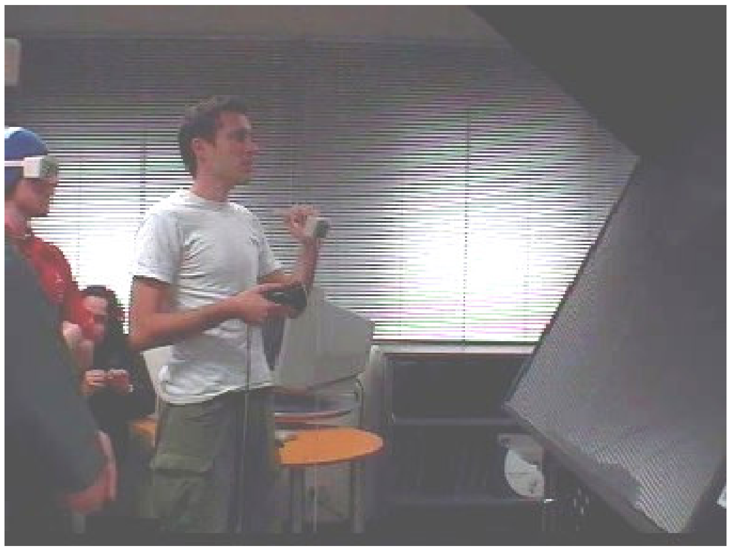


Figure 20 –Manipulating the stereo glasses to achieve the correct view (V-009)

It has been identified in Section 2 that design is a social activity. To enhance the social nature of the setting, providing social cues such as eye contact and peripheral vision is essential. However, given the physical design of the stereo glasses, the cues have been removed to enable the delivery of the stereoscopic image to the user. However, as demonstrated in the above examples, the students would compensate for this by the removal of the glasses during their design review to allow them to engage with all members of the group.

The effort required to rotate the virtual object was also significant in limiting the interaction of the design group. The relationship between the rotation angle required by the user and the impact this had on the virtual object's rotation on the screen was also highlighted as a concern across the design groups studied. In the following images, the design student is shown to be having difficulty rotating their virtual object. In this example the student is attempting to rotate the virtual object 180 degrees based on a question asked about a detail on the reverse side of their concept. In order for the student to show the detail she is required to make four to five large arms rotations with the wand device over a 60 second period. During this period, limited or no discussion is made by the group. When compared to the rotating the physical artifact, the same action could be achieved in a few seconds with just one action and no disruption to the design discussion.

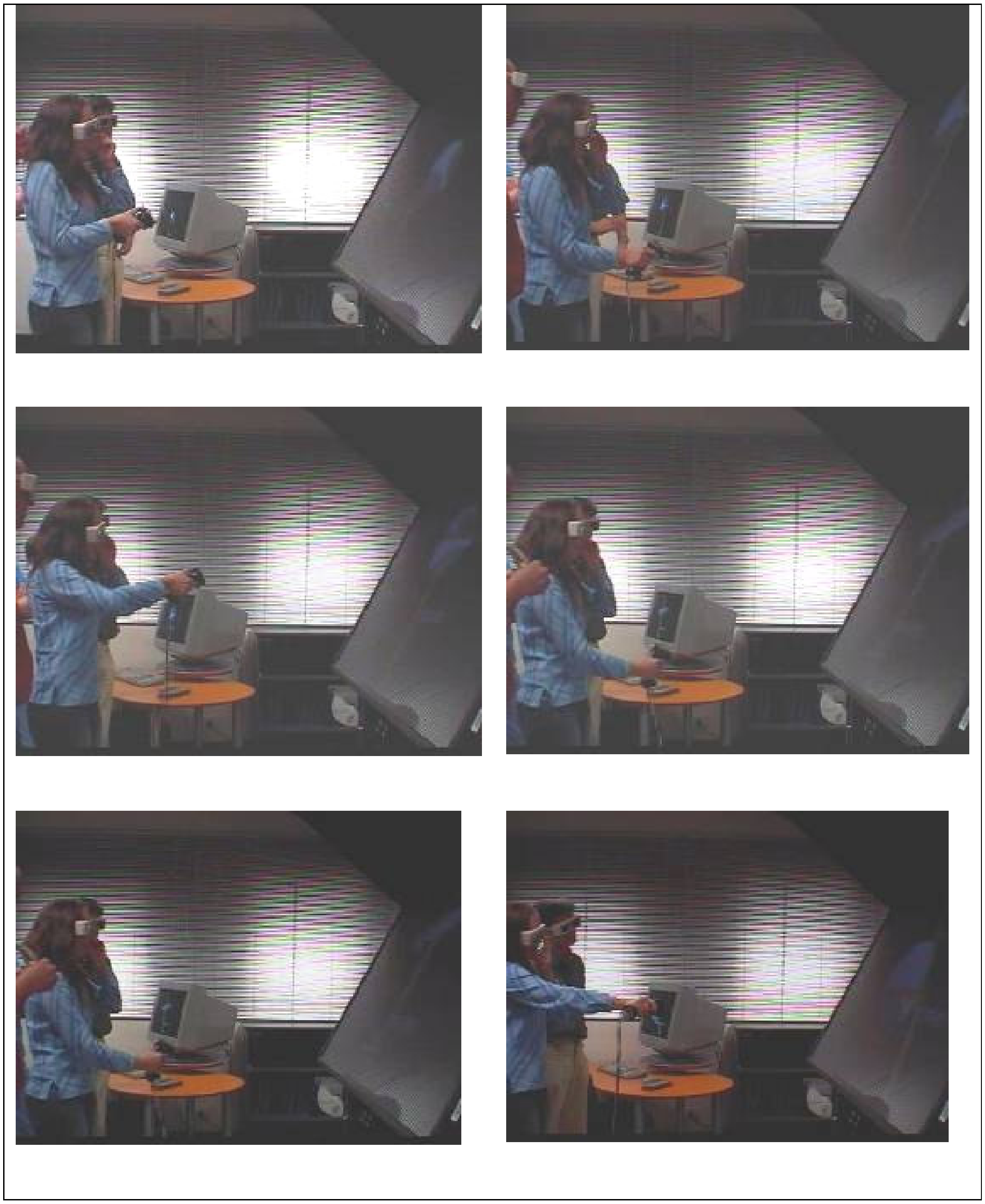


Figure 21 – Rotation of a Virtual Object (V-006)

Norman states that you should “design the tool to fit the task so well that the tool becomes a part of the task, feeling like a natural extension of the work, a natural extension of the person” (1998, p.52). As demonstrated in the traditional setting, the tool in this case was physical objects through which the language of the form and standard design representations (orthographic projection, perspectives renderings and shading to highlight 3D forms) provided the affordance and semantics allowing the participants to naturally interact with them. Within this setting the artifacts (tools) demonstrate the qualities of Norman’s statement. They became part of the task and there was little or no breakdown in communication with the wider group. This was in direct contrast to the virtual setting where the tool in this case was the interface (the ‘wand’ and ‘tracked’ glasses). As demonstrated, they did not have the qualities of providing a natural extension of the task. They did, however, create a significant barrier to the communication aspect of the design review.

Through the examples presented above, it was highlighted that the interface required additional cognitive demand from the presenter in order to generate the desired view. They had no easy direct control of the representation being generated, thereby limiting their natural interaction within the review as compared to the traditional design environment. In addition to this, the interface provided an artificial separation between the ‘presenter’ and the group. As the interaction was mediated by the interface, the remainder of the design group became passive participants within the review. To directly interact with the virtual artifact, the interface was required to be shared or they were required to point to the artifact, however, had to ‘check’ that what they were pointing to was actually correct. When the students were directly interacting with the models and were required to rotate the object, the rest of the design group remained passive as they were unable to ask questions due to the difficulty in navigating the interface.

Although it was identified in Section 4 that a shared understanding could be achieved in the virtual design review setting, the limitations of the interface reinforced the need for the students to compensate for such short comings. As described in Section 5.1, the use of additional language and gestures away from the artifact ensure that a shared understanding was achieved throughout the review.

6.2 Communication Breakdowns

Following on from the previous section, the interface has been demonstrated to distract the designers in their goal of undertaking a design review. In addition to the issues identified above which consists of shared views, mediation and unnatural interaction, fundamental usability issues were observed which contributed to the breakdown in communication during the design reviews. These are highlighted briefly in the section below.

During the design reviews and from the student reflections, the students commented on the weight of the glasses and the position of the cabling as issues which impacted on their ability to focus on their design review. In the examples below students are seen to either drop their glasses during a design review or take off their glasses completely to allow the design conversation to flow.

Figure 22 – Conscious and Accidental Removal of Glasses

In Figure 22 the student in the left image was responding to a question from the group and in his response he removed his glasses completely to ensure he could make eye contact with the other group members. This resulted in the image on the screen being altered and not having any relevance to his response. Following his response he then correctly replaces the glasses.

With the image on the right, during the course of the design review, the student had accidentally dropped their glasses. This was a common problem due to their weight and limited adjustment capability. When the glasses were accidentally removed, this caused a communication breakdown in the design review while the student readjusted their glasses and the view. There was no comparison in usability overhead in the traditional design review setting.

The design of the glasses and wand were constantly identified by the students as a major cause of concern during the design review. The following student comments reflect these concerns.

… I believe physical models are a better aid for a design critique, it is something tactile and is excellent for looking at the form, scale, proportions, usability, semantics and ergonomics. I also personally feel a lot more comfortable talking about a design with a model. This is because I do not need to concentrate about holding glasses on, on trying to navigate my product with a user unfriendly hand control. With a foam model I can concentrate on what is important, communicating the design. (V-002)

… I was also limited due to the undesirable usability problems of the ImmersaDesk, such as the glasses cord problems and the hand device problems with navigation and object manipulation. I personally find it quite hard to use the hand device and easily move objects around as I desire to explain details of the design. (V-002)

6.3 Section Summary

This section has presented the final finding from the thesis which focuses on the usability of the technology. Although it was not the intention of this study to undertake a usability evaluation, which it did not claim to do, the observations and student reflections highlighted specific usability concerns and their impact on the overall design engagement within the design review.

Issues relating to the weight, size and ergonomics of the interface associated with the Immersadesk Fakespace were constantly highlighted by the students undertaking the design reviews. Although specific design solutions could be considered which address these issues, they are outside the scope of this thesis. However, the issues identified have been generalised to identify the potential impact of usability overheads within a virtual environment and in the context of encouraging appropriate design engagement.

Interfaces which limit natural interaction impact on the ability of the designers to present and respond to questions while interacting with a virtual model. This results in a delay between the interaction and discussion. This resulted in students taking a passive role in the design review during these periods of inactivity. Further, as it was difficult for more than one designer to directly interact with the virtual artifact, the concept of having one presenter within the group was reinforced. To overcome this the students developed a strategy of pointing to the screen, but this required them to constantly check if their interaction was understood by all members of the group. These issues related to breakdown in communications within the virtual setting which was not evident when compared to the traditional environment. Although these breakdowns were overcome (as demonstrated in Sections 4 and 5), the potential for a usability overhead to impact on developing a shared understanding within a design review has been highlighted.

These observations present an opportunity for new technology developments of future systems. As Weiser (Weiser 1991) notes, “machines that fit the human environment instead of forcing humans to enter theirs, will make using a computer as refreshing as a walk in the woods” (p.75). Although Weiser’s vision of ubiquitous computing has not been realised by the technology used within this study, such findings provide a foundation to consider the redesign of such technology.

This concludes the three findings drawn from this research. These findings are summarised in the following section where they are presented as a comparative analysis to summarising the significance and contribution of this research.

7.0 CONCLUSION

The final chapter of this thesis concludes the research by drawing together the findings made and outlines its contribution to the growing body of design research and the practice of design. I have presented how I have addressed the aims of this research through a rigorous approach to capturing and analysing in-situ early stage design activity to gain a detailed understanding of the nature of interaction between designers and their artifacts within the early stages of the industrial design process. The contribution of this research is then presented as a framework to understand the role of artifacts in supporting the designer to reflect and make new discoveries during this phase of activity. The thesis then concludes by stating the significance and the implications of the outcomes from this work.

7.1 Reflecting on the Aims of the Thesis

This thesis had as its aim to develop a better understanding of the industrial design process and the tools required to support it, specifically at the early or conceptual stages of design activity. I was drawn to this question as I wanted to gain a better understanding of design activity and the role artifacts and their impact on it. Of specific interest was the role of new technology based artifacts to support the design process.

As a design academic and industrial design practitioner of 20 years, I was witnessing the rapid introduction of digital technology within the design profession and education curriculum. The introduction of emerging technology based tools seemed a natural evolution of the industrial design profession. However, I was unable to find within the literature sufficient evidence to demonstrate that the impact of the introduction of digital technology such as Virtual Reality was fully understood. Further, I was concerned that this technology was being introduced to replace exiting tools, which was being driven from an economic rather than theoretical perspective. Although I had embraced this new technology in my own practice, I believed that there was a significant gap in the knowledge related to the role of digital artifacts within industrial design practice which I aimed to contribute to. Therefore, I embarked on the research journey presented within this thesis to fill the knowledge gaps I had identified.

To understand the role of artifacts within this phase of activity, I required a better understanding of this phase of design activity. My starting point was that design is reflective in nature and that design is not solely a cognitive activity but relies on the environment and the interaction between designers and their artifacts to make new discoveries. Although the grounding theories of Schön (1983), Polanyi (1998), Ehn (1988), Hutchins (1995), Nardi (1996) and Suchman (1987) have expanded our understanding of designers and the nature of interaction between people and their artifacts and their environment, they do not provide a unique or authentic account of the activity within the early phases of industrial design. As noted by Winograd and Flores (1986), to conceptualise new interaction approaches, a grounding of the understanding of everyday interactions in the world is initially required. I have built upon these grounding theories from the fields of Design Research and Human Computer Interaction by substantiating an authentic account of the conceptual stage of the industrial design process.

Using a combination of video analysis methods and interviews I was able to observe student designers undertaking design reviews using both traditional and emerging technology based artifacts. To ensure that the activity was authentic, the design reviews were not fabricated and followed an ongoing design process. Further, to ensure that the activity was captured in the greatest level of detail, student designers formed the basis of the case study. The students allowed a time paused study of the moment to moment activity occurring within the design review process. The grounding of the field data in actual practice provided many challenges, however, in doing this I have made a significant contribution to the growing body of design research as such an account of everyday design activity is still lacking in design research.

It is through this knowledge of the authentic experience of design activity where my understanding of the role of artifacts has been grounded. This contribution to the field is presented in the following section as a comparative framework to enable both practitioners and researchers to consider the impact of artifacts to support design activity.

7.2 Statement of Contribution

As reported within the review of the literature, the role of the artifact is central to supporting design activity. However, as demonstrated through this research the attributes of the artifact, whether it is has the properties of traditional artifacts (sketches, physical models), or has the properties of a 3D Sketch Virtual Model, impacts on both the activity and nature of the interaction within the early phases of industrial design activity.

It is this understanding of the role of the artifact where this thesis makes its contribution. It presents how different types of artifacts impact on: the ability to reflect in action and make new discoveries; the need for additional resources to augment the artifacts; the ability to create a shared understanding; the use of temporal knowledge; and the interaction style within the early stages of industrial design activity. These contributions are discussed in greater detail below.

Reflection and Discovery – Designers do reflect in action. In both the physical and virtual setting, the designers followed Schön's (1983) interactive process of framing the design problem, making new discoveries which were mediated by the materials within the design review and then reframed the problem within the context of the new discoveries made. They follow this process as they try to resolve issues associated with manufacturing, aesthetics and usability concerns generated within the context of their design projects.

Within the traditional environment, artifacts are created to directly frame problems as part of the design review process. Multiple artifacts are created to frame particular problems but can also be seamlessly re-used within other contexts of problem setting activities. In the virtual environment, the one artifact must capture many problem setting concepts. Therefore, to use the artifact to reflect on the spectrum of issues often identified, they make use of the multiple views afforded by the technology and the ability to overlay abstract properties onto the virtual representation. Although the designers demonstrate a plan to frame their discussion in both settings, this plan is constantly altered through this different level of interaction with the artifact.

In both settings the artifacts are used to capture their existing knowledge which is brought to the design review. However, by directly interacting with the artifact in the traditional setting and by using the artifact as a prompt in the virtual setting, the designers are able to bridge what Polanyi refers to as the "logical gap" between their existing knowledge which is embedded in these artifacts and their new discoveries from the design review sessions. This activity and nature of the interaction is situated within the context of the review.

Augmenting Artifacts – Schön's (1983) description of the Reflection in Action Paradigm refers to the sketch as talking back to the designer. He notes that the physical prototype is a more active and evocative participant when compared to the sketch. Within the early stages of industrial design activity, and in both types of environments, there was no hierarchy of artifacts observed. Designers seamlessly augment their artifacts with multiple resources to support their design review. Within the traditional setting, the designers made use of additional resources such as gestures, rich language and pantomimes to support their review. Whereas in the virtual setting, these additional resources are essential as they are required to compensate for the lack of richness in the 3D Virtual Sketch models.

These additional resources are abstract in nature, but have meaning to all members of the design review group. It is critical that all members of the review have a shared understanding of this abstract language which is used to support the role of the artifact. If this does not exist the artifact is unable to compensate for this lack of knowledge which would impact negatively on the design review process. This is exacerbated in the virtual setting as the use of additional resources to augment the virtual artifact is significant.

Temporal (Prior) Knowledge – The designers relied heavily on their prior knowledge to generate new knowledge during their design review. Ehn (1988) notes that design artifacts bring our early experiences to mind and they act as a representation of the reality. These early experiences are often captured as part of the artifact creation process in the making and the creation phase of the artifact.

Within the traditional setting, designers make reference to this creation phase and use it to support the artifact within the design review. 3D Sketch Virtual Models require a different skill to create from traditional artifacts and are detached from the design exploration phase. Designers in the virtual setting do not refer to the knowledge gained during the creation of the virtual artifact, however, they do cross reference the creation of the physical artifacts during the virtual design review. Although virtual artifacts can be abstract in representation and allow for quick visualisation and various concepts which may frame a series of problems, the creation of the actual model does not support the design activity.

Interaction – Designers make use of their environment as part of the design review process and it is the interaction with their artifacts and their environment which allows for the designers to create new discoveries. Any unnecessary overhead to the interaction between the designer and the artifact or their environment will impact on the design review process.

The traditional environment provided a natural extension to the designer's ability which allowed them to freely interact with the artifacts without causing any breakdown in communication. Designers seamlessly move between the multiple artifacts which are present within the design review. Each participant is able to generate their own desired view through the sharing and the physical manipulation of the artifacts. Designers work together with the artifacts to enable their combined shared understanding of the design. This is in contrast to the virtual setting where the interaction is mediated through a single person. There is a significant usability overhead which the designers need to manage to maintain the same level of interaction. This requires the designers to physically move away from the artifact and rely on other resources during the design review.

The contribution of this research has been summarised in the following table which provides a comparative framework on the role of artifacts and their impact on the nature of design discovery within both traditional and virtual settings.

Theme	**Interaction with Physical Artifacts during a Design Review**	**Interactions with Virtual Artifacts during a Design Review**
Reflection and Discovery	Reflection in Action Artifact as Focus	Reflection in Action Artifact as Prompt
Augmenting Artifacts	Direct Manipulation with Multiple Distributed Artifacts	Compensation through language and gestures
Temporal (Prior) Knowledge	Embedded in Artifact creation process	Transfer from Physical creation process
Interaction	Natural Negotiation of Resources	Overhead Mediated and then conversations

It is hoped that this comparative framework will be used by both practitioners and educators to consider the impact of the artifact on the design activity and to plan strategies on how to best get value from the different approaches for effective design reviews.

7.2 Statement of Significance

Industrial design is a discipline which focuses on the creation of new knowledge. It is part of a range of disciplines which fits within the Creative Industries which have been shown to contribute significantly to the global economy, through the enhancement of product and services. As noted in the UK's Cox report on Creativity in Business, "technology that is not carried through into improved systems or successful products is opportunity wasted; enterprise that fails to be sufficiently creative is simply pouring more energy into prolonging yesterday's ideas. Creativity, properly employed, carefully evaluated, skilfully managed and soundly implemented, is a key to future business success – and to national prosperity" (Cox 2005, p3). Industrial design is a key part of this activity as it allows for the construction of new knowledge and discoveries through a process which extends our current understanding of a situation or context.

What has been identified within this research is that this process of reflective discovery relies heavily on the interaction with artifacts to represent existing and new knowledge, which offer designers a competitive advantage. The grounding theories used within the research have shown that the role of the artifact is central to the nature of discovery, however where this research extends this work is that the broader direct and indirect human interaction with the artifact is also critical in this process.

This is significant when considering new technology based artifacts to support design activity. As new technology based artifacts enter the design process the designer must ensure that the ability to make new discoveries must not be diluted. The adoption of technology based artifacts within all phases of the industrial design will be essential if the profession is to maintain its links with all other disciplines involved with the design and development of new products and services. However what has been shown through this study is that the adoption of technology artifacts in isolation during the early phase of design activity is cautioned and needs to be considered within the context of the level of expertise of the review participants and the nature of the environment where the review is occurring. If these limitations are understood and addressed, the use of virtual artifacts can effectively support early stage design activity. The significance of the findings and the opportunity it presents are outlined below.

Firstly, from a pedagogical perspective, the reliance on a designer's expertise to assist in the communication of the designer's concept within the virtual setting indicates that such a tool may only be beneficial to later year or experienced designers who are capable of working with abstract concepts and without the need for artifacts to communicate this abstraction. It would be expected that if this study was repeated with early year design students, the level of conversation observed within the virtual setting would have been reduced, as these student would not have the necessary experience to work with such abstract concepts. This is also applicable to design practice. Using technology based artifacts with industry clients who may not have the expertise to make the conceptual leap between the virtual artifact and the required abstract language may have a negative impact on the objective of the design review.

Secondly, within this study the design students were able to utilize their knowledge gained during the physical experimentation with the form studies which occurred outside of the design review. In both the traditional and virtual settings, this knowledge was referred to during the design review. However, had students only been able to use virtual tools in order to develop their designs, they would have had to draw on physical knowledge from prior projects and not from any direct prototyping experience on this specific design problem. It is unclear how provocative the virtual prototype would have been in this case in raising design, usability and manufacturing issues. Therefore, the benefit of virtual only tools within an education environment for design development draws into sharp focus the question of where students obtain the necessary physical knowledge in order to design.

Finally, the potential to influence the design of new interactive systems based on the findings of this study is significant. The findings identify that a combination of physical and virtual artifacts within the one environment may be advantageous. This is in line with the emergence of ubiquitous computing and tangible interaction solutions. The findings from this study complement the work from the Atelier project (Ehn 2004) in which they have demonstrated the design of a mixed reality system to undertake design reviews. The following study comment is a fitting summary on this aspect of the significance of the research.

… o*verall the virtual environment is relatively quick to prepare and is a great way of presenting a design concept onscreen. However, more traditional methods such as physical 3D models have always been an excellent communication tool because it is something that communicates straight away design issues that may not be so obvious onscreen, such as the size of the product. I think a combination of physical 3D models together with computer-generated images such as those created in VR is ideal for presenting a design concept. This is because both elements offer something unique which the other doesn't. So a combination of both traditional and new design tools such as a virtual environment would be ideal for a design presentation* (V-017).

By using the findings from this study which report on authentic in situ activity of the nature of the interaction between designers and their artifacts, it is hoped that new and innovative technology based artifacts and systems can be developed to positively support the design community.

In conclusion, through my study I personally feel more confident to proceed with the inclusion of digital technologies for both industrial design practice and within the design education curriculum. Industrial Design is a rapidly evolving discipline and will see the introduction of many new approaches and technologies which will claim to provide a competitive advantage over existing methods. It is hoped that this research will assist design educators and practitioners evaluate the adoption of new approaches by assisting them to reveal the nature of their own practice. I look forward to seeing the debate surrounding the introduction of new design artifacts and hope I have inspired others to continue to investigate the emerging themes from this thesis.

REFERENCES

Abowd, G. D., E. D. Mynatt, et al. (2002). "The human experience [of ubiquitous computing]." Pervasive Computing, IEEE **1**(1): 48-57.

Alexander, C. (1964). Notes on the Synthesis of Form. Cambridge MA, Harvard University Press.

Alexander, C. (1977). A Pattern Language: Towns, Building, Construction, Oxford University Press.

Ball, L. (2000). "Applying Ethnography in the Analysis and Support of Expertise in Design Engineering." Design Studies **21**: 403-421.

Barfield, W. and T. A. Furness (1995). Virtual environments and advanced interface design. New York, Oxford University Press,.

Bilda, Z. and H. Demirkan (2003). "An insight on designers sketching activities in traditional versus digital media." Design Studies **24**(1): 27-50.

Biocca, F. and M. Levy (1995). Virtual Reality As A Communication System. Communication in the Age of Virtual Reality. F. Biocca and M. Levy. NJ, Erlbaum Associates: 15-31.

Blaikie, N. (1995). Approaches to Social Enquiry, Blackwell Publishers.

Blake, E. (2000). "Presence as a means for understanding user behaviour in Virtual Environments." The South African Computer Journal **26**: 247-251.

Bloomberg, J., J. Giacomi, et al. (1993). Ethnographic field methods and their relation to design. Participatory Design: Principles and Practices. D. Schuler and A. Namioka. London, Lawrence Erlbaum Associates: 123-155.

Brereton, M. (2002). Video Interaction Analysis.

Brereton, M. and B. McGarry (2000). "An observational study of how objects support engineering design thinking and communication: implications for the design of tangible media." CHI Letters **2**(1): 217-224.

Bucciarelli, L. (1994). Designing engineers, MIT Press.

Bucciarelli, L. (1999). Designing Delta Design: Seeing/Seeing As. 4th International Design Thinking Research Symposium, Cambridge, MIT.

Buchenau, M. and J. F. Suri (2000). Experience prototyping http://doi.acm.org/10.1145/347642.347802 Proceedings of the conference on Designing interactive systems: processes, practices, methods, and techniques New York City, New York, United States ACM Press: 424-433

Buckner, C. (1993). "An Introduction to Computer Aided Industrial Design." Design World **26**: 32-54.

Bucolo, S. (1999). Computer Assisted Conceptual Design Tools For New Product Development. Proceedings of TMCE2000.

Bucolo, S. (2004). Understanding Cross Cultural Differences During Interaction Within Immersive Virtual Environments. VRCAI, Singapore, ACM.

Bucolo, S. and N. Chan (2001). "Emerging Computer Based Conceptual Design Tools - Implications for Design Education." Proceeding of ICSID Education Seminar.

Bucolo, S. and S. Curran (1995). Rapid Product Prototyping for the Industrial Designer. First Asia Pacific Conference on Rapid Product Development,, Brisbane.

Button, G. (2000). "The Ethnographic Tradition and Design." Design Studies **21**: 319-332.

Buur, J. and M. Andreasen (1989). "Design models in mechatronic product development." Design Studies **10**(3): 155-162.

Buur, J. and A. Soendergaard (2000). Video card game: an augmented environment for user centred design discussions http://doi.acm.org/10.1145/354666.354673 Proceedings of DARE 2000 on Designing augmented reality environments Elsinore, Denmark ACM Press**:** 63-69

Casanueva, J. and E. Blake (2000). "Small group collaboration and Presence in a virtual environment." The South African Computer Journal **26**: 163-171.

Chandrasekaran, B. (1999). Multimodal perceptual Representations and Design problem Solving. Visual and Spatial Reasoning in Design, University of Sydney.

Cox, G. (2005). Cox Review of Creativity in Business: building on the UK's strengths, Chancellor of the Exchequer.

Cross, N. (2007). "Forty Years of Design Research." Design Studies **28**: 1-4.

Cutler, L., B. Frlich, et al. (1997). "Two handed Direct Manipulation on the Responsive Work Bench." Computer Graphics: Proceedings of the ACM Symposium on Interactive 3D Graphics: 107-114.

Dahan, E. and V. Srinivasan (2000). "The predictive Power of Internet-Based Product Concept Testing Using Visual depiction and Animation." Journal of Product Innovation Management **17**: 99-109.

Deisinger, J., R. Blanch, et al. (2000). "Towards immersive Modelling - Challenges and recommendations: A workshop Analysing the needs of designers." Proceedings of EGVE 2000: 145-156.

Denzin, N. (1989). The Research Act: A Theoretical Introduction to Sociological Methods. NJ, Prentice Hall.

Dorst, K. and J. Dijkhuis (1995). "Comparing Paradigms for Describing Design Activity." Design Studies **16**: 261-274.

Downey, G. (1992). "Human Agency in CAD / CAM Technology." Anthropology Today **8**(5): 2-6.

Draper, J. (1998). "Special Section." Human Factors **40**(3): 354-375.

Draper, J. and L. Blair (1995). "Workload, flow and telepresence during teleoperation." Proceedings of the 1996 IEEE International Conference on Robotics and Automation **2**: 1030-1035.

Ehn, P. (1988). Playing the language-games of design and use-on skill and participation. Proceedings of the ACM SIGOIS and IEEECS TC-OA 1988 conference on Office information systems, ACM Press.

Ehn, P. (1988). Work-Oriented Design of Computer Artifacts. Stockholm, Arbetslivscentrum.

Ehn, P. (2004). Atelier Final Report.

Erickson, T. (1995). Notes on Design Practice: Stories and Prototypes as Catalysts for Communication. Scenario-Based Design: Envisioning Work and Technology in System Development. C. J. New York, Wiley and Sons**:** 37-58.

Ferguson, E. (1992). Engineering and the Mind's Eye. Cambridge, MA, MIT Press.

Fish, J. and S. Scrivener (1990). "Amplifying the Mind's Eye: Sketching and Visual Cognition." Leonardo **23**(1): 117-126.

Gedenryd, H. (1998). How Designers Work, Lund University Cognitive Studies.

Goel, V. (1995). Sketches of thought. Cambridge, Mass :, MIT Press,.

Goldschmidt, G. (1991). "The Dialectics of Sketching." Creativity Research Journal **4**(2): 123-143.

Harrison, S. and S. Minneman (1996). A Bike in Hand: A Study of 3-D Objects in Design. Analysing Design Activity. N. Cross. Chichester, Wiley and Sons**:** 417-436.

Henderson, K. (1995). "The Political Career of a Prototype: Visual Representation in design Engineering." Social Problems **42**: 274-298.

Henderson, K. (1998). "The Role of the Material Objects in the Design Process: A Comparison of Two Design Cultures and How they Contend with Automation." Science, Technology and Human Values **23**(2): 139-174.

Hennessey, J. (1994). The IDEATE project: Exploring computer enhancements for conceptualising. Automation based creative design: Current issues in computers and architecture. T. White and A. Tzonis. Amsterdam, Elsevier Science.

Hummels, C. and K. Overbeeke (1998). Designing and Testing Human Computer Interaction: A Case Study in Virtual Clay Modelling. 13th International Symposium on Automotive Technology and Automation, Automotive Automation Limited.

Hutchby, I. (2001). "Technology, Texts and Affordances." Sociology **35**(2): 441-456.

Hutchins, E. (1995). Cognition in the Wild, MIT Press.

Ishii, H. and B. Ullmer (1997). Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms. CHI 97, ACM.

Jones, J. (1970). Design Methods. Chichester, John Wiley and Sons.

Jordan, B. and A. Henderson (1995). "Interaction Analysis: Foundations and Practice." The Journal of the Learning Sciences **4**(1): 39-103.

Kirsh, D. and P. Maglio (1992). Some Epistemic Benefits of Action: Tetris a Case Study. Fourth Annual Conference of the Cognitive Science Society, Hillsade, NJ.

Laurenceau, T. (2000). An evaluation of traditional design processes in an evolving design environment. IDSA Conference on Design Education, USA.

Lave, J. (1988). Cognition in Practice, Cambridge University Press.

Lawson, B. (1980). How Designers Think. Oxford, Butterworth Architecture.

Leon'ev, A. (1974). "The problem of activity in psychology." Soviet Psychology **13**(2): 4-33.

Lindemann, U., G. Assmann, et al. (1999). The Development of a Mountain-Bike Frame. Visual and Spatial Reasoning in Design, University of Sydney.

Logan, G. D. a. R. D. F. (1998). Artefacting in a Cross-Discipline Design Team. DETC98, Atlanta.

Mackay, W. (1995). Ethics, Lies and Videotape. SIGCHI conference on Human factors in computing systems (CHI'95), New York, ACM.

Mahoney, D. (1994). "Designing a Computer with Computers." Computer Graphics World **17**(6): 55-56.

Mantovanu, G. and G. Riva (1999). "'Real Presence': How different ontologies generate different criteria for Presence, telepresence and virtual presence." Presence: Teleoperators and Virtual Environments **8**(5): 540-551.

McGarry, B. (2005). Things to Think With. ITEE. Brisbane, University of Queensland.

Miles, M. B. and A. M. Huberman (1984). Qualitative Data Analysis: A Source Book of New Methods. Beverly Hills, California, Sage Publications.

Nardi, B. A. (1996). Context and consciousness : activity theory and human-computer interaction. Cambridge, Mass :, MIT Press,.

Nichols, S., C. Haldane, et al. (2000). "Measures of Presence and its Consequences." International Journal of Human Computer Studies **52**: 471-491.

Norman, D. (1998). The Invisible Computer. Cambridge, Massachusetts, MIT Press.

Perry, M. and D. Sanderson (1998). "Coordinating Joint Design Work: The Role of Communication and Artefacts." Design Studies **19**: 273-288.

Polanyi, M. (1998). Personal Knowledge : Towards a Post-Critical Philosophy. London, Routledge.

Potter, C. (1994). "A Select Few Push the Edge of Design." Computer Graphics World **17**(4): 21-28.

Purcell, T. and J. Gero (1998). "Drawings and the Design Process." Design Studies **19**(4): 389-430.

Robson, C. (2002). Real World Research: A Resource for Social Scientists and Practioner- Researchers. Oxford, Blackwell Publishers.

Schön, D. A. (1983). The Reflective Practitioner - How Professionals Think in Action. New York, Basic Books.

Schön, D. A. and G. Wiggins (1992). "Kinds of seeing and their functions in designing." Design Studies **13**(2): 135-156.

Sheridan, T. (1992). "Musings on telepresence and virtual presence." Presence **1**: 120-126.

Sheridan, T. (1996). "Further musing on the psychophysics of Presence." Presence **5**: 241-246.

Simon, H. A. (c1996.). The sciences of the artificial. Cambridge, Mass :, MIT Press,.

Slater, M., M. Usoh, et al. (1994). "Depth of Presence in virtual environments." Presence **3**: 130-144.

Söderman, M. (2002). "Comparing Desktop Virtual Reality with handmade sketches and real products. Exploring key aspects for end-users' understanding of proposed products." Journal of Design Research **Volume 2**(Issue 1).

Stoll, H. W. (1999). Product Design Methods and Practices. New York, Marcel Dekker.

Strauss, A. (1987). Qualitative Analysis for Social Scientists. Cambridge, University Press.

Suchman, L. (1987). Plans and Situated Actions: The Problem of Human Machine Communication. Cambridge, Press Syndicate of the University of Cambridge.

Suwa, M. and B. Tversky (1997). "What do Architects and Students Perceive in the Design Sketches? A Protocol Analysis." Design Studies **18**(4): 385-403.

Tang, J. C. and L. J. Leifer (1991). "An observational methodology for studying group design activity." Research in Engineering Design **2**(4): 209-219.

Tovey, M. (1989). "Drawing and CAD in Industrial Design." Design Studies **10**(1): 24-33.

Tovey, M., S. Porter, et al. (2003). "Sketching, concept development and automotive design." Design Studies **24**(2): 135-153.

Ullmer, B. and H. Ishii (1997). "The metaDESK: models and Prototypes for tangible User Interfaces." Proceedings of UIST: 1-10.

Ulrich, K. and S. Eppinger (2000). Product Design and Development. Boston, McGraw Hill.

Valkenburg, R. (1998). "Shared Understanding as a Condition for Team Design." Automation in Construction **11**: 111-121.

Van der Lugt, R. (2005). "How Sketching can affect the idea generation process in group meetings." Design Studies **26**: 101-122.

Visser, W. (2006). The Cognitive Artifacts of Designing. Mahwah, NJ, Lawrence Erlbaum Associates.

Weiser, M. (1991). "The Computer for the 21st Century." Scientific America **265**(3): 94-104.

Weiser, M. (1993). "Ubiquitous Computing." IEEE Computer.

Winograd, T. and F. Flores (1986). Understanding Computers and Cognition, Alex Publishing Corporation.

Witmer, B. and M. Singer (1994). Measuring immersion in virtual environments (Tech Report 1014). Alexandria, US Army Research, Institute for the behavioral and social sciences.

Witmer, B. and M. Singer (1998). "Measuring Presence in virtual environments: A presence questionnaire." Presence: Teleoperators and Virtual Environments **7**(3): 225-247.

Yang, M. C. and D. Epstein (2005). "A study of prototypes, design activity, and design outcome." Design Studies **26**(6): 649-669.

Appendix A

ADB206	Industrial Design 4	Studio

Aims

- ☐ Consumer Product Design based on Existing Manufacturing Constraints
- ☐ Control of Design Intent based on Manufacturing Constraints
- ☐ Detail Design Development

Project 1 – Consumer Product Design (45%)

Consumer product design is a specialised field of Industrial Design. It focuses on the physical design or redesign of objects based on needs determined by the user / consumer. Your first design project requires you to redesign an existing product based on manufacturing constraints for the product to remain competitive within its existing market.

Project 1 – Consumer Product Design, focuses on the redesign of an existing consumer product of your own choice. It requires you to explore the market, usability, tooling and specification stage of your final design solution and their impact on concept design decisions. You will be required to control your design concept from a final design freeze through to manufacturing specification – a design-balancing act.

The project will be linked to the Manufacturing Technology 4 program, which will allow you to analyse the existing product through a Design For Manufacturing methodology and then apply this to your own design work.

Consumer Product Redesign

Due to the large number of imported overseas products, competition within the consumer appliance market is extremely fierce. Manufacturers will often compete on cost rather than product features however if the product is still to remain viable it must still meet the user needs of its target market. If a manufacturer can reduce the cost of manufacture by $1 on a product this can represent hundreds of thousands of dollars saving to the company for the duration of the product lifecycle.

To achieve this, manufacturers will often conduct frequent redesigns of the product based on Design for Manufacturing principles. Costing for each feature or function is generated and design teams look at how small savings may be made through innovative redesign of the feature or function. In some case it is possible to remove that feature completely. However this process must be balanced with still providing a product that is of value to the user. This is the role of the industrial designer to act as the liaison between manufacturing requirements / costing and user needs.

In this project you will have the opportunity to act in this role. In-groups of two you will be required to purchase a consumer product which will act as the focus for your re-design. Suggested products suitable for this task have been suggested on the following page. You will be required to undertake a user centred design analysis of the product to areas of design improvement. You will also be required to undertake a manufacturing analysis of the product to identify areas for manufacturing design improvements.

Following this extensive analysis you will be required to redesign the product, around existing design constraints, which address users needs and then balance this with reducing the cost of production for the manufacture of the product.

Suggested Products

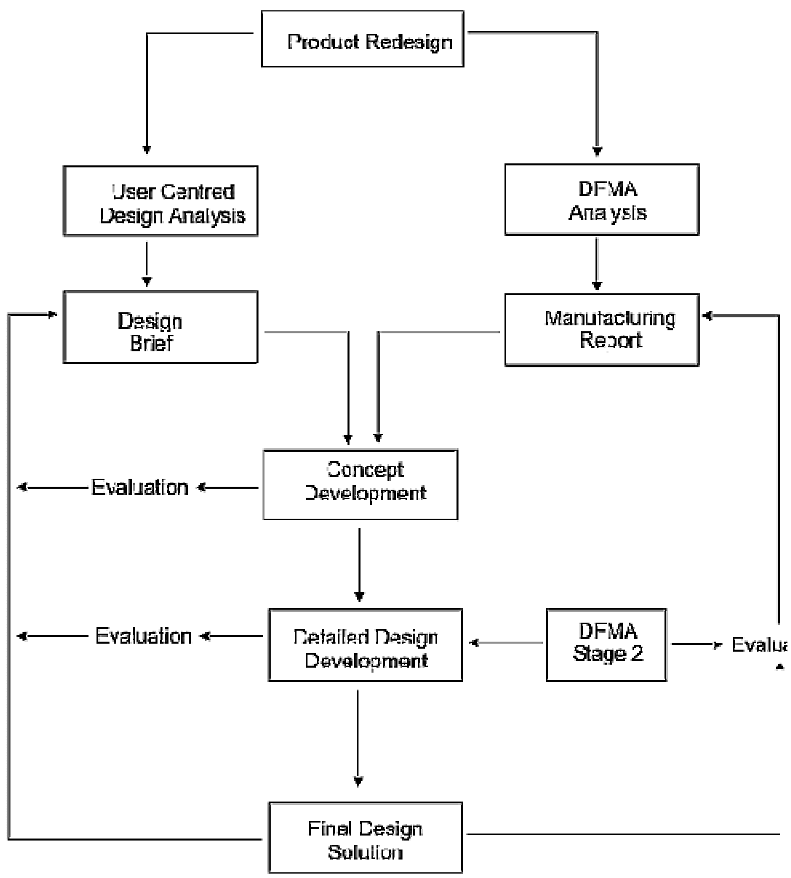
Due to the short time frame of the project – the following consumer products have been suggested based on their relative simplicity in manufacturing and potential for product redesign. Further as the product will consider Design for Manufacturing Analysis – products, which consist primarily of injection moulding, will only be considered. For each product you will be required to identify the unique product constraints, that can not be changed in the redesign and therefore must be accounted for in your product re-design. General design constraints for the product have been noted below.

Domestic Plastic Kettles (cost $50 - $70) Constraints □ Element □ Power Supply
Food Processor (approximate cost $70 - $80) Constraints □ Power Supply □ Motor □ Cutting Elements
Filter Coffee Maker (approximate cost $60 - $80) Constraints □ Heating Element □ Power supply □ Jug / Filter
Dehumidifier (approximate cost $50 - $70) Constraints □ Power supply □ Motor □ Fan
Hairdryer (approximate cost $50 - $70)

Constraints
□ Power supply □ Blower □ Heating Element

You can choose any product within the range above or suggest a similar product not identified. However there should be no duplicates of products / model types within the class. As you will be required to undertake a complete analysis of the product which will require disassembly of the product you will be required to disable the electrical aspects of the product (by cutting the power cord) once you have finalised the usability testing – this will be checked in class.

Design Approach



As this project will be linked to the Manufacturing Technology 4 Program aspects of this design approach may be conducted within that unit.

- Form a group of two and purchase a product suitable for redesign. Obtain approval for the product type before purchasing the product.

- Conduct a feature analysis of competitor products within your market segment.

- Determine the user profile of your market segment

- Conduct a usability evaluation of the functioning product. Once complete you must then disable the product. DO NOT DISASSEMBLE BEFORE DISABLING THE PRODUCT (BY CUTTING THE POWER CORD) AND DO NOT ATTEMPT TO USE THE PRODUCT AFTER THIS STAGE – THIS WILL BE CHECKED IN CLASS AND ENFORCED

- Utilise the information gained in your DFM analysis of the product to determine component specification, assembly procedure and component and assembly cost.

- ☐ Equivalent to a final design presentation
- ☐ Communicate both concepts – will required sketches and models
- ☐ One concept to be selected from presentation

- Generate a design proposal and list the design criteria for your redesign. The proposal should indicate key areas to be considered. The proposal should be a series of A2 boards, which relate to the market, usability and DFMA analysis. Both the analysis and findings should be shown on each board. The board will also make up part of your final presentation. **This will be presented in class during week 7.**

- Generate multiple product variations (minimum 30) based upon the design constraints. This should be completed using quick rendered concept sketches and with the use of overlay's. These will be presented as a round table discussion in class in week 8 and developed further in the workshop through 3D form studies. The use of quick concept models and the 3-axis router is recommended for this stage.

- Evaluate the concept sketches and refine to two final designs. Add manufacturing detail inline with findings from your DFMA report. Present your two concepts to the class. The presentation should be the equivalent of a final design client presentation in which sign off for manufacturing development will be considered. Select one product variation for design development. The design will be frozen at this stage. This should be completed by week 11 to be presented during this class.

  Design Freeze Submission Requirements

  An interim submission will be required in week 11. This will consist of a presentation of your final two concepts. The format of the presentation will include:

  Formalised A3 concept sketches for each concept (perspective + orthographic)
  Form Model (1:1) for each concept

5 minute presentation

Due Date: 25 September @ 9.00am
Weight: 15%

Detail Design / Evaluation Phase

- Refine manufacturing detail of the selected frozen design. Evaluate decisions and modify design detail as required. CAD / Technical representation is recommended at this stage. Subtle changes to the form may be required based on tooling / manufacturing / costing requirements – you will need to ensure that you control your design intent during this phase of the project. Detail these subtle changes in your concept development book. If you use CAD and form models ensure that you use screen shots and photographs to document the design process.

- Provide a manufacturing report on the redesign of the product. This should include component resolution for each part, a Bill of Materials, costing and justification for manufacturing processes, assembly processes and materials specified.

- Organise a presentation of your final design and the overall process. You will be required to present and justify the process undertaken throughout the project.

Final Design Submission Requirement

The final submission for this project will be a folio, which includes:

Design Folio Should be:
- ☐ A2 format
- ☐ Sturdy
- ☐ Clearly labelled (External)
- ☐ Include Index

- Design Proposal which includes A2 Research and Design criteria boards for Usability Evaluation, User Profile and Manufacturing Analysis
- Concept development book outlining design process and design variations at each stage of the process – include your reflection of the process (A3). Include a visual summary page outlining the process undertaken.
- Selected Concept within its intended environment for its market segment showing progression from existing design to your solution. Demonstrate the control of your design solution (A2 Boards)
- Complete Set of Dimensioned Technical Specification including General Assembly and Components documentation (A2)
- Manufacturing Report (ADB236 Man Tech Project 2 Submission) which includes, Bill of Materials, costing and justification for manufacturing processes, assembly processes and materials specified. (A4)
- Form Model 1:1
- Oral presentation (10 Minutes)

- CD of images

Due Date: 30 October @ 9.00am (D413)
Weight: 30%

During the project interim presentations (starting at 9.00am) will be required to obtain formal feedback from staff and other students. These will take the format of round table discussions or individual critiques sessions. The dates are indicated in the unit outline. You will be required to provide a criteria sheet for each session to assist you in the development of your work.

Considerable workshop times have also been allocated and the appropriate safety clothes are required for entry.

Your final grade will be based on the process you apply (60%), the final design presented (40%). One Grade will be provided per group.

Appendix B

BNB011 Fundamentals of Synthetic Environments - Unit Outline

The term Synthetic Environment (also know as Virtual Reality) refers to an interactive computer generated 3-dimensional representation of an existing environment or conceptual design. This emerging field of study has significant potential to Design and Engineering disciplines as the technology allows enhanced communication to a multi-layered audience.

Week	Date	Activity	Submission
1	**14 July**	No Class	
2	**21 July**	Semester Overview Ejournal 1 - Introduction to VR Tutorial - VRML Exploration	Editorial • Reflection on Ejournal 1
3	**28 July**	Tutorial • VRML Development	Case Study • Experimental VRML World + Initial Reflections
4	**4 August**	Ejournal 2 - Web Based VR Tutorial – Importing CAD Data	Editorial • Reflection on Ejournal 2
5	**11 August**	**Project Week**	
6	18 August	Tutorial • VRML Development	Case Study • Storyboard of Proposed Project
7	25 August	Ejournal 3 - Immersive VR Tutorial - VRML Animation	Editorial • Reflection on Ejournal 3
8	**1 September**	Digital Design Critique • VRML	Case Study • VRML Digital Design Critique Reflection
9	**8 September**	Ejournal 4 - Mulitmodal Interfaces Tutorial - Publishing	Editorial • Reflection on Ejournal 4
10	**15 September**	Digital Design Critique • Reality Centre (UQ) • I-Desk (QUT)	Case Study • Reality Centre / I-Desk - Digital Design Critique Reflection
11	**22 September**	Ejournal 5 – Evaluation Tutorial – VRML Development	Editorial • Reflection on Ejournal 5
		Mid Semester Break - No Class	
12	**6 October**	Digital Design Critique • Reality Centre (UQ) • I-Desk (QUT)	Case Study • Reality Centre / I-Desk - Digital Design Critique Reflection
13	**13 October**	Tutorial • VRML Development	

20 October	**Project Submission (50%)** Final Design Critique Reality Centre / I-Desk	

Unit Aims

This unit will provide an overview of Virtual Reality (VR) focusing on the application to Design and Engineering disciplines as a tool for enhanced communication within a design process. The theory (lecture) component will provide an overview of historical and contemporary issues related to Virtual Reality, whereas the tutorials will provide you with the necessary skills for the creation of an interactive 3D Virtual Environment.

Unit Objectives

On completion of this unit, students should be able to:

- develop an Interactive 3D Virtual Environment suitable to their own discipline
- apply theoretical and conceptual skills to the practical application of the technology
- develop and evaluate a methodology for the application of this technology suitable to their own discipline
- critically evaluate emerging technology related.

Approaches to Teaching and Learning

The unit will use a project-based methodology, where students will be applying the knowledge and skills gained within the theory component of the unit to a current design project. Extensive use of OLT (online teaching template) will be used throughout the semester to assist in the flexible delivery of this unit. The OLT site URL is http://olt.qut.edu.au/bee/bnb011. In addition to this, extensive use of the Synthetic Environment Laboratory (D207) will be required for completion of projects related to the unit – specifically the VR projection hardware.

Each fortnight, one Ejournal will be released which will cover topics related to the use of Virtual reality and Design. This information will be summarised at the beginning of each fortnightly lecture, however all the information will be provided to you online, therefore allowing you the flexibility to access the information at a time most convenient to you. A tutorial will follow this lecture where you will gain the necessary skills for the creation of a virtual world. Every second fortnight you will have the opportunity to apply these skills to your design project where you will be require to discuss your design using the virtual tools being made available, within a digital design environment. In total 5 fortnightly Ejournals / tutorials and 5 case study submissions will form the basis of the unit.

Assessment

- Weekly reflections on the theory covered in each Ejournal, as supplied to your own discipline area. You will form your responses as short discussion responses within a discussion list. A total of five responses are required to complete this assessment.

  Weight: 25% (5 x 5% for each response)
  Due Date: Continuous

- Case Study Submissions on the development of your virtual world. The Case Study will be submitted as either a example of the virtual world and / or a reflection on your experience of using the technology within a design critique.

  Weight: 25% (5 x 5% for each Case Study Submission)
  Due Date: Continuous

- A project demonstrating the application of the development of a Synthetic Environment within your discipline. You will be assessed on the skills applied and you're demonstration of the application of the technology to design critiques. Full details will be provided in additional handouts.

  Weight: 50%
  Due Date: 20 October @ 10.00am

Texts and References

- Biocca, F, ed. (1995), Communication in the Age of Virtual Reality, Erlbaum Associates NJ
- Carr K, ed. (1995), Simulated and Virtual Realities: Elements of Perception, Taylor and Francis London
- Hartman, J (1996), The VRML Handbook: Building Moving Worlds on the WEB, Addison Wesley, Mass
- Stuart, R (1996), The Design of Virtual Environments, McGraw-Hill, NY
- Tittel, Ed(1997), Building VRML Worlds, McGraw-Hill, California
- Vince, J (1998), Essential Virtual Reality Fast: How to Understand the Techniques and potential for Virtual reality, Springer NY