PHD

Characterising the relationship between practice and laboratory-based studies of designers for critical design situations

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Award date:
2012

Awarding institution:
University of Bath

Characterising the Relationship Between Practice and Laboratory-based Studies of Designers for Critical Design Situations

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A thesis submitted for the degree of Doctor of Philosophy

University of Bath

Department of Mechanical Engineering

June 2012

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Preface

"By endurance we conquer"

Sir Ernest Shackleton

Abstract

Experimental study of the designer plays a critical role in design research. However, laboratory based study is often poorly compared and contrasted to practice, leading to a lack of uptake and subsequent research impact. The importance of addressing this issue is highlighted by its significant influence on design research and many related fields. As such the main aim of this work is to improve empirical design research by characterising the relationship between practice and laboratory-based studies for critical design situations.

A review of the state of the art of methods in design research and key related fields is reported. This highlights the importance and commonality of a set or core issues connected to the failure to effectively link study of practice and study in the laboratory. Further to this a technical review and scoping study was carried out to establish the most effective capture strategy to be used when studying the designer empirically. Subsequently three studies are reported, forming a three-point comparison between practice, the laboratory (with student practitioners) and an intermediary case (a laboratory with practitioners). Results from these studies contextualise the critical situations in practice and develop a detailed multi-level comparison between practice and the laboratory, which was then validated with respect to a number of existing studies.

The primary contribution of this thesis is the development of a detailed multi-level relationship between practice and the laboratory for critical design situations: information seeking, ideation and design review. The second key contribution is the development of a generic method for the empirical study of designers in varying contexts – allowing researchers to build on this work and more effectively link diverse studies together. The final key contribution of this work is the identification of a number of core methodological issues and mitigating techniques affecting both design research and its related fields.

Acknowledgements

The Innovative design and Manufacturing Research Centre (IdMRC) at the University of Bath, funded by the Engineering and Physical Science Research Council (EPSRC) under grant reference GR/R67507/0, has supported the work reported in this thesis. The author gratefully acknowledges this support and its importance for the reported work.

I would like to thank my academic supervisors Dr Ben Hicks and Prof. Steve Culley for their guidance, constructive criticism and support throughout my PhD. I could not have completed this work without their input.

I acknowledge the constructive input of my examiners Dr Peter Törlind and Dr Linda Newnes whose comments have improved this thesis. I would also like to thank the industrial collaborators and students whose participation in the various studies reported in this thesis made this research possible.

I would also like to thank my colleagues, particularly Dr Hamish McAlpine and Chris Snider, for their input in terms of lively debate. Finally, I thank Mel who has supported me throughout my PhD contributing via discussion and proof reading of this thesis. I also thank my parents for all their support.

List of Publications

Journal Articles

CASH, P., ELIAS, E. W. A., DEKONINCK, E. & CULLEY, S. J. (2011) ***Methodological Insights from a Rigorous Small Scale Design Experiment***. Design Studies, 33, 2, 208-235.

Conference Articles (Peer-reviewed)

CASH, P., HICKS, B. J. & CULLEY, S. J. (2012) ***A comparison of the behaviour of student engineers and professional engineers when designing***. Design 2012 International Design Conference. Dubrovnik, Croatia. 21-24 May.

BOA, D., CASH, P. & HICKS, B. J. (2012) ***A review of state of the art and emerging interaction technologies and their impact on design and designing in the future***. Design 2012 International Design Conference. Dubrovnik, Croatia. 21-24 May.

CASH, P., HICKS, B. J., CULLEY, S. J. & SALUSTRI, F. (2011) ***Designer behaviour and activity: An industrial observation method***. ICED 11 International conference on engineering design. Copenhagen, Denmark. 15-18 August.

MCALPINE, H., CASH, P., STORTON, A. & CULLEY, S. J. (2011) ***A technology selection process for the optimal capture of design information***. ICORD'11 International conference on research into design. Bangalore, India. 10-12 January.

CASH, P., HICKS, B. J. & CULLEY, S. J. (2010) ***An information requirement strategy for capturing and analysing design activity and behaviour***. Design 2010 International Design Conference. Dubrovnik, Croatia. 17-20 May.

MCALPINE, H., CASH, P., HOWARD, T. J., ARIKOGLU, E. S., LOFTUS, C. & O'HARE, J. (2010) ***Key themes in design information management***. Design 2010 International Design Conference. Dubrovnik, Croatia. 17-20 May.

CASH, P., HICKS, B. J. & CULLEY, S. J. (2009) ***The challenges facing ethnographic design research: A proposed methodological solution***. ICED 09 International Conference on Engineering Design. Stanford, CA, USA. 24-27 August.

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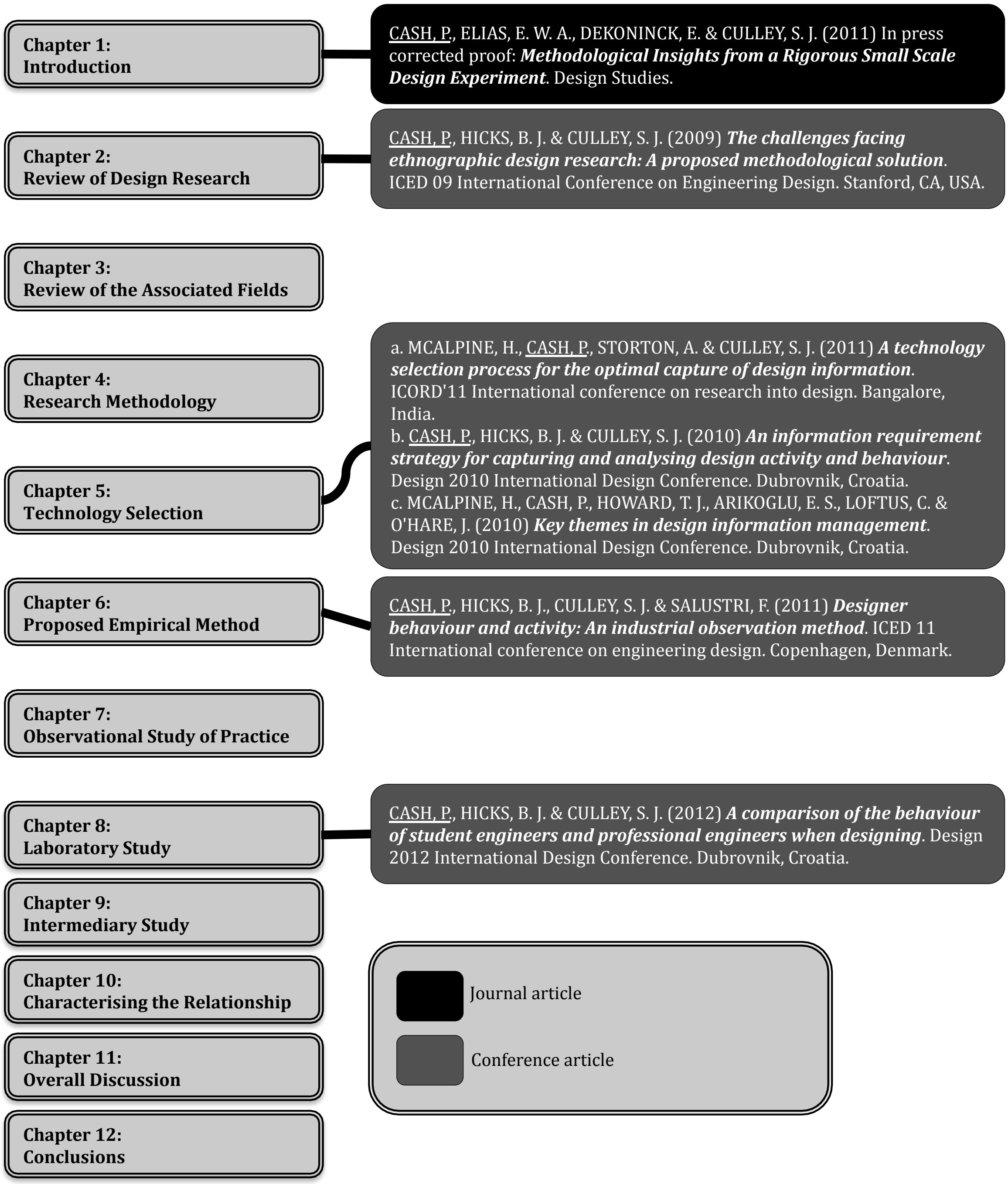

Figure 0.1: Summary of publications

Figure 0.1 shows where the authors' journal and conference articles have contributed to this thesis.

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Abbreviations

DRM	**D**esign **R**esearch **M**ethodology
DS	**D**escriptive **S**tudy
Int	Results: An **int**ermediary type study
KAI	**K**irton **A**daption-innovation **I**nventory
Lab	Results: A **lab**oratory type study
MEng	**M**aster of **Eng**ineering: A masters level degree classification used at the University of Bath
N.A.	**N**ot **A**pplicable
NLP	**N**atural **L**anguage **P**rocessing
OED	**O**xford **E**nglish **D**ictionary
PS	**P**rescriptive **S**tudy
RQ	**R**esearch **Q**uestion
SME	**S**mall to **M**edium size **E**nterprise

Preface

Nomenclature

Core issue: A fundamental issue affecting a particular aspect of empirical research such as control and normalisation.

Design: A process including activities, behaviours and situations associated with problem solving or development.

Designer: Any person undertaking a design activity. This can include mechanical engineers, electrical engineers or programmers.

Design process: A process whose main aim is problem solving. The whole of the design cycle is represented by multiple divergent and convergent events. The design process is in general structured as follows: process > stage > activity > task > designer behaviour.

Design situation: A specific activity in a defined context during the design process. This can be a brainstorming session, review meeting, individual product development or information seeking.

Experimental error: A difference between the results produced during a study and the real situation. This is inherent in all types of experiment and all branches of science.

Intermediary: An experimental study using practitioners in a setting with some contrived elements.

Issue: A specific problem that forms a sub-set for each Core Issue.

Laboratory: An experimental study typically using students, in a custom environment.

Methodology: An overarching framework connecting a number of methods to the rationale, theory and philosophical assumptions that underlie a particular study.

Mitigating approach: An overarching group of techniques affecting a particular aspect of empirical research such as control and normalisation.

Mitigating technique: A specific methods, which form a sub-set for each mitigating approach.

Mitigation: A reduction or elimination of experimental error for a specific situation or study.

Practice: An ethnographic or fully embedded study of practice, typically assed observationally using fieldwork techniques with no contrived elements.

Team: A group of two or more designers working in a design situation. These can be collocated or distributed and can include non-designer roles such as managers or coordinators. Teams are not necessarily the same throughout the design process and can change depending on the situation or process stage.

Characterising the Relationship Between Practice and Laboratory-based Studies of Designers for Critical Design Situations

"By endurance we conquer"

Sir Ernest Shackleton

1

Introduction

In the UK the independent design engineering sector accounted for over 14% of GDP in 2008 and is growing (Moore et al. 2008). In addition, 70% of a product's life-cycle costs are committed in the early design stage (Asiedu and Gu 1998). This growth in the complexity, scope and importance of engineering design, particularly in the UK, has led to an increasing demand for more effective research. However, a key barrier to effective research uptake has emerged as the perceived dichotomy, expressed by many practitioners, between research and practice (Maffin 1998). This thesis takes a step towards addressing this problem, however, it is first important to understand the wider context of design and design research.

Design is a complex subject and is best understood in its historical context. At its most basic level – producing something with a premeditated goal – it predates modern humans and arguably the *Homo* genus itself, with stone tools dated at over 2.5 million years old (Semaw et al. 1997). In this case, the first use of design probably occurred with the manufacture of simple hand tools by *homo habilis* or one of their close ancestors (Friedman 2000). Indeed the premeditated production and use of objects or process to solve problems is part of what defines humanity and could have been one of the evolutionary factors behind large brains in humans (Gibbons 1998). As such it is perhaps justifiable to claim design as one of the most important elements affecting human development, shaping our history and future.

The pace of design has, however, not remained constant over the long history of the *hominids*. The tempo has dramatically quickened, from the first basic spears, followed by specialised stone tools, architecture, civil planning and ultimately technology, as we understand it today. The rate of change today far exceeds that of ancient times and the trend seems set to continue with the rate of technical progress doubling, approximately, every decade (Kremer 1993; Kurzmeil 2001). In the UK alone the design engineering sector has doubled its percentage of GDP (7% - 14%) between 1988 and 2008 (Moore et al. 2008).

It is also important to note that, as the pace quickened, the scope of design has also broadened. Design now encompasses areas such as societal change, economic planning, policy, biological and technical engineering with scales ranging from macroscopic to microscopic (Kurzmeil 2001). As such design research encompasses the study of not only tools and technologies but also process, people, teams, management and environments (Hicks et al. 2008). In addition the increasing complexity of the world, engineering and the design process drive an increasingly important role of planned, rigorous design (Calvano and John 2003).

With this increase in importance, complexity and scope have come a number of significant changes in the nature of design. This is most clearly seen as the shift from design as an art or craft to design as a complex industrialised process, often described systematically (Pahl and Beitz 1996). This has lead to a split between the artist and the specialist designer as an engineer. It is these design engineers (practitioners) operating in the industrial complex with which this work is concerned and as such 'designer' will henceforth be used to mean those individuals operating within a constrained industrial design process as apposed to unconstrained artists or craftspeople.

From this perspective design is considered to be a branch of engineering. The Oxford English Dictionary (OED) (2010) defines engineering as:

'The branch of science and technology concerned with the development and modification of engines (in various senses), machines, structures, or other complicated systems and processes using specialized knowledge or skills, typically for public or commercial use; the profession of an engineer. Frequently with distinguishing word.'

Thus engineering design research focuses on, addressing identified problems and seeking to scientifically understand and characterise design as a comprehensible process. As such, it is the introduction and contextualisation of design in this sense that preoccupies the next section.

1.1 Design

Design is a multifaceted field that, despite its antiquity, has only been addressed academically relatively recently (Cross 2007). This dichotomy between age and study has lead to a wide diversity of perspectives (Cross 2007). The OED defines design as:

'*The art or action of producing a plan or drawing… conceive or produce a design'*

For design research, it is possible to refine these definitions to include any case, becoming: '*The process of producing X*' where X can be any artefact or more general solution identified from a need. It is in this sense the definition becomes analogous to that given by Blessing and Chakrabarti (2009) and the one used throughout this thesis:

'Activities that actually generate and develop a product from a need, product idea or technology…' (p. 1 (Blessing and Chakrabarti 2009))

Further to this, design can be considered as an overarching process within which there are interlinked but distinct design situations undertaken by individuals, groups or wider communities using various tools and methods. The output of the design situations can be technical or non-technical solutions in varying forms. This broadness of scope gives rise to an incredibly diverse field of research (Finger and Dixon 1989; 1989). Typical examples of this diversity are found in the modelling of the relationship between problem and solution (Dorst and Cross 2001) or the development of convergent/divergent thinking for concept generation (Liu et al. 2003).

There are numerous perspectives from which to consider the design process: Phal, Beitz (1996) and French's (1998) mechanistic approaches; Ullman's (2002) broader more directly practical approach as well as others (Eppinger 1991; Friedman 2000; Bucciarelli 2002). A review of the methodologies used in academic and industrial design is presented by Tomiyama (2009). A typical design process can be drawn from Hales' (1991) seminal thesis, here design has been broken down into a series of steps forming a single phase in a larger process which, itself sits within the macro scale context of social, economic and environmental constraints.

Perspectives on the design process can vary from extremely mechanistic (Pahl and Beitz 1996) to relatively abstract (Hatchuel and Weil 2003). Fuller (1970) attempts to address this variation by developing a general perspective of both the research process and the design process, linking them conceptually. Indeed this similarity between the two processes inevitably stems from the fact that research is often a problem solving process much like the design activity itself. Thus the next section introduces and briefly contextualises design research.

1.2 Design Research

The complex multifaceted nature of design is reflected by design research. Indeed, design research covers such diverse research areas as the development of abstract theory (Hatchuel and Weil 2003), specific tool development (Yamashina et al. 2002) and computational modelling (Schuette and Rotthowe 1998). This is reflected in the extreme diversity discussed by Finger and Dixon (1989; 1989) and, more recently, by Horvath (2004). It is important to consider this diversity as it has a number of serious implications for the field – primarily it is difficult for design research to be effectively bounded as there is substantial debate as to its uniqueness compared to other fields such as human computer interaction or behavioural psychology (Blessing and Chakrabarti 2009). However, as with design, there is a focus on the practical impact of research as well as the codification of scientific knowledge, which goes some way to differentiating design research. This manifests itself as a practitioner focused drive for impact in various forms, such as:

- Improving practice (e.g. collaboration (Bergstrom et al. 2005).
- Innovation (Ulijn and Weggeman 2001; Howard et al. 2008)).
- Improving understanding (Design-Society 2002; Cross 2004).
- Improving integration between research and practice (Design-Society 2002).
- Providing valid metrics (Hicks et al. 2007).
- Providing viable models (Hicks et al. 2007).

In this 'problem solving' goal it can be seen that design research mirrors the fundamentals of design practice as discussed by Friedman (2003), Horvath (2004) and Sheldon (2004; 2006). It is also important to emphasise the fact that just as design is a synthesis of disciplines, so is design research. Friedman highlights this, stating that:

"*The foundation of design theory rests on the fact that design is by its nature an interdisciplinary, integrative discipline.*" (p. 508)

Friedman (2000) identifies six domains from which design research draws: natural sciences, humanities and liberal arts, social and behaviour sciences, human professions and services, creative and applied arts and technology and engineering. Although each of these associated fields contributes to design research some are preeminent in their influence and similarity of context, and it is from these core fields that much of the literature has been drawn (Chapter 3).

In addition design research itself has a very broad scope, including philosophy of science, philosophy of engineering design science as well as engineering design science, methods, practice and knowledge (Horvath 2004); which are subsequently applied to a wide range of research foci as discussed above. However, one area that is of increasing importance within design research is that of empirical study. This is primarily due to the fact that empirical validation of work in all areas of design research is becoming significantly more important as the complexity of the design process under investigation increases. As such, empirical design research can be seen as a key area for facilitating the development of the wider field. Empirical study often takes the form of experimental investigation to elucidate the researchers world. Further, as empirical study is most often used to investigate designers or product users it is appropriate to focus on the human-centric aspect of this field. It is upon this aspect of design research that the main focus of this work will fall and is thus introduced next.

1.3 Empirical Design Research

Empirical study is a key element in successful research (Briggs 2006). When used effectively it can offer detailed information on the real situation, support theory building and validation, and allow causal relationships to be established. This wide scope gives a high degree of variation in the types of empirical studies used. Depending on the type of information required these generally form three types: fieldwork, scenarios and games (Camerer and Fehr 2004).

Fieldwork – The description of the situation in practice (Mer et al. 1996; Ball and Ormerod 2000; Ulijn and Weggeman 2001). This draws on many aspects of ethnography and is usually an attempt to gain an uncontrived record of what practitioners do and how they do it (Bucciarelli 1988; 1990). However, fieldwork also has a more active interventionist aspect in which researches implement large-scale changes in the field and seek to examine both the normal case and the new case.

Scenarios – An intermediate between fully contrived laboratory studies and practice (Cross et al. 1996; Martin and Vernon 2003). This draws on elements of fields such as behavioural, psychological and education research. It forms a middle level of contrivance where researchers seek to elucidate information about specific aspects of a situation. Typically these take the form of experiments or quasi-experiments.

Games – The elucidation of specific variables or causal relationships (Smith and Tjandra 1998; Garner 2001; Falk and Heckman 2009). This draws on specific elements of fields such as psychological and social research and usually takes the form of a contrived study seeking to control most aspects unrelated to the focus (Hicks et al. 2009). This normally has the aim of elucidating specific information about the fundamental nature of the activity under examination, for example the thinking processes (Stempfle and Badke-schaub 2002). Typically these take the form of experiments or quasi-experiments.

These three approaches form a continuous spectrum varying from contrived laboratory studies to ethnographic field studies. However, in order to effectively develop a scientific knowledge base, all are necessary components. Design research depends on these three types of study; as exemplified by the diverse range of areas they are collectively used to investigate, including the psychological characteristics of designers (Ahmed et al. 2003), the effectiveness of tools (Howard 2008) or understanding designer behaviour in practice (Robinson 2010). Many of these approaches can be seen to have evolved indirectly from pre-existing empirical ideas such as ethnography in social research or laboratory study in psychology research. Over the past two decades there has been a proliferation of specific examples of these approaches, ranging from tools and technologies (Rosenschein 2004; Torlind et al. 2005; Lindahl 2006; Torlind and Larsson 2006), to experience and use (Tang 1989; Smith and Tjandra 1998; Cross 2004), or linguistic analysis (Bucciarelli 2002; Dong 2005).

This diversity of these three contexts – and their associated methods – has contributed to a number of issues affecting empirical design research, and thus design research in general, forming serious barriers to uptake and impact (Chapter 3). A key issue is the difficulty in linking between the three contexts – fieldwork, scenarios and games – and, subsequently, to the situation in practice. This is particularly relevant as, with the increasing use of fieldwork in design research, there is also growing body of experimental work. However, there is little work relating them either empirically or theoretically. Although this issue is not unique to design research it is particularly relevant in this field due to its problem solving/practice focus. Thus, it is this problem that this research addresses using all three types of empirical approach as its tools. To this end the next section gives an overview of what this research addresses specifically, and what methods were used to achieve this.

1.4 Overview

Design research is a complex multifaceted field with numerous associated fields. A diverse base of empirical studies employing a wide range of theory, methodology and methods supports it. These include fieldwork, scenarios and experimental games. However, issues such as validity, perceived value, uptake and impact have persistently dogged empirical design research. For example, there are few instance of validation or replication of studies in different contexts or using different techniques such as fieldwork and games (Dyba and Dingsoyr 2008). Also, there is commonly a lack of appreciation of how methods from the associated fields can be applied to design research e.g. Frey's outright dismissal of clinical methods as not applicable to design research (2006). This work addresses these issues by developing a rigorous relationship between practice and laboratory through a series of empirical studies. The following sections outline the main aims, research questions and structure of the research as well as what is to be found in this thesis.

1.4.1 Knowledge Gap

A review of design research reveals several problem areas such as a lack of theory building or contextualisation of studies (Chapters 2 and 3). These collectively contribute to diminish external validity and subsequently impact. Although much work has focused on either practice-based fieldwork or on laboratory-based experiments there has been little work on linking the two. This has led to a perceived dichotomy between research and practice and also detrimentally affects external validity, reliability and theory development.

The importance of design is undeniable, however, without the effective support of design research there are many opportunities for growth and refinement that could be missed. The key to offering this support for design research is successfully making the case for the relevance of its work and methods. In order to do this, clear and unambiguous relationships must be made between research and practice.

Firstly, detailed observational study of design practice was used to identify critical situations of particular importance within the design process. Secondly, these situations were replicated in the laboratory study using students. Thirdly, the situations were validated using an intermediary study set in practice and using practitioners. Based on this, laboratory and practice-based situations can be directly compared allowing researchers to quantifiably identify the relevance and applicability of their research while offering solid evidence to back up research claims within the industrial sector itself. In summary, three studies were carried out in order to: describe a situation in practice, replicate it in the laboratory and validated the subsequently identified relationships using an intermediary study in practice.

1.4.2 Research Aim

As design research increasingly uses experiments to examine complex design situations it is essential to relate these studies to the extensive body of existing practice-based research. As such, the aim of this research was:

"To improve empirical design research by characterising the relationship between practice and laboratory-based studies for design situations."

1.4.3 Research Questions

The research is broken down into two main Research Questions (RQs). This is necessary as there are two distinct problems that must be addressed in order to tackle the research aim: the need to adopt rigorous methods – particularly by drawing on the associated fields – and then to address the relationship between contexts empirically. Without both steps the research would not be able to effectively address the stated aim or the main issues affecting design research. As such the first RQ addresses the theoretical aspects of the work, while the second addresses the application.

RQ 1:

How can designer behaviour and activity be characterised to enable comparison between design situations?

This addresses the development of the theory and methods required to compare two different empirical studies such that they can be quantifiably related. Objectives 1, 2 and 3, answers this RQ. For the purposes of this work activity has been defined as the tangible acts carried out by the designer e.g. interacting with a tool or carrying out a discreet task, while behaviour has been considered as interpersonal acts e.g. offering opinion in a conversation or showing enthusiasm.

RQ 2:

What is the relationship between designer behaviour in practice and laboratory-based critical design situations?

This addresses the development of rigorous relationships between the types of empirical study for the identified critical design situations. Objectives 4 and 5 answer this RQ.

1.4.4 Research Objectives

Both RQ's have a number of elements required to answer the overarching question. As such the RQ's have been broken down into a series of objectives to be addressed separately. The major objectives are:

1. To create a methodology for investigating the relationship between practice and laboratory-based studies (Chapter 4).
2. To review and devise a technology strategy for capturing designer behaviour and activity (Chapter 5).
3. To create an empirical method to capture, code and analyse designer behaviour and activity (Chapter 6).
4. To identify and characterise designer behaviour and activity for critical design situations (Chapters 7, 8 and 9).
5. To characterise the relationship between practice and laboratory-based studies for critical design situations (Chapter 10).

1.4.5 Methodology Summary

This work builds on the existing methodological work in design research (Blessing and Chakrabarti 2009). Developing the methodology within an existing model gives a degree of standardisation while also helping to clarify the research approach. Blessing and Chakrabarti's model was selected for this work as it is widely accepted and understood in design research and as such provides the best opportunity for standardisation within the field. This model forms four distinct phases: research clarification, Descriptive Study (DS) one, Prescriptive Study (PS) and DS two. This methodology has been used as the foundation for this work (Chapter 4). It is important to note that although this work builds on Blessing and Chakrabarti's work the methodology developed for comparing the various empirical contexts is itself distinct. Figure 1.1 outlines the overall progression of the work, highlighting the major stages and stage gates as well as their associated chapters in this thesis (TS – Technical Scoping, P – Practice, L – Laboratory, I – Intermediary). This gives an idea of the order in which the work has been carried out as well as when key elements were specified e.g. the critical design situations are selected *after* the study outlined in Chapter 7.

Research clarification was undertaken primarily through a review of the literature in design research and its associated fields, as well as a series of workshops in method development and empirical research design (Chapters 2 and 3). DS one was developed from a synthesis of problems and mitigating techniques identified in the literature and subsequent prototyping work. The main capture and analysis methods were also developed at this stage.

The PS used situations identified in practice and replicated these in the laboratory. This was then used to form a direct comparison with analogous situations in practice achieved using a coding protocol that allowed for coding of both types of study. DS two then validated these findings by implementing the contrived laboratory situation, used in the PS, in practice with practitioners. Finally links were drawn between these three studies using the common coding protocol as a foundation for comparison. To summarise, the following work was undertaken:

1. Literature review of design and the associated fields.
2. Literature review of capture technologies and a technical assessment using a scoping study.
3. Three main studies – observational, laboratory and intermediary.
4. Comparison of the three studies and the identification of relationships
5. Validation of the relationships using studies extant within design research.

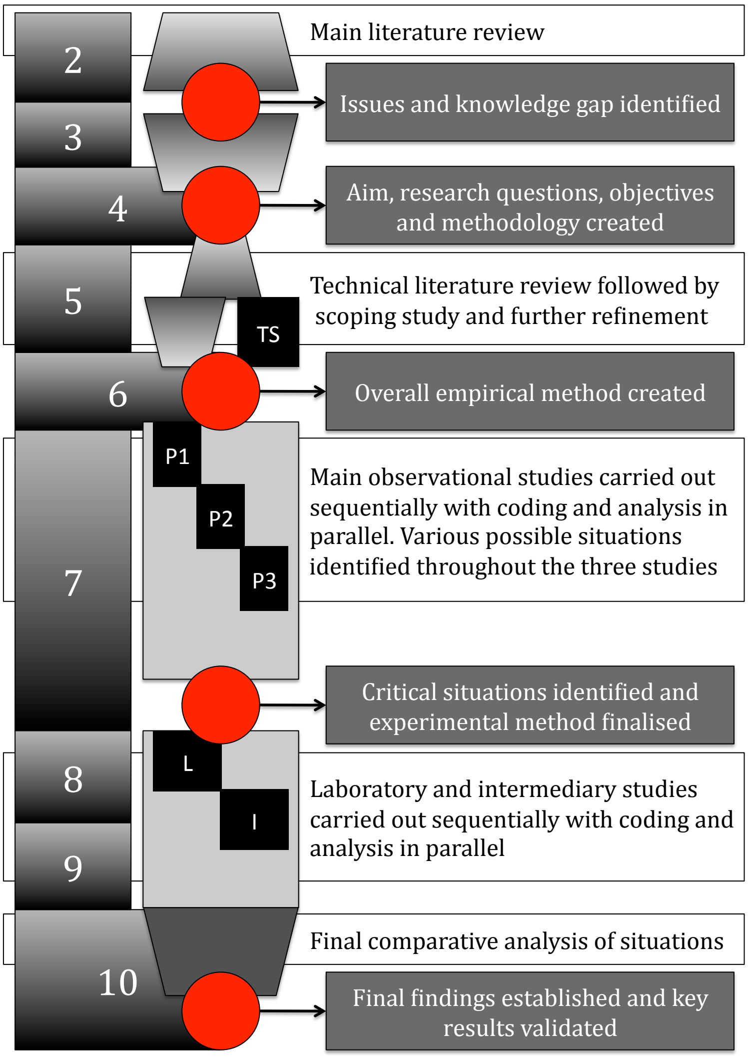

Figure 1.1: Overall approach with key work and stage gates highlighted

1.4.6 Content

This section summarises the content of this work, giving an overview of the purpose, methods and contribution of each chapter in the remainder of this thesis (Figure 1.2).

Chapter 2: Review of Design Research

Chapter two describes the background for this research and reviews the methodological aspects of design research. This chapter identifies the knowledge gaps to be addressed and highlights the major methodological issues affecting empirical design research.

Chapter 3: Review of the Associated Fields

Chapter three describes the methods, methodology and theory of the core associated fields: social, education, psychology, behavioural and clinical research. The primary outcome of this is the identification of a number of problems and methods common to design research and the associated fields.

Chapter 4: Research Methodology

Chapter four describes the overall research methodology and lays out the structure of the research and the studies. It also discusses the scope and limitations of the research and how this affects the subsequent studies.

Chapter 5: Technology Selection

Chapter five reviews existing laboratories and technologies as well as outlining a prototyping study. The outcome of this is the identification of the optimal technology and deployment strategy for capturing the required empirical data.

Chapter 6: Proposed Empirical Method

Chapter six outlines the core method for undertaking the observational studies. This includes the development of a novel multifaceted capture approach as well as a layered coding and analysis protocol utilising multiple information streams – both qualitative and quantitative.

Chapter 7: Observational Study of Practice

Chapter seven describes the specific methods used in the practice-based study and the format of the results. The chapter also gives background on the participant company and practitioners and describes the results of the observational study. Finally, three critical situations are identified and characterised.

Chapter 8: Laboratory Study

Chapter eight gives the method for undertaking the laboratory studies using students as participants. The same coding and analysis approach was used to allow the comparison of the studies. Finally the results are described in detail and characterised for the student population.

Chapter 9: Intermediary Study

Chapter nine implements the laboratory recreations in industry again using the same capture and analysis methods for comparison purposes. This provides a baseline case for a contrived task in industry. Finally the results are described in detail and characterised for the practitioner population.

Chapter 10: Characterising the Relationship Between Laboratory and Practice

Chapter ten compares the three studies in detail. Each study is related across the range of metrics, both qualitative and quantitative. The primary output of this process is the identification of overarching relationships between the critical situations in the laboratory and practice.

Chapter 11: Overall Discussion

Chapter eleven discusses the implications of the findings, relating them to the objectives, research questions and aim. This chapter also discusses research limitations and threats to validity.

Chapter 12: Conclusions

Chapter twelve identifies the main contributions to knowledge, the overall contribution of this work and identifies important areas for future research.

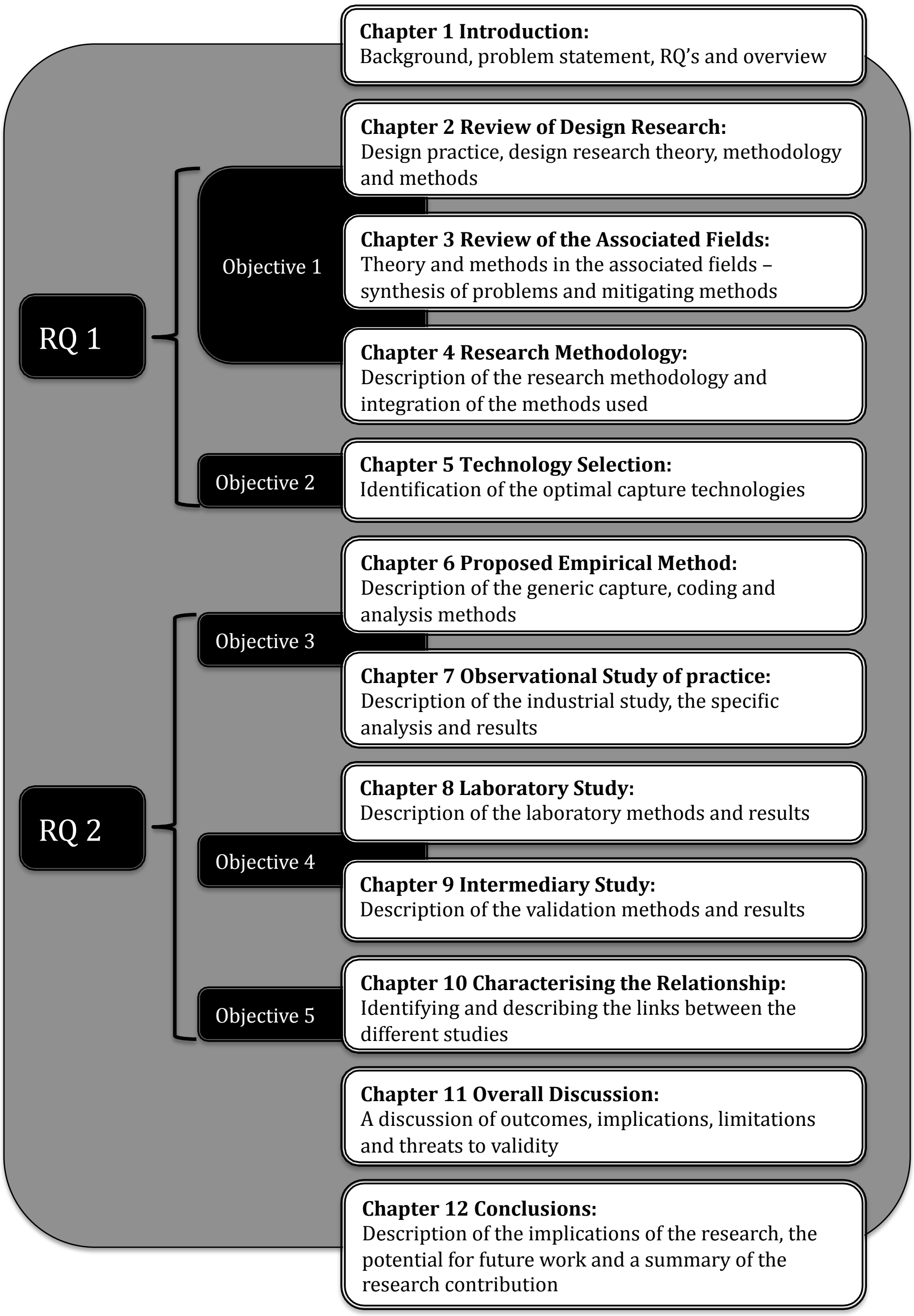

Figure 1.2: Thesis diagram

"First learn the meaning of what you say, and then speak"

Epictetus

2

Review of Design Research

Design research has an extremely wide range of research foci and associated methods, including computational modelling (Schuette and Rotthowe 1998), abstract theory development (Hatchuel and Weil 2003), process modelling (Tang et al. 2010), tool development (Yamashina et al. 2002) and human-centric research (Stones and Cassidy 2010). However, as the main aim of this research is associated with empirical design research involving designers the review focuses on this area and is not intended as a commentary on areas outside this scope. As such the methodological review has four specific aims:

1. The review seeks to establish and develop the important issues associated with empirical design research – particularly involving human subjects. These issues are identified through a systematic review of empirical methods in design research and are used to form the basis for the identification of research gaps and the formulation of the research aim.
2. It aims to show that design research is closely linked to a number of associated fields and that these can be used to guide the solution of the identified research question.
3. It explores and develops core issues by drawing on a review of the associated research fields. The core issues are subsequently analysed and categorised and

further investigation of the literature is undertaken to identify suitable techniques to mitigate these issues – reduce the threat to research validity (Table 2.1). Mitigating approaches are established based on a synthesis of techniques that have been shown to work effectively in both design research and the associated fields. The implications and benefits of addressing some of these core issues and applying the mitigating approaches are discussed using two exemplars of particular relevance to design research.

4. Finally, with the core issues established to be common and a number of mitigating approaches explored, the review is used to form the basis for addressing the identified research aim.

These four stages have been split into two chapters for clarity – Chapter 2 focuses on design research and the initial identification of the research aim whilst Chapter 3 focuses primarily on the associated fields and their implications for this research. In particular Chapter 3 brings together the literature necessary to develop the methodological approach created in Chapter 6 (the term 'associated fields' is used throughout this paper based on the six domains of design identified by Freidman (2000)).

There are a number of terms that are used extensively throughout this review and definitions are summarised in Table 2.1 for clarity. There are a wide variety of overlapping definitions and uses of these terms in the literature thus this is a distillation; forming a foundation set, used throughout this work.

Table 2.1: Definitions of terms

Term	**Description**
Core issue	This is used to describe fundamental groups of issues affecting a particular aspect of empirical research such as control and normalisation
Issue	This is used to describe specific problems which form a sub set for each core issue
Mitigation	The reduction or elimination of experimental error associated with research activities
Mitigating approach	This is used to describe overarching groups of techniques affecting a particular aspect of empirical research such as control and normalisation
Mitigating technique	This is used to describe the specific tools, techniques and methods which form a sub set for each mitigating approach

Review of Design Research

Considerable work has been undertaken to improve empirical methods used in design research (Adelman 1991; Cross et al. 1996; Gero and Mc Neill 1998; McDonnell and Lloyd 2009). However, there remain a number of issues affecting both design research and its associated fields that will be explored during this methodological review. Design research is a diverse field, indeed there is some difficulty in establishing what exactly bounds appropriate design research methods (Horvath 2004). It can thus be difficult to support the improvement of standards as underlying issues and methods may not always be fully appreciated across the field. As a consequence, a lot of the methodological approaches used when studying designers are based on a particular researcher's focus, background or viewpoint. For example, consider two approaches for describing and researching about design creativity: Dorst and Cross (2001) used protocol type methods to validate a theoretical model and Howard et al. (2008; 2008) integrated elements of psychology into design research and then validated their findings using participatory action research.

What do we learn from the variation in what is considered good research work highlighted throughout this review? We learn that there is a range of methods and approaches used, but with little clear guidance on what the important issues for their application are or how they can be identified or mitigated. This was highlighted by Blessing and Chakrabarti (2009) who state that: "the observed lack of scientific rigour, in particular with respect to the application of research methods, the interpretation of findings, the development of support and the validation, and documentation of results" (p.8) are major issues in design research. There is also a lack of clarity as to what particular aspects of design research these methods and approaches actually apply (Friedman 2003; Horvath 2004; McMahon 2010). This lack of guidance for research methodology was recognised and exemplified by Blessing and Chakrabarti (2009) and led to the subsequent development of their 'Design Research Methodology'.

Notwithstanding this existing work, an important area that has not been given significant attention is the contribution from similar or associated research fields such as social, education, psychology, behavioural and clinical research. Thus one purpose of the review sections of this thesis is to address this gap and to show how and where learnings from the key related disciplines – listed above – can be used or integrated into empirical design research.

2.1 Review Method

This section introduces the method used to conduct the review. This section explores the review method before leading into the first part of the review proper (Section 2.3). As such, this section establishes the scope and method used to carry out the review.

This section outlines the review method with particular attention given to the scope and keyword search. The wide scope of design research means empirical methods draw on numerous aspects of other associated fields as highlighted by Hanington (2007) in his discussion of generative methods. This in turn is reflected in this review. Friedman (2003) establishes six associated fields: the natural sciences, humanities and liberal arts, social and behaviour sciences, human professions and services, creative and applied arts and technology and engineering (Friedman 2003; Horvath 2004). Of these associated fields only those most closely related in terms of empirical context to this research were selected for further investigation– i.e. human subjects in complex environments. These were: social and education research, psychological and behavioural research, and clinical research. These fields were selected, as they are the main fields associated with the exploration of human behaviour in complex environments. Although there are between these fields, the review aims to clearly link each to design research and demonstrate the commonality of core issues, approaches and techniques. To achieve this the review aims to:

- Contextualise in relation to design research and the other fields.
- Understand how issues and mitigation manifest in design research.
- Draw effective parallels between design research and its associated fields.

The review consists of two elements, a systematic keyword search and a classic literature survey. The systematic keyword search was used to identify patterns, trends and directions for further reading/searching, building on existing sampling methods (Schiller and Mandviwalla 2007). This was primarily used to give quantifiable support to claims, identify important trends, and to clarify the focus and scope of the review. The journal series of Design Studies (using the ScienceDirect (2011) database) and Research in Engineering Design (SpringerLink 2011) were selected to represent design research. These journals were selected for two reasons: they focus on research methods and they have the highest impact factors in the design research field (1.354 and 1.25 respectively). Keywords were then selected from terms found to be common, including: empirical, review, methods, critique and theory. With the search terms selected two searches were carried out:

- Full text searches to establish general trends.
- Title, abstract and keyword searches to identify potentially important gaps or similarities.

Both used the range 2000-2010 and the ScienceDirect (2011) and SpringerLink (2011) databases. The search terms used were: experiment, empirical, review, research methods, case study, critique, critical, reflect and theory. This was then used as the basis for starting the literature survey, which explores the different areas based on existing reviews, expanding through linked papers as well as searching based on the indentified works, allowing a wide range of sources to be covered.

Figure 2.1 outlines the structure of the review chapters. Based on the abstract, title and keyword search, all abstracts and conclusions were examined with relevant papers being reviewed in full (Figure 2.1). The combination of review approaches allowed the review to be effectively directed while covering a wide scope. Once the papers had been reviewed it was possible to synthesise issues and techniques in each field as well as identifying particularly relevant exemplar issues and techniques for design research.

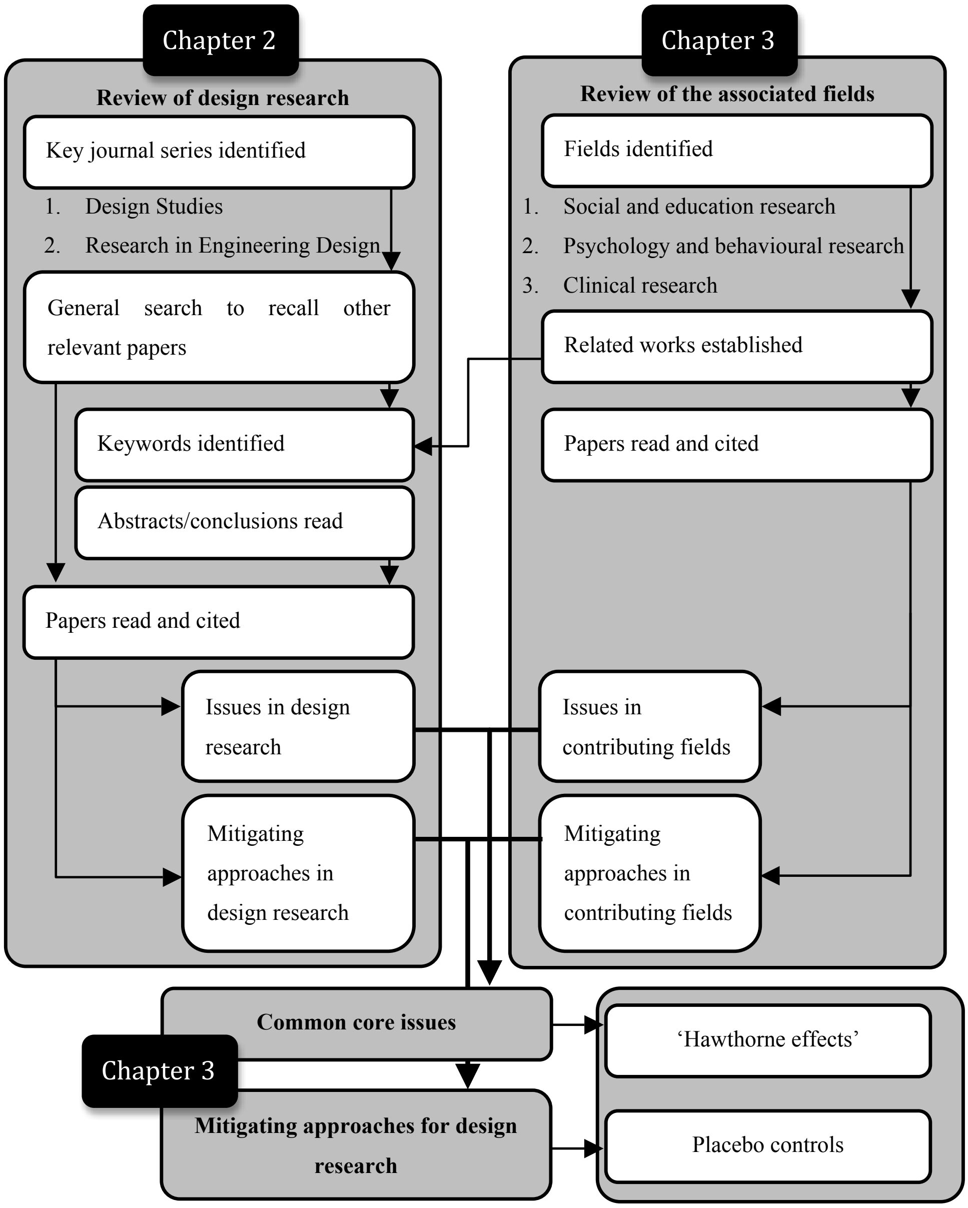

Figure 2.1: Method diagram for the review outlined in Chapters 2 and 3

2.2 The Keyword Search of Design Research

With the method established, it is necessary to examine the results of the keyword search (Section 2.2.1) and to identify those fields associated with or related to design research (Section 2.2.2).

2.2.1 Results from the Keyword Search

With the method established, it is important to clarify the context in which design research is situated and subsequently the most appropriate reviewing approaches. Friedman (2000) identifies four areas underpinning design research: philosophy and theory, research methods and practices, design education and design practice. In order to build practical and robust research, it is necessary to consider these areas synergistically (Manicas and Secord 1983; Cook 2000; Briggs 2006). This synergy is commonly sought through the use of empirical and experimental study (Salomon 1991; Edmonds et al. 2005; Blessing and Chakrabarti 2009). The perceived value of empirical study can be seen in the number and scope of the studies carried out under its auspices (Horvath 2004; Tomiyama et al. 2009). For example, Horvath identifies nine broad areas of design research while Tomiyama identifies 23 different design theories or methodologies. Highlighting these points are the works of Lloyd et al. (2007), who emphasize the scope of empirical approaches, and Gero and McNeill (1998), who underline the power of an empirical approach for providing insight.

Figure 2.2 shows the steady increase in experimental papers over the last ten years based on keyword searches (Section 2.2.1). This emphasizes the on-going importance of empirical and experimental study within the design research field (linear best-fit lines have been used to show trends). However, over the same period (2000 – 2010), the number of papers using the term 'research method' as a phrase in their title, abstract or keywords, was only 40. This highlights a possible disparity between methodological development and design research experimentation. The need to develop methods, theory and methodology specific to design research is emphasized by Blessing and Chakrabarti (2009), and Ball and Ormerod (2000). In response to this, there is an increasing demand for effective empirical methods.

Design research is an increasingly diverse field as exemplified by the works of one single author, ranging from machine design (Hicks 2007), to personal information (Hicks et al. 2008), and ethnographic studies (Hicks et al. 2008) over a single year. With this variety comes a number of issues such as complexity of mixing methods (Hansen et al. 2001), potentially limited impact due to constrained resources (Lindahl 2006), and numerous methodological and theoretical issues (Cook 2000) such as comparability and context. Again, this demands the development of effective research methods and theory. However, in order to effectively develop new methods it is important to understand the state of the art in associated fields where similar research is undertaken.

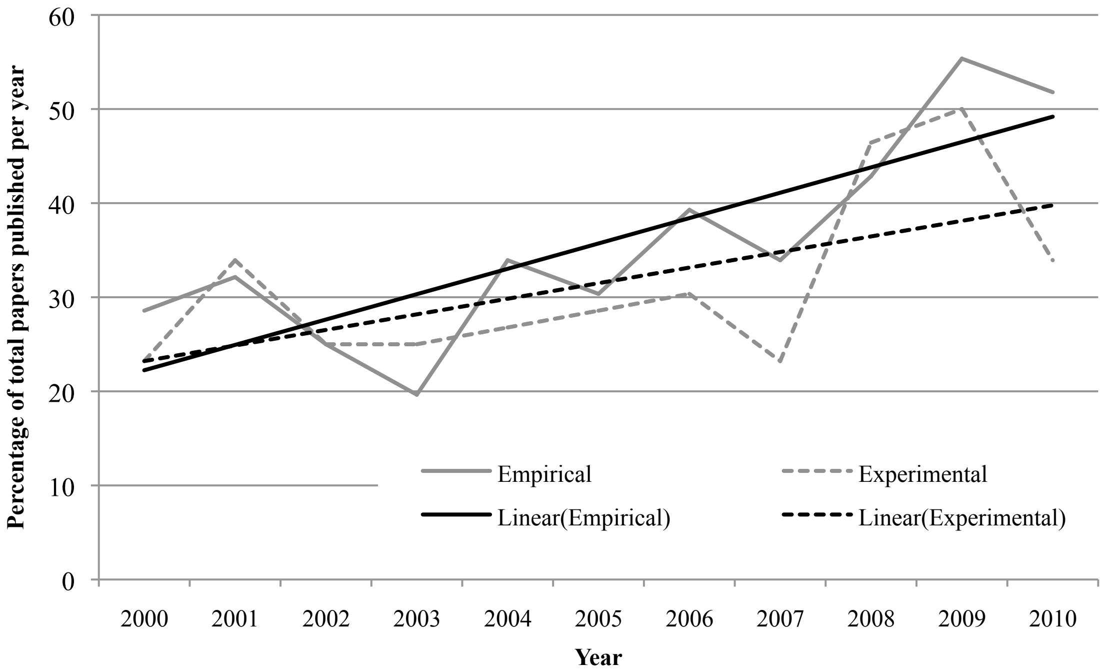

Figure 2.2: Percentage of papers responding to the terms "Empirical" and "Experiment" over the last ten years (hits/total papers)

2.2.2 Parallels with the Associated Fields

Design research is by no means alone in facing the issues outlined here and many parallels can be drawn with the associated fields where the issues have been researched for some time. Examples include the on-going debate about which methods yield the strongest evidence (Cook 1962; Gorard and Cook 2007); the conflicting demands of flexibility and standardisation (Miles and Huberman 1994); validity and reliability (Adelman 1991); the need for both laboratory and field studies (Salomon 1991); improving uptake and impact (Glasgow and Emmons 2007); and the constraints of practicality (Dong et al. 2004). These factors combine to affect all types of validity, replicability, reliability (Ball and Ormerod 2000), uptake and impact (Goodman-Deane et al. 2010), much as in design research (Adelman 1991; Gray and Salzman 1998). There are a number of terms that define different aspects of validity and reliability, which are used in design research and throughout the associated fields. As much of this chapter is focused on how these factors affect design research, it is essential to build on a common foundation, in order to be able to effectively draw on the learning's identified in the associated fields. As such Table 2.2 summarises these common terms, highlighting their relevance to the issues discussed in this review. It should also be noted that as design research is a relatively young field

(Finger and Dixon 1989; 1989; Cross 2007) compared to many of the associated fields, its nascent development of specific methodology, methods and theory is unsurprising.

Table 2.2: Terms affected by research methods and issues

Term	**Description**
Validity Different types:	Demonstrating that the study and its findings are well founded and rigorous
Internal*1&2	Establishing causal relationships: showing that certain variables lead to certain other variables
Causal construct*2	Having good methods or operations to measure the concepts being studied
Statistical conclusion*1	Ensuring there is sufficient sensitivity to support any stated conclusions
External*1&2	The generalizability of the results in different contexts, populations etc.
Conclusion*2	Conclusions and advice outside the scope of the data set are explicitly split
Replicability*4	The study operations can be repeated with the same result
Reliability*1,4&5	Same as above – also used to mean: the relevance of study results in practice
Uptake*3	The level to which the research is adopted in practice/research community
Impact*3	The level of effect the research has on practice/research community

*Relevant definitions or references: *1(Adelman 1991), *2(Gray and Salzman 1998), *3(Glasgow and Emmons 2007), *4(Goetz and LeCompte 1981), *5(Pope and Mays 1995)*

With the context of design research and it links to the associated fields established it is now possible to review design research effectively.

2.3 Design Research

As highlighted in Section 2.2.1, design research is a complex multifaceted field reflecting the highly complex nature of design. Further to this, design research is an impact-orientated field, specifically focused on affecting practice (Cross 2007). However, in order to effectively change the design process through research, clear, effective and valid research methods are needed. As such this section explores the three main aspects of design research methods – theory and methodology, research methods, and validation – before examining empirical study specifically. In addition to specific design research literature, relevant work from the fields of software design, product design and human computer interaction are included in this review.

2.3.1 Research Theory and Methodology

Horvath (2004), amongst others (Pettigrew 1990; Lloyd et al. 1995; Friedman 2003), highlights the high level of diversity and interlinked nature of design research and its associated fields. Examples include Frey (2006), who explores the relationship with clinical research, and D'Astous (2004), who draws on cognitive research. Despite this diversity, one uniting factor is the drive for impact on design practice. However, numerous interrelated issues affect impact. Briggs (2006) emphasizes the need for both scientific and pragmatic engineering elements in order to develop applicability. This manifests as the need to link experiments, field studies and reality through theory (Moreau and Back 2000; Sheldon 2004; Sheldon 2006).

Briggs (2006) states that without linking theory, scientific research is impossible as studies cannot be separated from their context. Buchanan and Gibb (2008) also emphasize the need for methodological development to link theory and empirical study. Blessing, Chakrabarti and Wallace (1998; 2009) acknowledged many of these points in their development of DRM. Hanington (2007) and Robson (2002) emphasize the use of complementary qualitative and quantitative methods, again, highlighting the need for a theoretical and methodological framework in which to combine them. Despite the importance of theory and methodology, it is, at present, neglected in design research compared to its associated fields (Blessing and Chakrabarti 2009; Tomiyama et al. 2009). This is highlighted by Blessing and Chakrabarti's discussion the methods used in design research, where they note that methods adopted from the associated fields are often poorly understood due to a lack of field specific expertise in design research methods.

"*The unfamiliarity with many of the methods also leads to incorrect use, resulting – unknowingly – in biased and useless data.*" (p. 8)

This is further emphasized by the small number of papers focused on research theory as outlined in Table 2.3 (<15% of responses for the keyword 'theory'). There are, however, some notable examples such as Stempfle and Badke-Schaub (2002) who use laboratory-based studies to build and validate theory. Indeed, there has been considerable work in developing theory for the design process i.e. theory relating to design practice and how it should be carried out (Pahl and Beitz 1996; Suh 1998; Hatchuel and Weil 2003; Gero and Kannengiesser 2004). However, this is not mirrored by research-focused theory development i.e. theory relating to the research methods or methodology. This further highlights the importance of theory building and the lack of theory development in design research.

Table 2.3: Design research keyword review breakdown

Search term	**Search restrictions**	**Journal**	
		Design Studies	Research in Engineering Design
Experiment	Full text– 2000 - 2010	194	35
Empirical	Full text– 2000 - 2010	220	41
	Total	414	76
Experiment	Abstract, title and keywords – 2000 - 2010	31	20
Empirical	Abstract, title and keywords – 2000 - 2010	40	9
Review	Abstract, title and keywords – 2000 - 2010	22	10
"Research methods"	Abstract, title and keywords – 2000 - 2010	25	15
"Case study"	Abstract, title and keywords – 2000 - 2010	60	13
Critique	Abstract, title and keywords – 2000 - 2010	1	0
Critical	Abstract, title and keywords – 2000 - 2010	16	9
Reflect	Abstract, title and keywords – 2000 - 2010	4	3
Theory	Abstract, title and keywords – 2000 - 2010	60	26
	Total	259	105

2.3.2 Research Methods

The diverse nature of the design research field means that there is a wide range of methods used. As the research reported in this thesis is focused on the designer as the core element of design research, this section will predominantly focus on human-centric methods.

Theory

In addition to the work of Lloyd et al. (1995; 2007) various authors highlight the numerous perspectives from which to view the design process. For example, Smith (1998) emphasizes the scope of empirical investigation in design research, noting observation of the designer as an area of particular breadth. Martin et al. (2006) also draw attention to the multiple views of the design process, highlighting the disconnect between theory and methods. Finally, Valkenburg and Dorst (1998) identify four coding schemas (for reflecting on the design process) at the project level and use these to emphasize the large number of metrics and the lack of theoretical guidance for examining the design process. This finding is of particular importance because Valkenburg and Dorst's coding schemas were specifically chosen to provide concise accounts of long periods with minimal 'data loss'. Due to this lack of theoretical clarity and subsequent guidance, Valkenburg and Dorst conclude that it is unclear what other researchers might require for validity and reliability and how this could affect their data gathering. This again highlights the lack of theoretical grounding in empirical methods and links to the wide range of influences brought together by design research.

Methodological Diversity

In drawing on numerous different fields, design research combines techniques from many research perspectives. This diversity can be clearly demonstrated by taking a number of examples of empirical studies in design research. Edmonds et al. (2005) discuss what they describe as the 'complex, unpredictable and apparently unstructured' nature of collaborations between art and technology. Gero and Tang (2001) focus on the particular problem of long-term memory decay when conducting protocol studies. Ball and Ormerod (2000) and others (Bucciarelli 1988; Button 2000; Robinson et al. 2007) focus on adapting ethnographic techniques for use as practical tools, termed applied ethnography. Although these studies cover a range of topics and issues, they are typical of a wide and extremely diverse field. In addition to these examples, design research has drawn on methods from a varied set of fields. Examples include: the ethnographically informed work of LeCompte and Goetz (1982), Purcell and Gero's work on protocol studies (1998), Hansen et al.'s work on ontology (2001), and Lloyd et al.'s work on designer behaviour (2007).

Although there is much that is similar in the associated fields, it is important to acknowledge that design research is often unclear about its research goals or primary focus: directly aiding practice or developing scientific knowledge. Thus, it is critical to not only understand the many available methods, but to use this understanding to adapt them to the purposes of design research. Ball and Ormerod (2000; 2000) offer a classic example of this by discussing the principles of applied ethnography with regard to design research. They initially identify the key features of 'pure' ethnography before characterising how this can be adapted to serve the more interventionist purposes of design researchers. Other than this major differentiating element, they go on to highlight distinguishing features such as the intensity of observation, being less independent of prior theory, and requiring a degree of verifiability or objectivity in interpretation – comprising a synthesis and formalisation of ideas already extant within design research (LeCompte and Goetz 1982; Bucciarelli 1988; 1990; Baird et al. 2000).

Methods

Further to the profusion of methodological influences, there are a similarly large number of empirical methods. Lloyd et al. (1995) uses an examination of 'thought aloud' protocols as the bases for highlighting several key issues. Firstly, methods used to examine designers or the design process can themselves affect the observed system e.g. the concurrent verbalisation technique can affect designer performance (Gero and Tang 2001). Secondly, 'designing' is a number of interlinked cognitive activities and not one isolated process. Gero and McNiell (1998) also emphasize the lack of research that is based on quantifiable evidence as apposed to anecdote, particularly in relation to designer behaviour.

Due to the complexity in the interaction between the designer and design process, it becomes clear that a single method or metric is unlikely to provide the breadth of information necessary to effectively develop theory. As such, Lloyd et al. (2007) propose an entirely different research approach: the common data set method. This method uses multiple complementary analysis approaches to assess a single data set rather than attempting replication. Although this superficially seems to solve some of the issues highlighted in this section it is argued that it fundamentally builds upon the same foundations of validity and reliability and is thus affected by many of the same issues. This is exemplified by the rather inelegant adage, “garbage in – garbage out” (Lidwell et al. 2010), i.e. if the core study is not conducted in a rigorous manner, no amount of common analysis will yield valid results.

Metrics

Although this diversity of methods has many strengths when applied effectively it also has a critical inherent weakness. This is that methods are applied without the required theoretical understanding or adaption necessary. This can lead to a lack of clarity, confusion of results or methods, and, ultimately, reduced validity and reliability. An example of one such issue emerges from the profusion of works on measuring the design process. This is highlighted by Mabogunjie and Leifer’s (1996) work to introduce ‘noun phrases’ as a metric due to the lack of a clear single performance measure. Other metrics include, Purcell and Gero’s (1998) descriptive ‘drawing activity’, Smith’s (1998) use of ‘total time to completion’, or Bakeman and Deckner’s (2003) use of quantitative coding of behavioural streams. Although each of these initially appear to offer a solid basis for assessing performance, it quickly becomes unclear as to when and where each metric is appropriate or how they should be combined to develop theory effectively for the multiple contexts encountered by design research.

The key issues identified from this review are: lack of theory, the complexity of design research and inappropriate use of methods. These align with the points highlighted by Dyba and Dingsoyr (2008), who review 33 design research studies. They found that of the 33 studies examined only eight scored ‘ok’ for sampling and only ten for the use of control groups. Most notable is the finding that only one scored ‘ok’ for the consideration of possible research bias or experimental effects. They go on to summarise the main issues they found throughout the review as follows:

> “*We frequently found the following: methods were not well described; issues of bias, validity, and reliability were not always addressed; and methods of data collection and analysis were often not explained well. None of the studies got a full score on the quality assessment…*” (Dyba and Dingsoyr 2008) (p. 842)

Although the review of Dyba and Dingsoyr focuses only on design research, its findings are consistent with the issues identified throughout this review. This highlights the commonality and severity of methodological issues in design research. Based on the findings outlined in this section, it is important to further examine the scope of methods and issues in empirical design research specifically (Section 2.4). However, before that can be carried out, it is first necessary to briefly outline what validity and reliability mean in this context and how they relate to design research.

2.3.3 Validity and Reliability

Validity and reliability are both extremely relevant and in need of development in design research. Although LeCompte and Goetz (1982) are from education research they succinctly highlight the relevance of these factors with regards to scientific research in general, emphasising the nature of validity and reliability in research with the following statements:

"*The value of scientific research is partially dependent on the ability of individual researchers to demonstrate the credibility of their findings*." (LeCompte and Goetz 1982) (p. 31)

Expanding on this, this section draws on numerous fields for the discussion of validation as there is little research focused on this area in design research itself, as highlighted by Barth et al. (2011) who note that 26 out of 71 reviewed studies included no validation. This emphasizes the need to develop the credibility of research not only within the research community but also in the wider field, distilling a major theme identified by many other researchers (Smith 1998; Ball and Ormerod 2000; Edmonds et al. 2005; Hemmelgarn et al. 2006). Further to this LeCompte and Goetz (1982) emphasizes the need for both internal and external validity in order to develop research across multiple perspectives and allow the reuse and development of studies by multiple researchers. This is again highlighted by numerous researchers within design research: D'Astous et al. (2001; 2004) emphasize the use of multiple perspectives in order to drive validation, while Hansen et al. (2001) and Lloyd et al. (2007) develop the importance of developing common methods and data respectively; finally Dyba and Dingsoyr (2008) stress many of the aspects associated with validity and reliability in their assessment of research methods. Many of these issues are concisely summarised by LeCompte and Goetz as external and internal reliability:

"*External reliability addresses the issue of whether independent researchers would discover the same phenomena or generate the same constructs in the same or similar settings. Internal reliability refers to the degree to which other researchers, given a set of previously generated constructs, would match them with data in the same way as did the original researcher*" (LeCompte and Goetz 1982) (p. 32)

In order to improve validity and reliability, many of the previously cited authors have argued for improved methods, formalised theoretical frameworks and the development of control and evaluation procedures. Hansen et al. (2001) highlight the development of a common methodological perspective to facilitate communication, reuse, method improvement and ultimately validity. To this end, Hansen et al. propose an ontological approach to forming such a framework as a starting point for addressing these issues. LeCompte and Goetz (1982) and others (Smith 1998; Ball and Ormerod 2000; Hemmelgarn et al. 2006) note the importance and current lack of effective recording and reporting of contextual factors, researcher influences and measures of validity and reliability. The specific need for recording contextual factors using mixed qualitative and quantitative methods is highlighted, in particular, by Gray and Salzman (1998), Ball and Ormerod (2000), and Dyba and Dingsoyr (2008).

With the acknowledgement of these issues there has been a drive to develop improved methods and techniques in order to address the critical issues of validity and reliability. Gray and Salzman (1998) decompose validity into a number of areas (see also Section 2.2.2 for a summary of terms). Understanding how each of these areas can be developed is key to effectively assessing the weaknesses of current methodological practice and as such they are outlined in this section.

Statistical conclusion validity: This uses effective planning to triangulate multiple measures for a single question to give better statistical validity (LeCompte and Goetz 1982; Lloyd et al. 1995). Further, Gray (1998) highlights the use of multiple experiments with different participants including practitioners to improve statistical significance. Finally, planning to effectively focus a study during the method development phases is critical to avoiding the collection of excessive inappropriate information (Lloyd et al. 2007).

Internal validity: Baselining participant factors such as training, tools, environment, background and group composition to reduce variation as much as possible (Gray and Salzman 1998; Hemmelgarn et al. 2006). Hemmelgarn et al. (2006) go further, detailing the need for randomization and rigorous control groups to account for such factors. Randomization – in participant selection and test allocation – is of particular importance and is highlighted by numerous authors (Torgerson and Torgerson 2003; Verstappen et al. 2004). Using rigorous coding schemes as well as checking them with controls such as Cohen's Kappa (a measure of inter-coder reliability) (Bakeman and Deckner 2003). Finally, Kitchenham et al. (2002) detail the appropriate capture and reporting of experimental context.

Causal construct validity: It is critical to explicitly detail the operations and methods used. Using independent groups to test each tool or treatment. This is expanded upon by Kitchenham et al. (2002) who note a number of factors that must be considered during the experimental design phase. Again, the use of appropriate controls such as randomization, placebo groups and blindness are emphasized (Gray and Salzman 1998). The use of multiple independent observes and the idea of participants themselves informing and 'checking' inferences is introduced by LeCompte and Goetz (1982) and used recently by Robinson (2010).

External validity: This is driven by replication and if this is not possible, the explicit description of possible restrictions affecting scope of findings (Gray and Salzman 1998). It is also important to thoroughly examine possible limitations using tools such as deviant case analysis (the specific study of cases qualitatively or quantitatively different from the expected result) (Alan 1963; Lloyd et al. 1995; Ball and Ormerod 2000). This is highlighted by Kitchenham et al. (2002) who identify data collection and accurate reflection of deviant cases and experimental dropouts as critical factors.

Conclusion validity: It is important not to assert conclusions that are outside the data set recorded (Gray and Salzman 1998; Ball and Ormerod 2000). When the researcher aims to give advice based on their experience rather than the specific findings of a study, it should be explicitly separated from the conclusions (Gray and Salzman 1998). This is explored in detail by Kitchenham et al. (2002) who also highlight the need for appropriate methods of analysis and presentation. This is further supported by the work of Dyba and Dingsoyr (2008), who use this as one part of their quality assessment.

2.4 Empirical Design Research

As highlighted in Section 2.3 empirical research plays a key role in modern design research. The main reason for this is probably the practice focused nature of the field and the overwhelmingly positivist philosophy. Empirical study takes two main forms: observation and experimentation, with a spectrum of approaches existing between these two extremes. These can be deployed individually or in combination to answer a wide range of research questions. This section explores the scope of observation and experimentation in design research and in addition to the basic review aims to highlight common issues affecting work in the field in order to guide the subsequent method development work.

2.4.1 Observation and Experimentation Issues

This section examines a number of studies, critiquing various aspects of the research in order to identify common issues and knowledge gaps. Issues are highlighted and discussed throughout this section before they are distilled into overarching issues in Section 2.4.3.

One major issue is the complexity of design research studies and the difficulty of disentangling causal relationships. Several researchers propose methods for countering this. Bucciarelli (2002) uses a philosophical, high level approach while Fischer et al. (2005) focus on the construction of a theoretical framework in order to establish wider patterns. There are several examples where high level theory and framework-based approaches have been used to structure and compare empirical findings. Yamashina et al. (2002) examine the integration of the design tools QFD and TRIZ while Hicks et al. (2002) explore a theoretical framework for reuse. The use of such an approach allows researchers to develop comparisons, identify patterns and describe behaviours in a general manner without being burdened by identifying specific causal relationships (Cross 2004; Goldschmidt and Tatsa 2005; Hertel et al. 2005; Robinson 2005).

Although this approach can offer insights, it can lead to issues if links between the framework, theory and empirical findings are not fully developed. Abdel-Hamid (1996) uses specific examples embedded within a pre-existing framework to simulate experiments. However, this is used to give extremely general statements despite focusing on a relatively limited number of studies where context and theoretical underpinnings are neglected. Prudhomme (2007) does not try to establish causal relationships, instead focusing on a rich description of the general effect certain variables produce. Although this method appears to simplify causal reasoning it invokes a number of other issues; in particular there is no standardised means of linking descriptions into a coherent whole. Ultimately this leads to difficulties in replication and internal validity. This can, however, be countered through the use of rigorous definition and standardisation (Pettigrew 1990; Robinson et al. 2007). It is to be noted that Pettigrew highlighted this more than twenty years ago in organisational science.

One factor highlighted by Prudhomme's (2007) study is the lack of contextual characterisation in design research. This is an extremely important issue and negatively affects reuse as well as validity and reliability. Although most authors treat study specific aspects of context, areas regarding population, background, culture and setup are commonly neglected. For example, Mulder et al. (2002) use a population of students but do not describe their background and fail to define relevant terminology; Lahti et al. (2004) also neglect factors other than their primary experimental metric while Sosa et al. (2003) also fail to define critical terminology. This negatively affects the reliability, rigour and validity of a study (Dorst and Cross 2001; Bergstrom et al. 2005; Eris et al. 2005).

The importance of fully characterising context and the detrimental impact of its omission in terms of reuse, validity and reliability have been highlighted by several authors (Robinson et al. 2005; Dillon 2006; Robinson et al. 2007; Sharp and Robinson 2008). Dillon (2006) uses the notion of place as a core tool for describing the context of a situation and emphasis its importance in making generalizations. Sharp and Robinson (2008) develop three themes: physical, artefact and information flow to represent the overall context of a situation. Further, there are numerous examples where context has been well characterised and forms an integral part of validity and reliability, further highlighting its importance, e.g. Carrizosa (2000), Kavakli (2002), Chong (2005), Chen (2007) and Bilda (2008).

In addition to the issue of contextualisation there is a lack of control for bias and experimental effects. The importance of controlling for bias is highlighted by Goldschmidt and Tatsa (2005) who note its significance in experimental validity. There are several different techniques for controlling bias such as the concepts of blindness, anonymity and randomisation (Boland et al. 2001; Luck 2007).

Other related issues are the failure to explore counter examples or to make generalizations despite insufficient data (Lahti et al. 2004). Addressing counter examples through deviant case analysis or similar techniques is important to both validity and reliability. There are numerous instances where authors have used this type of analysis to greatly increase the relevance and value of a study e.g. (Hunton and Beeler 1997; Goldschmidt and Tatsa 2005; Sharp and Robinson 2008). However, it is also extremely common for studies to neglect this type of analysis reducing their overall impact, e.g. Kavakli (2002), Bergstrom (2005), Luck (2007) and Kim (2008).

One method that has been used in an effort to improve deviant case analysis is that of participant feedback. Robinson et al. (2005; 2007) highlight this as a key method for assessing the external validity of a study. A second technique used to account for bias and reduce experimental effects is that of control. Control can involve placebo or no-treatment groups which, when used effectively, can greatly increase the validity and reliability of a study (Carrizosa and Sheppard 2000; Chen et al. 2007). However, where these are not implemented effectively, inappropriate controls can seriously undermine findings (Chong et al. 2005), e.g. Corremans (2009).

Another major issue prevalent in empirical design research is a lack of standardisation (Hicks et al. 2002; Howard et al. 2008). There have been several attempts to resolve this, the most radical being the concept of the fixed data method where standard data is re-examined from numerous perspectives (Cross and Cross 1995). More conventional solutions are the use of common frameworks (Hicks et al. 2002), modular structuring of methods (Meehan et al. 2007), and synthesising existing definitions (Howard et al. 2008).

A final technique found throughout empirical research is that of triangulation (Mulder et al. 2002; Dillon 2006; Bilda et al. 2008). When used effectively this technique utilises multiple methods/metrics to examine a common focus from different perspectives, effectively increasing statistical and general validity (Boland et al. 2001; Robinson et al. 2005; Chen et al. 2007; Cash et al. 2011). Although this technique is both widely understood and extremely effective it is still commonly neglected or improperly utilised in design research as highlighted by Kuijt-Evers et al. (2009).

Finally, as most empirical studies involve small groups it is important to consider the possible effect of group size.

2.4.2 Group Size

A key consideration often affecting empirical design research is team size, highlighted by several authors (Brewer and Kramer 1986; Drach-Zahavy and Anit 2001; Stewart 2006). Opinion on optimal team size varies. For example, some studies show that larger teams produce more ideas (Hare 1952; Campion 1993; Guzzo and Dickson 1996), while others dispute this (Hackman and Vidmar 1970; Hwang and Guynes 1994). In general larger teams tend to take longer to reach a decision and require clear leadership to be consistently effective (Cummings et al. 1974). This is due to the fact that member dissatisfaction increases and participation/contribution decreases with size (Cummings et al. 1974; Gorla and Lam 2004). However, small teams show higher levels of tension and what Hoffman (1965) calls “ideational conflict”, preventing them from quickly settling on a single idea. This conflict makes them more conducive to creative problem solving. Various drawbacks and benefits of team size are summarised in Table 2.4.

Table 2.4: Team size drawbacks and benefits matrix

Team size	Recording method	Drawbacks/benefits
1	Concurrent Verbalisation	A single strong / weak participant may affect results. Not a suitable representation of industrial teams that are normally three or more.
2	Listen to Discussion	Dyads are not representative of larger groups, but two people remove the need for verbalisation.
3	Listen to Discussion	Strong / weak participants are balanced amongst other team members. Participant discussion is easy to follow. No parallel discussions possible.
4	Listen to Multiple Discussions	Strong / weak participants are balanced. Multiple parallel discussions may be hard to follow.
5	Listen to Multiple Discussions	The same drawbacks and benefits as having 4 people per team but the literature suggests they would also require formal team leadership to be most effective.

In addition, there are logistical requirements to consider when recording the actions of a team. As team size increases, the difficulty in recording these different aspects also increases due to the increasing amount and complexity of interaction. However, small teams (one or two people) increase the amount of silent 'thinking' time where audio and video recording are less effective. Recording small teams relies on 'thinking aloud' protocols or concurrent verbalisation where a participant gives a continuous narration of their thoughts. Although these types of protocol can be effective, there is debate as to the level of influence they have on the participants' design process – this is particularly important in practice-based studies, were concurrent verbalisation is often not possible (Cross et al. 1996; Gero and Tang 2001). The other major drawback of using small teams is that they are not widely representative, with significant differences in the behaviours of individuals and dyads when compared to larger groups (Hackman and Vidmar 1970; Salas et al. 2008).

In conclusion, team size is an important area that must be considered when designing empirical studies. From the reviewed literature four key points emerge. Firstly, it is important to acknowledged the uniqueness of individuals and dyads. Secondly, for groups facing a mix of task types, a compromise between size and ability to organize and communicate is important (Stewart 2006). Thirdly, the differences between groups ranging from three to twelve members are relatively small (Slater 1958; Baltes et al. 2002). Thus, the recommended ideal size for studies aiming to represent groups larger than dyads falls at approximately five members which can be increased or decreased for optimum performance depending on the task (Hackman and Vidmar 1970). Finally, due to the small variation caused by group size it can be argued that in cases of limited resources three members would be the minimum acceptable number to limit the influence of team size, capture approach and complexity. However, there are a number of other facets such as odd and even numbered groups, cognitive level and expertise, that affect performance. Thus careful consideration should be given based on the task at hand and the target population (Cummings et al. 1974; Stewart 2006).

2.4.3 Synthesising Current Issues

Based on the review of design research (Section 2.3) and empirical design research (Section 2.4.1) several recurring and important issues become apparent. There emerge four factors that can be distilled from the literature, which are particularly difficult to deal with. These are theory development; complex experimental systems, dealing with context and improved methods and critique – each of which is now summarised.

Theory Development

One of the main difficulties encountered by design researchers is the complex nature of the interactions between the designer, the design process and the wider context (Edmonds et al. 2005). This makes theory development extremely complex. There are a number of approaches, developed in the associated fields, used to address these factors. For example Ball and Ormerod (2000) and others (Ball and Ormerod 2000; Robinson et al. 2007) focus on adapting ethnographic techniques; Robinson (2005; 2010) focuses on diary type techniques, while Gero and Tang (2001) and others (Purcell and Gero 1998; Howard et al. 2008) look at cognition. Although much can be drawn from the associated fields, it is imperative to develop approaches with specific regard to design research (Bucciarelli 1988; Bucciarelli 1990; Ball and Ormerod

2000). To this end it is essential to be familiar with the methods used in design research and the associated fields.

Complex Experimental Systems

Another theme to emerge from the literature is the difficultly in understanding and reporting the complex systems often studied by design researchers. Bucciarelli (2002) takes a philosophical approach to identifying relationships between thought and object in design research, while Fischer et al. (2005) and others (Abdel-Hamid 1996; Yamashina et al. 2002; Hertel et al. 2005) take different perspectives, attempting to establish wider patterns or offer richer descriptions of effects rather than identify specific causal relationships. In order to develop such relationships, it is necessary to understand the underlying mechanisms at work in a system. However, at present this is hampered by the lack of underlying theory and the lack of methods that effectively elucidate complex situations. Methods, in particular, have been limited in their explorative power by the difficulties in contextualising the situation (Prudhomme et al. 2007).

Context

Context in terms of empirical design research can be taken to describe the physical, social, cultural and historical setting in which a study takes place (Dillon 2006). In terms of research, context can sometimes be used to describe the methods used or the experimental conditions. As such, numerous authors highlight a lack of context as a significant issue for validity and replicability (Robson 2002; Robinson et al. 2007; Sharp and Robinson 2008). Dillon (2006) emphasizes that the mind operates in a dynamic interaction with the environment and the task, as such it is necessary to contextualise both the task (Lave 1988; Robinson et al. 2007), the research (Sharp and Robinson 2008), the population's cultural and social context (Dillon 2006), as well as the methods and activity. Although there are good examples such as Kavakli and Gero (2002), Chong et al. (2005), Bilda et al. (2008) and others (Dorst and Cross 2001), context is often insufficiently covered (Mulder et al. 2002; Sosa et al. 2003). Although these context deficient studies succeed in many areas, each has specific failings, which undermine their overall validity as discussed in Section 2.4.1. The failure to effectively capture and report method and context affects all types of study and validity but particularly replicability and reliability.

Methods and Critique

One aspect of addressing context is the effective use and reporting of empirical methods. Numerous methodological approaches have been used in design research (Mabogunjie and Leifer 1996; Purcell and Gero 1998; Smith 1998; Bakeman and Deckner 2003). Although these methods have each had varying degrees of success, it has become clear that individual metrics are limiting and require combination and triangulation to give rich information. Lloyd et al. (2007) and others (Valkenburg and Dorst 1998; Martin et al. 2006) emphasize this by demonstrating that by using multiple methods to interrogate a single rich dataset, it is easier to discuss what is true. This is supported by Lanubile (1997), who highlights the use of complementary qualitative and quantitative data as well as effective dissemination of methods and subsequent replication. The proliferation of methods without underlying theory gives rise to a key issue: what methods are appropriate and valid, and how can they be rigorously assessed for design research? (Valkenburg and Dorst 1998).

In addition to this, the effective use of control techniques is relatively underdeveloped in design research compared to the associated fields. This also highlights a related issue – design research has a strong tendency to produce small sample size studies using idiosyncratic or under-reported methods, indeed instances of independent replication, validation or reuse are extremely rare. This is related to the detailed reporting of context. In particular there is a lack of systematic characterisation of social and cultural context, which hinders the modelling of relationships between the sample population, wider population and task in which they are involved (Lave 1988; Dillon 2006).

Dyda and Dingsyr (2008) highlight the issues of sampling, control, system understanding and effective methods in their review of 33 studies. In addition Dyda and Dingsyr found that studies consistently failed to report their methods in sufficient detail as to allow a third party to attempt replication or validation. The review also highlights an additional issue in design research – the lack of effective and widespread critique (e.g. only 1 response for the search terms 'repeat', 'replicate' and 'critique' (Table 2.3)). Other than the study of Dyda and Dingsyr there are almost no examples of critical reviews of method implementation or empirical study in design research compared to the associated fields.

2.4.4 Critical Design Situations

Due to the issues highlighted in Section 2.4.3, relating practice to laboratory studies can be challenging (Moreau and Back 2000; Sheldon 2004) and can lead to the dismissal of laboratory studies despite their critical role in exploring complex phenomena (Briggs 2006; Levitt and List 2007) such as design activity. As such, an important gap in current design research is the exploration and explicit characterisation of the relationship between laboratory and practice.

The importance of improving understanding of this relationship is highlighted by the impact of related work in other fields e.g. Nordgren and McDonnell (2011) (psychology) and Bolton (2008) (economics) who both emphasise that developing this understanding can allow strong and credible relationships to be established and provide a basis for the development of theory. This is further illustrated in political science by the development of Duverger's Law (Reed 1990) or the seminal work of Vygotski and Cole (1978) who discuss the difficulties of developing 'law-like' (i.e. strong) relations. Critically, each of these works has identified key situations commonly examined in practice and laboratory as the focus of their comparison efforts.

Based on these considerations, this work adopts a similar approach to developing such relationships for design research. As such, the first step in this process is to identify key situations – henceforth referred to as critical design situations – suitable for developing the comparison. As the method is developed in more detail in Chapter 4 it is only important here to outline what is meant by 'critical design situation' in the context of this work. As such, they can be characterised as situations that are:

- Core to the design process.
- Commonly studied in both practice and the laboratory.

- Have discreet elements that can be replicated experimentally.

In this context these differ from the other common uses of the term 'critical situation' (Badke-Schaub and Frankenberger 1999), which focus on the design process. Instead situations are termed critical where they provide key bridges between practice and laboratory based empirical design research, focusing on the research aspect.

2.5 Concluding Remarks

This chapter explored the nature of design research and its associated methods. From this review, a number of underlying features of design research guide its use of theory, methodology and methods. Design research is a highly practice-focused field and has emerged from the engineering sciences – leading to a relative immaturity in the uptake and use of qualitative methods such as those used in many of the related fields identified in Section 2.1. This has led to the propagation of several specific issues within design research.

A number of important issues are established associated with design research and human-centric empirical design research specifically. These were highlighted in Section 2.4.3 and include: theory development; the need to capture context; the difficulty in understanding the experimental system; the need for improved methods and controls, and the lack of effective critique. There are many specific methods for dealing with these issues such as: blindness and randomisation, deviant case analysis, participant feedback, control groups, standardisation of data or methods, and triangulation of methods and metrics.

These methods, taken from a wider range of literature, are discussed in the next chapter. However, despite this, these important issues remain and require a higher level of mitigation – combining mitigating techniques into a cohesive approach. This is currently difficult due to the weakness of empirical study in design research. In particular the complexity of design activity and the amount of domain knowledge specific to a designer demand field specific method development and empirical validation. As such, this can only be created through cohesive laboratory and fieldwork, which are mutually supportive – thus requiring the characterisation of the relationship between them.

Clear and unambiguous relationships between laboratory and practice are critical to experimental and empirical validation as emphasized in Section 2.3. However, in order to achieve this validation, it is first necessary to understand and develop these relationships. Linking practice and laboratory in this way provides more powerful evidence, which can be used to address the issues of complexity in interactions and in systems across diverse contexts (Section 2.4.3).

Building on these conclusions, it is clear that in order to address the issues affecting design research, a cohesive high-level approach is needed, supported by rigorous empirical study. However, in order to achieve this, an effective relationship must be established between experimental study and practice. This leads to an initial specification of the knowledge gap to be addressed by this thesis as:

"The lack of understanding with regard to the relationship between practice and laboratory-based studies of the design practitioner."

It is first necessary to explore the issues and methods present in the associated fields as highlighted by Section 2.2.2. Many of the design research issues and methods discussed in this chapter are also present in the associated fields and, critically, are often addressed in greater detail, allowing potential lessons to be learned. As such the next Chapter examines the parallels between design research and the associated fields, highlighting the commonality of issues and the transferability and relevance of methods for mitigating these.

"On no man's word."

Motto of the Royal Society

3

Review of the Associated Fields

Before it is possible to fully address the knowledge gap identified in Chapter 2 it is necessary to understand the methods used to examine similar research questions in the fields associated with design research: natural sciences, humanities and liberal arts, social and behaviour sciences, human professions and services, creative and applied arts as well as technology and engineering (Friedman 2003). As such, this chapter presents a review of the associated fields most relevant to design research, which is broken down by area and includes: social and education research, psychological and behavioural research, and clinical research. Each section examines the field's links to design research, theory, issues and methods.

3.1 Social and Education Research

There are many similarities between the challenges facing researchers in social, education research and those facing the design researcher. These fields all deal with subjects, where complex synergistic systems are under examination – in particular, human subjects in complex environments (Brown 1992; Lynch 1995; Hanington 2007).

3.1.1 Issues

Goetz and LeCompte (1981; 1982) emphasise the importance of understanding the constraints on a study and how they affect the results. Interestingly, they identify idiosyncratic methods as a major issue, one which is still relevant nearly 25 years later (Shadish et al. 2002). Indeed the works of Goetz and LeCompte (1981; 1982) are still extremely relevant today because, while much progress has been made, the key issues affecting empirical research remain the same (Gorard and Cook 2007). Shadish et al. (2006) highlight the use of empirical study as a key technique in offering causal knowledge, while Lewis and Moultrie (2005) discuss some of the advantages and disadvantages of the development of research laboratories. Denzin (2009) offers an overview of many of the issues and methods used in social research, while Gorard and Cook (2007) distil the education research process into seven phases – noting the issues where research either skips through phases or gets stuck and does not progress. Table 3.1 shows the seven phases identified by Gorard and Cook (2007). In addition, examples of common issues at each phase have been added in order to highlight the commonality between the different fields.

Table 3.1: The seven research phases and associated example problems

Phase	Description	Example problems
1	Evidence synthesis	
2	Development of idea/artefact	There is confusion as to how questions should be investigated and most appropriate techniques (Miles and Huberman 1984)
3	Feasibility study	Insufficient pre-study planning detrimentally effects statistical significance, validity and repeatability (Cobb et al. 2003)
4	Prototyping and trial	Researchers often stop at this phase and fail to fully validate the research through rigorous laboratory and field studies (Gorard and Cook 2007)
5	Field studies and design stage	Later phases are often applied without completing phases 1 – 4 (Gorard and Cook 2007)
6	Definitive testing	Studies are often carried out with insufficient consideration for, or recording of context (Cobb et al. 2003)
7	Dissemination impact and monitoring	Methods are often unspecified, idiosyncratic, or insufficiently reported to allow replication and validation by the community (Shadish et al. 2002)

Building on this examination of the research process several common issues can be distilled that affect all of the research phases:

1. The need for underlying theory to link varied studies and contexts together, and to promote wider understanding (Klein et al. 1994; Collective 2003).
2. The need for theory and study to link research to the real world (Bolton and Ockenfels 2008).
3. The important, interlinked nature of complex behaviours and context (Lynch 1995).
4. The need to understand, describe and report context (Lave 1988; Simon et al. 1995).
5. The importance of using laboratory and field-based studies as well as complementary methods to elucidate and isolate fundamental causal relationships (Brown 1992).
6. The importance of developing effective methods that are validated and can therefore be replicated, reused and built upon (Seale 1999; Bannan-Ritland 2003).

3.1.2 Mitigation

In order to effectively address these issues and assess complex systems, it is widely acknowledged that experimentation, observation and theory must progress hand in hand (Brown 1992; Klein et al. 1994; Cook 2000; Bender et al. 2002; Collins et al. 2004). Brown (1992) states that, without theory to link studies, it is extremely difficult to establish why a particular intervention works and make it repeatable and reliable. Bell (2004) and others (Lynch 1999; Shavelson et al. 2003) also discuss the complexity and breadth of study. They conclude that methods and context need to be addressed by theory in order to develop meaningful constructs and scientifically rigorous generalizability. They also identify the key role played by empirical research in the development of understanding, as highlighted by Cook (2000) and Bell (2004). Sandoval (2004) emphasises the need to develop rigour, experimental control and validity using effective empirical methods in order to make credible claims. Many of these points as well as points 1 - 6 listed above are also emphasised by Klein and Myers (1999).

Looking more closely at empirical research in these fields reveals two major types: quantitative (Hammersley 2000) and qualitative (Cook et al. 2008). The relevance and use of different methods has formed the centre of long running debate (Cook

1967; Cook 2000; Gorard and Cook 2007). However, from this debate has come the acknowledgement that in complex fields both qualitative and quantitative methods are necessary for developing causal relationships (Salomon 1991; McCandliss et al. 2003; Gorard and Cook 2007). There is also a drive to develop the link between the laboratory and the real world (Newman and Cole 2004; Levitt and List 2007), with Lynch (1999) highlighting the need for replication of studies in various contexts in order to develop external validity.

3.2 Psychology and Behavioural Research

The link between design research and behavioural research is made by Winter (2008) who states that disciplines are fundamentally underpinned by psychology and sociology. Winter also reveals that behavioural research is better developed in terms of theory building and methodological rigour when compared to design research. Bonnetti et al. (2010) also highlights how psychology models and theory can be used to form a foundation for developing models and theory in related fields.

3.2.1 Issues

Wilkinson (1999) highlights one of the key issues affecting complex fields: identifying causal relationships and disentangling these from the numerous other mechanisms in a given context. Hemmelgarn (2006) discusses issues such as normalising for cultural and environmental effects, while Bakeman and Deckner (2003) highlight difficulties in data collection and analysis. Elimination of these issues is a major consideration with numerous factors that must be considered during method design and selection. Such factors include:

- Selecting the most suitable research approach (Hanson et al. 2005; Morrow 2007).
- Designing the study to be statistically viable (Wilkinson 1999; Erceg-Hurn and Mirosevich 2008).
- Identifying and eliminating method bias (Podsakoff et al. 2003).
- Deploying clear control procedures (Leber 2000).

3.2.2 Mitigation

Driven by these issues, a key tenant of research in these fields is the use of mixed methods utilising both qualitative and quantitative in a mutually supportive framework to fully characterise a system (Malterud 2001; Dures et al. 2010). Hanson (2005) offers a breakdown of how these approaches are integrated, identifying six types of mixed approach: sequential explanatory, sequential exploratory, sequential transformative, concurrent triangulation, concurrent nested and concurrent transformative. The work of Hanson not only emphasises the range of possible methodological approaches but also the more sophisticated theory supporting the implementation of those approaches in the associated fields. Finally, the seminal text by Watson (1919) identifies the crux of scientific research: in order for a field to push forward as a science, it must abandon dogma and tradition, turning a critical eye on its philosophy, theory building and methods – an axiom as true today as in 1919.

Building on this, Taborsky (2008) identifies the need for theory and experimentation as essential tools for unravelling the fundamental mechanisms in a system. The need for theory building is mirrored in psychology where philosophy and theory are considered essential prerequisites for carrying out sound research (Manicas and Secord 1983; Bermudez 2005). Establishing a research philosophy has significant implications for both theory building and method selection (Ponterotto 2005). Empiricism also plays a key role in both fields – psychology and behavioural research (Danziger 2000). Wilkinson (1999), Hemmelgarn (2006), Bakeman and Deckner (2003) emphasise empirical methods; looking at statistical methods, the recording and controlling of context, and the development of coding schemes respectively. These authors amongst others (Ramos Alvarez et al. 2008) highlight numerous approaches for improving the field. Kingstone (2003) emphasises the need to link laboratory and real world studies in order to develop validity, while Merrell (2010) identifies the need for pragmatism and real world impact in order to effect change. A series of studies by Nordgren and Morris-McDonnell (2011) highlight the importance of establishing these links, especially where the relationship is unintuitive. Again theory building, context, system understanding, effective methods and improving standards are recognised as key factors. This mirrors Glasgow and Emmons's (2007) drive, in clinical research, for valid and pragmatically applicable research.

3.3 Clinical Research

Roll-Hansen (1998) highlights a critical element in developing the relevance of research – linking the laboratory to reality (Eifert et al. 1999). In the case of clinical research this is the development of the theory for specific treatments to assess their results in the real world. This bears a remarkable similarity to some of the work carried out by empirical design researchers, namely, taking tools and techniques based on theory or observation and developing them in practice (Briggs 2006). Glasgow and Emmons (2007) and others (Bowling 2002; Tunis et al. 2003) also highlight the drive for real world impact in clinical research, even going so far as to specifically promote clinician led research in order to develop this link (Nathan 1998).

3.3.1 Issues

The similarity of clinical research design research is also highlighted by Zaritsky et al. (2003), who emphasise the importance of establishing meaningful and relevant success criteria, and Grimes (2002), who looks at types of studies in clinical research. Several common issues facing design and clinical research can be synthesised:

1. The need to address barriers to dissemination through effective theory.
2. The need to integrate multiple types of evidence and methods.
3. The need to use research design to give multiple baselines across contexts and to conduct broader examinations in order to address generalizability.
4. The need to use effective, recognised methods and controls in order to develop and maintain consistently high levels of validity and reliability.
5. The need to use critique to improve methods throughout the field.

3.3.2 Mitigation

Similar to psychology research (Section 3.2) there is again an emphasis on mixed methods (Pope and Mays 1995; Seale and Silverman 1997), strong experimental design (Verstappen et al. 2004), standardisation of methods (Malterud 2001; Elwyn et al. 2007) and critical review (Boutron et al. 2010). These are focused by the demand for strong causal claims and the serious consequences of false findings. The drive for strong claims is underpinned by a critical community that is willing to re-examine studies and the methods by which they are reported (Ioannidis 2005; Boutron et al. 2010). There is also an emphasis on developing community wide standards of rigor (Seale and Silverman 1997; Malterud 2001). Indeed, the term 'gold standard' is used to describe the randomised controlled trials deployed within clinical research (Grimes and Schulz 2002; Riehl 2006). An overview of clinical research methods is described by Hulley (2007), who emphasises the philosophical link between research and reality, the key issues and mitigating approaches. In addition, Hawthorne-type effects (Section 3.6) are common and important in clinical research and play a large role in shaping methods (Taris 2006; McCarney et al. 2007). In response to this type of effect, the placebo control group is one of the fundamental mitigating techniques used in clinical research (Quitkin 1999; Hrobjartsson 2002).

3.4 Combining the Reviews

In order to effectively draw out important findings for design research it is necessary to combine the results from the two reviews: design research and the associated fields. As such three areas must be addressed. Firstly, fundamental commonalities are established in the context of all the fields considered. These form the foundation for further comparison between the fields and give a common reference frame for the establishment of related issues and mitigating approaches. Secondly, common issues are established based on the discussion of each field outlined in this chapter. These offer a means of assessing the severity of each issue across the fields and thus the identification of appropriate mitigation approaches. Finally, key mitigating approaches are identified in order to synthesise the learnings from across the reviewed fields. Based on these considerations the next section combines the reviewed literature in order to identify key learnings for design research.

3.5 Issues and Mitigation

The review of design research (Chapter 2) highlighted several important issues including theory and the complexity of design studies. However, combining this with the associated fields (Sections 3.1 to 3.3) reveals six core issues: theory development; the need to capture context; the difficulty in understanding the experimental system; the need for improved methods and controls, and the lack of effective critique. In combination, the two reviews (Chapters 2 and 3) emphasised the wide scope and varied but strongly interlinked nature of design research and its associated fields.

In addition to the similarity of the core issues across the fields, there is much commonality in the mitigating approaches. This is exemplified by comparing the work of Gorard and Cook (2007) in education research, Seale and Silverman (1997) in social health research, and Gray and Salzman (1998) in human-computer interaction research. All these authors highlight the importance of triangulation, mixed methods, strong study and method design and strong theory. Indeed, Gray and Salzman specifically suggest adopting aspects of behavioural research experimental design as a way of addressing some of the issues identified within their field. It also becomes evident when the two reviews are compared that despite widespread acknowledgement of the core issues and long standing discussions of mitigating approaches in the associated fields, relatively little has so far been transferred to design research (Bender et al. 2002). Nevertheless, some progress has been made in internally developed design research methods (Blessing and Chakrabarti 2009), while the suitability of techniques used in the associated fields has only been acknowledged by a small number of researchers (Olson et al. 1992; Mabogunjie and Leifer 1996; Lindahl 2006). However, as it stands, there is still much to be done in terms of empirical method refinement and improvement of the wider design research culture (Cross 2007).

To counter this lack of methods and knowledge transfer, it is necessary to understand the underlying core issues and thus, the suitability of mitigating approaches employed in the associated fields. It is also important to recognise these issues and techniques as complex interconnected subjects (Klein et al. 1994; Dyba and Dingsoyr 2008), which require multiple mutually supporting techniques to counter (LeCompte and Goetz 1982; Kitchenham et al. 2002). Therefore, while existing works have concentrated on a single type of approach such as protocol analysis (Gero and Tang 2001) or common datasets (McDonnell and Lloyd 2009), this chapter takes a higher-level perspective, developing the interconnected nature of the research issues and mitigating approaches across fields. The approach taken in this chapter is to identify the common areas of overlap between the fields and then to distil a number of the most important issues. Appropriate or relevant mitigating approaches are then discussed. These three elements are covered in the next sections.

3.5.1 The Common Areas

It becomes clear from the review that while psychology, behavioural, education, social and clinical research demand certain levels of rigour and self criticism, design research is, by contrast, still at an early stage in the development of, e.g. theory, contextualisation, system understanding, method implementation, control and normalisation, and critique. Although the specific focus or methods used for experimental work in the associated fields differ from design research, the subjects and the level of system complexity are very similar, i.e. design research is often looking at intangible human processes carried out in the context of complex external processes, environments and cultures (Buur et al. 2000; Bucciarelli 2002; De Dreu and Weingart 2003). From the review, it is possible to identify six common areas relevant across the reviewed fields:

1. Theory: The use of underlying theory and methodology to develop and implement research or to assess and implement findings.
2. Context: The social, cultural, activity and methodological factors affecting the behaviour of the population/participants or the reporting of the results by the researcher.
3. System understanding: How the variables/mechanisms within the system under examination are characterised, decomposed and reported.
4. Method implementation: The use, reporting and assessment of empirical methods, techniques and methodologies.
5. Control and normalisation: The specific use, reporting and assessment of methods designed to control empirical variables.
6. Critique: The critical assessment of research quality through channels such as third party review, replication, validation and re-evaluation of existing study – this goes beyond the work of reviewers and editors although these also play a key role.

Within each of these common areas there is an associated core issue. For example, the main issue in 'control and normalisation' is the widespread use of no-treatment control groups in inappropriate situations coupled with little or no baselining. As such the core issues are examined in the next section.

3.5.2 The Six Core Issues

As discussed in the review, the associated fields experience many of the same challenges faced by design research, such as the need for underlying theory building; developing and applying empirical methods in a scientifically rigorous manner; the difficulty of controlling or normalising empirical studies involving human subjects in complex situations; and most notably the difficulty in linking experimental study to real world impact. Table 3.2 highlights a range of specific issues associated with each area giving examples of their consequences in design research as well as an example reference. The table then presents the main 'core issue' within this area. Based on the review, a set of six fundamental issues has been established Table 3.2.

The core issues established in Table 3.2 form a set of closely interrelated but distinct empirical research problems. Although the core issues are shown in a one to one correspondence with the research areas, there is considerable overlap. Each core issue interacts with the others to make mitigation significantly more difficult. An example of this interrelation is: the difficulty in developing work in the theory area without sufficiently revealing/rigorous methods and conversely the difficulty in developing methods without sufficiently developed theory. In this example, two areas interact to produce a more complex and difficult to resolve problem requiring multiple mitigation strategies, as will be dealt with in the next section.

Table 3.2: The six 'core issues'

Area	Specific issues	Core Issue	Description
1. Theory	Widespread difficulty in developing context independent findings, lack of theory to support method selection/methodology development, lack of widespread impact. (Blessing and Chakrabarti 2009)	**Theory deficit**	The failure to develop theory associated with methodology, method implementation, integration of contexts, framework development and method adaption.
2. Context	Widespread reporting of studies with insufficient contextual information, no accepted guidance on what or how to record context. (Adelman 1991)	**Insufficient contextualisation**	The failure to adequately define, record or account for contextual information including, social, cultural, activity and study/method related context
3. System understanding	Difficulty in isolating key experimental factors, lack of predictive power in different contexts, difficulty in developing underlying theory. (Cook 2000)	**System clarity**	The failure to fully account for, characterise and report the possible variables at work in a test system. Little accounting for Hawthorne type effect
4. Method implementation	Widespread instances of bespoke method development, very little method dissemination – very few 'method' papers, no standardized accepted method standards and little triangulation. (Goetz and LeCompte 1981)	**Method variability**	The inadequate definition of methods and terms, the lack of standardization and consistency in experimental design, recording and reporting
5. Control and normalisation	No instances of placebo use, widespread use of no-treatment control group in inappropriate situations and little baselining. (Goldschmidt and Tatsa 2005)	**Experimental control**	The inappropriate or insufficient use of control and normalisation techniques.
6. Critique	No instance of studies being replicated/validated, few instances of reviews of methods, no instances of reviews of significance and no critical reviews. (Dyba and Dingsoyr 2008)	**Closing the loop**	The lack of study replication/validation, lack of method review and criticism, lack of community wide development of standards.

3.5.3 Mitigation of the Six Core Issues

With the core issues established, it is important to consider their mitigation; i.e. their elimination or reduction. The review of associated fields reveals that considerable efforts are being made to develop mitigating techniques. However, when compared to the associated fields, design research is relatively underdeveloped in this area (Cross 2007). This affects all aspects of empirical research. Table 3.3 establishes the mitigating approaches and gives examples of specific mitigating techniques in design research as well as an example reference. The six mitigating approaches – theory building, standardisation, triangulation, implementation of methods, improved control theory, and critical review – are shown to be primarily related to one core issue. There is, again, considerable overlap. The mitigating approaches must be considered and applied collectively to effectively address the core issues as a whole. An example of this interrelation is the need for effective theory building to identify and appropriately implement control and normalisation techniques. Further, each approach may constitute many interrelated techniques. For example, control and normalisation can be achieved in numerous different ways that can be combined to give a greater or lesser degree of control as required. Some examples from the review are the elimination of bias through study design (Quitkin 1999), using baseline data (Bowling 2002), placebo controls (Adair et al. 1989), statistical normalisation (Erceg-Hurn and Mirosevich 2008), triangulation of measures (Ameri et al. 2008) or the development of appropriate theory (Atkinson and Hammersley 1994).

In order to highlight the importance of the core issues Section 3.6 provides a detailed example of the Hawthorne Effect, which is one of the major contributors to core issue 3: system understanding.

Table 3.3: The six mitigating approaches

Core Issue	Mitigating approach	Description	Mitigating techniques
Theory deficit	**Theory building**	Developing an underlying framework of theory to guide method selection and development, context awareness and relevance.	Use of linking research methodologies, developing theory with research, encouraging replication across contexts, improving system understanding and reporting. (Brown 1992)
Insufficient contextualisation	**Standardisation**	Developing standards for reporting context evidence validity, method reporting, method implementation, metrics, and levels of evidence/best practice.	The development of standardised methods for reporting or structuring research, developing accepted standards and improving capture and reporting of common contextual variables. (Malterud 2001)
System clarity	**Triangulation**	Developing multiple evidence paths for a single focus including: multiple metrics, methods (quantitative and qualitative) and contexts.	Making effective use of both qualitative and quantitative methods, using multiple linked metrics, using multiple contexts and populations. (Onwuegbuzie and Leech 2006)
Method variability	**Implementation of methods**	Developing improved methods, study planning, methodology development, theoretical and contextual grounding, and improved reporting.	Improving pre-study planning, using theory and methodology to help method selection and use, using deviant case analysis, improving statistical measures and contextual grounding of studies. (Lloyd et al. 2007)
Experimental control	**Improved control theory**	Developing better, more appropriate control conditions based on both theory and method development. Drawing effectively on the associated fields.	The use of baselining, placebo and no-treatment control groups, considering bias and other experimental effects in study design, basing control and normalisation on theory. (Price et al. 2008)
Closing the loop	**Critical review**	Developing a critical attitude beyond the existing review process addressing reporting, method execution, standards development, levels of validation and evidence.	Creating review bodies to comment on research, replication and validation of studies by other researchers, publishing of critical reviews of study significance and research impact etc. (Ioannidis 2005)

3.6 Issue: The Hawthorne Effect

The Hawthorne effect is a term that, although now defunct, expresses a concept which is highly relevant, if in a modified form (Holden 2001; Falk and Heckman 2009) and extremely prevalent throughout social (Leonard and Masatu 2006), educational (Adair et al. 1989) and clinical (Verstappen et al. 2004) research. Not only that, this section aims to show that it is also relevant to any design research using human subjects. This is discussed as an example of a contributing factor to a core issue (in this case system understanding) and is not intended as an exhaustive review of all possible experimental effects e.g. priming.

3.6.1 Example

An example of a Hawthorne type effect is were participants are affected by their awareness of the research procedures and modify their behaviour accordingly e.g. a lazy worker acts more diligently during a period of observation. These types of issue are widely recognised in the associated fields and are highly relevant to design research but critically, are not general considered.

3.6.2 Discussion

The Hawthorne studies, as interpreted by Mayo (1933), found that a subject's awareness of being part of an experiment generated an improvement irrespective of any active intervention. This interpretation gained widespread acceptance (Adair 1984; Macefield 2007) before the original findings of Mayo were debunked, being reinterpreted by Parsons (1974) and others (Franke and Kaul 1978; Holden 2001). Despite this, there is a widespread recognition within the associated fields that significant non-treatment experimental effects have been repeatedly shown to exist (Adair et al. 1989; Diaper 1990; Barnes 2010). However, the specific term 'Hawthorne effect' has become increasingly ambiguous with repeated reanalysis and redefinition (Taris 2006; Chiesa and Hobbs 2008), and mainly due to the success of Mayo's interpretation, there is still confusion as to the meaning of the term with some researchers still using out-dated definitions (De Amici et al. 2000). Despite this ambiguity, the term is still widely used and the effects it describes should be considered when conducting a study on knowing participants. Adair gives a commonly used definition:

"... The problem in field experiments that subjects' knowledge that they are in an experiment modifies their behaviour from what it would have been without the knowledge." (Adair 1984) (p. 334)

Due to the ambiguity of meaning and imprecise definition of the Hawthorne effect, it can no-longer be accepted as a definitive description of an experimental effect and should not be reported as such (Barnes 2010). Instead, the Hawthorne effect can be used as a 'catchall' type term referring to the multiple interlinked experimental effects which, depending on the study, have a varying degree of impact (Cook 1967; Diaper 1990). These various effects, referred to as Hawthorne type effects, are described in Table 3.4, which has been synthesised from the review, with Barnes (2010), Gephart and Antonoplos (1969) forming the main sources. Examples of the effects described here can be found in texts such as Rosenthal (1976), Leonard (2006), Cook (1979), McCarney (2007) and Chiesa (2008). The placebo effect is included in this table as although it is commonly distinguished from the Hawthorne effect it is still sometimes reported or interpreted as a Hawthorne type effect and is critical to mitigation.

These effects have significant impact on studies involving people and must be accounted for either in the design of the study or through use of control and normalisation (Cook 1962; Diaper 1990). Thus, it is essential that design researchers consider these effects when planning studies and they have been included here with the express intention of bringing them to the attention of the community.

Table 3.4: The Hawthorne type effects

Specific effect name	**Brief description of effect mechanism**
Experimenter bias effect or Pygmalion effect *[1&4]	Researchers expect certain participants to improve and reinforce these expectations
Novelty *[1]	Participants are affected by the novelty of research procedures and modify their behaviour
Awareness of participation *[1]	Participants are affected by awareness of the research process and modify their behaviour
Altered social structure *[1]	Participants interact amongst themselves and the researcher and modify their behaviour
Hypothesis awareness *[5]	Participants become aware of the hypothesis and modify their behaviour
Knowledge of results *[1]	Participants become aware of the reporting of their performance and modify their behaviour as a result
Demand characteristics *[1]	Participants perception of their role in a study acts to modify their role in the study
Halo effect or social desirability *[1,2,3&4]	Participants feel the need to disguise negative behaviour or emphasise positive behaviour
Learning effect *[4]	Participants give more thought to the subject based on the research questions and attempt to give 'correct' answers
Contamination *[6]	Participants improve performance not only for topics under study but also for related ones
Message contamination or leaking effect *[4&6]	Participants learn of the intervention and are indirectly exposed to the intervention
John Henry effect or compensatory rivalry *[4&5]	Participants indirectly learn they are not receiving the intervention and compensate for this lack by improving their behaviours
Placebo effect *[1]	Control participants interactions with the experiment affects their behaviour altering the performance of control subjects

*Relevant definitions or references: *1 (Gephart and Antonoplos 1969), *2 (Green 1977), *3 (Podsakoff et al. 2003), *4 (Barnes 2010), *5 (Adair 1984), *6 (Verstappen et al. 2004)*

3.7 Concluding Remarks

Design research is a complex field, which is closely related to a number of associated fields including: social science, education research, psychology and behavioural research, and clinical research. At present, there is relatively little knowledge transfer of key problems or mitigating approaches/methods from the associated fields to design research. To address this, a review and analysis of design research and the associated fields (Chapters 2 and 3) was undertaken.

It was possible to establish, six common areas from this review. These include theory, context, system understanding, method implementation, control and normalisation, and critique. Core issues associated with each area have been established and can be summarised as: theory deficit, insufficient contextualisation, system clarity, method variability, experimental control and closing the loop. These core issues are of critical importance to all the reviewed fields and form fundamental problems relevant to design. Despite this commonality or overlap, it was noticeable that many of the core issues receive significantly less attention in design research than in the associated fields. For example, this is illustrated by the lack of attention paid to Hawthorne type effects in design research.

Examining ways to deal with these core issues in an appropriate manner, six mitigating approaches were established. Again these were both significant for, and relevant to the design research field. These approaches emphasised areas such as: theory building – to improve relevance and validity; standardisation and the development of effective standards for evidence and research quality; triangulation – to improve evidence generation and validity; implementation of methods – to improve planning, contextualisation, replicability and reliability; control techniques – to improve validity; and critical review – to allow effective assessment of progress in research practice. This is illustrated by the important role that the placebo control has taken in comparable associated fields, which is contrasted against its almost non-existence within design research.

In addition to these issues there is a clear focus on the designer as a core feature of design research (Schuette and Rotthowe 1998; McDonald et al. 2012). As such their interactions with a complex design process form a key window for the examination of design activity.

Based on these two conclusions, the identified issues and the importance of the designer, a knowledge gap can be defined: the need to effectively understand the relationship between the behaviour of the designer in the laboratory and in practice. This draws on the mitigating approaches to tackle the identified issues (Table 3.5).

Table 3.5: Core issues and how they are to be addressed by this research

Core issue	How addressed
Theory deficit	Comparing design activity across contexts allows the development and validation of links that can also be related to or developed into theory
Insufficient contextualisation	Comparing the designer in various contexts such as the laboratory and practice makes contextualisation a core element of the research
System clarity	Comparing design activity across contexts allows the for triangulation of sources and studies to give superior system clarification
Method variability	The development of a method able to examine the designer across contexts promotes standardisation and consistency
Experimental control	A method that can be used to compare designer activity across contexts must also address Hawthorne type issues as well as normalisation
Closing the loop	Linking the laboratory with practice will close the loop for design research set in a laboratory and will open the way for further study

In addition to this research gap, the two major conclusions from Chapters 2 and 3 also highlight the dual aspects that must be addressed by this research: methods used to characterise designer activity and the relationships between contexts. As such the research gap can be decomposed into these two broad areas which, when tackled in sequence, address the core issues highlighted in this chapter. This is reflected in Chapter 4 where two research questions are identified, corresponding to the two main elements.

Building on the literature review and the analysis of the various methodological issues and techniques discussed in this chapter a number of broad research objectives present themselves based on the two main research areas. These are listed here and discussed with respect to the research questions and wider theory in Chapter 4.

Objectives:

1. To create a methodology for investigating the relationship between practice and laboratory-based studies.
2. To review and devise a technology strategy for capturing designer behaviour and activity.
3. To create an empirical method to capture, code and analyse designer behaviour and activity.

4. To identify and characterise designer behaviour and activity for critical design situations.
5. To characterise the relationship between practice and laboratory-based studies for critical design situations.

With the knowledge gap and major elements established, it is next necessary to outline the overall research methodology. As such the next chapter details the research approach and introduces the studies to be conducted.

"Think and act for yourself' is the motto for the future, not 'Let us wait for orders'"

Admiral John Fisher

4

Research Methodology

In order to contextualise the methods used in this research, there are four major areas that need to be considered – each area informing the next. Firstly, defining a philosophical foundation allows a particular research worldview to be developed – critical to effectively structuring theory. Secondly, defining a theoretical structure links the specific work to the wider research context and also supports the identification of an appropriate approach for investigating the identified problem. Thirdly, developing a methodological approach, based on theory, supports the specification of appropriate investigative methods and subsequently links these into a cohesive whole. Finally, the methods and studies are outlined, specifying their aims and contributions within the context of the methodology. These areas are dealt with in the subsequent sections.

Developing this philosophically grounded, layered understanding of the research methodology is critical for several reasons: maintaining internal consistency, linking to the wider body of research, structuring the research approach and identifying optimal methods. This is based on the idea of the 'research onion', as described by Saunders et al. (2009). As with the 'research onion' the first step that must be taken is the identification of an appropriate research philosophy.

4.1 Research Philosophy

The role of a research philosophy is to guide and structure the broad worldview of the researcher. This informs what is possible, points towards appropriate methods and techniques, and structures the development of more detailed theory. Although there are many specific approaches, four main governing philosophies emerge from the literature (Robson 2002). These are outlined in Table 4.1.

Table 4.1: Philosophical perspectives – based on Robson (2002)

Name	**Description**
Post-positivism	One common reality – understood probabilistically due to the limitations of the researcher. Primarily quantitative but acknowledges and attempts to account for researcher bias (Wildemuth 1993)
Constructivism	No single common reality – knowledge and meaning are individual or social constructs. Primarily qualitative with researchers seeking to understand various perspectives of meaning (Phillips 1995)
Feminist, Emancipatory or critical	No single common reality – aims to facilitate the perspectives of minorities or underrepresented groups. Primarily qualitative with researchers seeking to elucidate the experiences of minorities (DeVault 2009)
Critical realism	Knowledge is a social and historical construct – attempts to develop theory to explain the real world and then test these through rational criteria. Utilises both quantitative and qualitative approaches (Bhaskar 2008; Gerring 2008)

The research philosophy underpinning this research is *critical realism*. This has several key features that make it appropriate – primarily, the manner in which critical realists describe the subject under examination, the system. From a critical realist perspective, systems can be characterised as the *outcome* of an *action* following from particular *mechanisms* in a particular *context.*

4.2 Theory

There are two main types of reasoning: inductive and deductive. In deductive reasoning, the main steps are: theory > hypothesis > observation > confirmation while in inductive reasoning, the steps are: observation > pattern > tentative hypothesis > theory. As this research builds on existing theory and hypotheses deductive reasoning has been used. For the research outlined here it is first necessary to develop a theoretical model before a hypothesis can be developed or tested. Key to this is structuring the problem, such that it can be addressed empirically – a central tenant of realist philosophy. From a realist perspective, it is possible to characterise the context of this research as three linked, yet separate, systems: fieldwork (practice), intermediary and laboratory. These are summarised below, however, a more detailed discussion is provided in Chapter 5. Figure 4.1 outlines a theoretical model of these three systems. In each case the differences in context and mechanisms produce a different output for a given action.

- Practice: Ethnographic or fully embedded study of practice, typically assed observational using fieldwork techniques.
- Intermediary: Experimental studies using practitioners, varying little from normal practice.
- Laboratory: Experimental studies typically not using practitioners, in a custom environment.

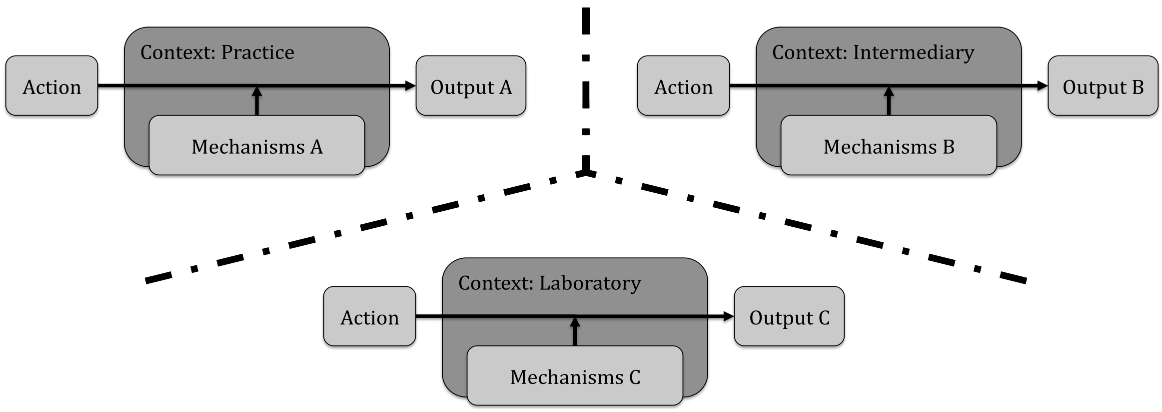

Figure 4.1: The three systems: practice, intermediary and laboratory

Using this model, it is possible to identify the theoretical ways in which two systems differ, given a common input action. In the case outlined in Figure 4.1 Output A differs from Output C because the context and mechanisms are different. Thus, in order to effectively compare (and subsequently develop links between) two systems it is necessary to characterise the differences in context and mechanisms.

Mechanisms can include a number of variables. However, in the case of design research, these often act within the mind of the designer (e.g. their internal processing of design information). As such, these mechanisms are not directly observable and can only be derived implicitly. Therefore, in order to compare two systems, it is necessary to not only characterise the action and context, but also the output – allowing implicit comparison of the mechanisms. A further issue arising from the unobservable nature of the mechanisms at work within the designer is the difficulty in comparing practitioners to non-practitioners. This forms the theoretical basis for much of the perceived difference between laboratory and practice identified within the literature (Chapters 2 and 3)

Despite these issues, however, comparisons based on mechanism understanding offer major advantages over those based on simple comparison between outputs. Key to this is the development of linking theory, which depends on the deeper and more complete understanding of a system given by the characterisation of all aspects – action, output, context and mechanisms. Briggs (2006) highlights this in his discussion of the theory driven design of collaboration systems:

"*If we understand nothing of the causal mechanisms, then we can only achieve a given outcome by accident at first and by rote thereafter*" (Briggs 2006) (p. 581)

Thus, in order to effectively compare two systems involving people it is necessary to characterise all four aspects of a system. However, due to the nature of engineering design, actions are not normally discreetly separated; tasks may be stopped or tackled in parallel with other activities (Blessing and Chakrabarti 2009). Counter to this, actions in the laboratory must be contrived and tend to form discreet blocks of activity with little interruption and defined endpoints. Thus, when the laboratory system is compared to the practice system, the initial actions forming the basis for comparison can be made similar but not identical. Therefore, in order to validate any links made between laboratory and practice, a third comparison must be made in order to validate the similarity of the initial action.

This validation of the action and, thus, the identified links requires a third system to be described – an intermediate case. In order to validate the action used in the laboratory system it is necessary to make the context and mechanisms as similar as possible to practice. Thus, the intermediary case must have the following characteristics: action – from laboratory; context – from practice; mechanisms (in this case the participant) – from practice. Using this configuration, it is possible to directly compare Output A to Output B (Figure 4.1) where the only significant difference is the input action. Based on this comparison, it is subsequently possible to validate the similarity of the action used in the laboratory system.

Comparing and contrasting these three systems allows the researcher to explore the underlying mechanisms and consequently develop strong theoretical links. Further, using closely related systems allows these links to be validated empirically. However, in order to do this a clear methodology is required to examine and link the systems empirically.

4.3 Methodology Approach

There are numerous design research methodologies found in the literature such as the works of Duffy and Andreasen (1995), Eckert et al. (2003), Langdon et al. (2001) or Stacey et al. (2002). From this wide range of approaches the three most appropriate, in terms of scope and philosophical grounding, are: Blessing and Chakrabarti's 'Design Research Methodology' (DRM) (2009), Duffy and O'Donnell's 'Design research approach' (1998), and Checkland's 'Soft systems methodology' (2000). Table 4.2 summarises each of these approaches.

DRM was selected from these three for several reasons. Primarily, it was the most closely aligned with the aims and focus of the research – being easily adapted to focus on design research rather than design. Secondly, the use of reference and impact models to structure the researcher's thinking closely aligns with the critical realist perspective identified in Section 4.1. Thirdly, it is well established and has been used for a number of studies such as those outlined in the appendices of Blessing and Chakrabarti's book (2009). This consistency of model is a key element in improving the applicability and generalizability of research (Chapter 3) and as such is an important element in the selection of a methodology. Finally, the stepped approach outlined by DRM fits closely with the theoretical model developed in Section 4.2, i.e.

describe the current situation (poor links between laboratory and practice), develop an improved case (establish links), and validate the improvement (validate links).

Table 4.2: Design research methodologies

Name	Description
DRM	A four-step approach: research clarification, descriptive study 1, prescriptive study and descriptive study 2. Focuses on linking reality – reference model – and the improved case – impact model (Blessing and Chakrabarti 2009)
Design research approach	A multi step approach: research vision, needs analysis, framework, approach and validation. Emphasises linking 'reality' and 'envisaged reality', focused on development of computer support (Duffy and O'Donnell 1998)
Soft systems methodology	An action research based approach. Focuses on particular problem situations that can be affected directly rather than problems. However, also emphasises the initial description of reality (Checkland 2000)

4.3.1 DRM – Design Research Methodology

DRM has four main steps each with a different focus and a number of associated deliverables for the wider research. The structure of this research and this thesis has been based on these steps, which are: Research clarification, Descriptive Study 1 (DS 1), Prescriptive Study (PS) and Descriptive Study 2 (DS 2). This section briefly describes each step and introduces the methods to be used. A more detailed breakdown of the methods is given in Section 4.4.

Research Clarification

The clarification step contextualises the research and identifies the scope, deliverables and goals.

The method selected for this clarification period was a literature review complemented by a technical scoping study. A detailed breakdown of the review method is given in Chapter 2. From this review (Chapters 2 and 3), design research was contextualised and the issues to be addressed were identified. Based on this review, the scope was specified as: *The improvement of validity in laboratory based empirical design research involving human participants*. The details of the technical scoping study are given in Chapter 5. Using the reference and impact model techniques (Blessing and Chakrabarti 2009), two research questions were identified. Section 4.3.2 explores these questions in more detail and outline how they are to be addressed.

Descriptive Study 1

DS 1 increases the understanding of the system under investigation and is typically used to characterise a baseline or the current situation.

In this case the relationship between design practice and design research in the laboratory. From this, possible 'success factors' are identified. These are then measured in the PS and DS 2 steps. As such the most appropriate approach at this stage was a detailed ethnographic style study, able to characterise design activity using both qualitative and quantitative metrics. This allowed the construction of the practice system described theoretically in Section 4.2. In addition, this detailed recording of the design activity supported the identification of three suitable action/output systems for further comparison.

Prescriptive Study

The aim of the PS step is to address the issues identified in the research clarification and DS 1 steps to improve the overall system.

In this case the selected issue was the link between laboratory and practice in design research. As such the logical corollary to the practice based DS 1 was a contrived laboratory study. When coupled with DS 1 this pair of studies allowed the construction of links between the two systems. The PS step is also used to specify measurable success criteria that can be validated; in this case, these were the links between the two systems.

Descriptive Study 2

DS 2 evaluates the effectiveness of the PS step and is typically used as a validation step.

In this case DS 2 assesses whether the supporting links developed in the PS step can be used for their intended purpose and to subsequently establish their validity. Based on the theoretical model outlined in Section 4.2, the most appropriate approach at this step is a contrived intermediate study using practitioners in a practice context. This allows the input actions, and subsequently the established links, to be validated. Finally, DS 2 is used to identify any weakness and evaluate any theoretical assumptions.

Scope of DRM Adoption

In addition to the structural aspects of DRM (clarification, DS1, PS and DS2) there are three other important elements: the reference model, impact model and success criteria. Although these elements are an important part of DRM they are of limited benefit in terms of communication, lacking intrinsic context, being highly complex and not necessarily significantly clearer than a narrative approach. As such, these elements have not been explicitly included in this thesis, which adopts a narrative approach in order to more effectively contextualise the research and its associated aims and objectives.

Before the study methods are described in detail, it is first necessary to explore the theoretical underpinnings of each research question and its associated studies. As such Section 4.3.2 details the theory related to each research question and acts as a foundation for the selected methods.

4.3.2 Theoretical Underpinnings for the Research Questions

This section describes the theory that underpins the two research questions and discusses how the questions are to be answered at a theoretical level.

Research Question 1

How can designer behaviour and activity be characterised to enable comparison between design situations?

In order to effectively compare one system to another, the input action must be similar if not the same (Section 4.2). As such, it is first necessary to identify and describe a number of actions and their associated outcomes before any comparison studies can be made. Based on observations from the first study (Section 4.4.1), a number of actions are identified and used to form the basis for the laboratory studies (Section 4.4.2). For example, the action recorded in practice might be a group of practitioners 'brainstorming' product ideas. To replicate this in a laboratory a number of students would be briefed and given explicit instruction that they should 'brainstorm' product ideas. Based on this, it is possible to compare the two systems and build up a hypothetical relationship (Section 4.2). Figure 4.2 outlines the principles behind this comparison process. In this case actions are considered to be analogues while context and output are explicitly comparable (solid arrow – Figure 4.2). From this an implicit comparison of the mechanisms can be established (dashed arrow – Figure 4.2).

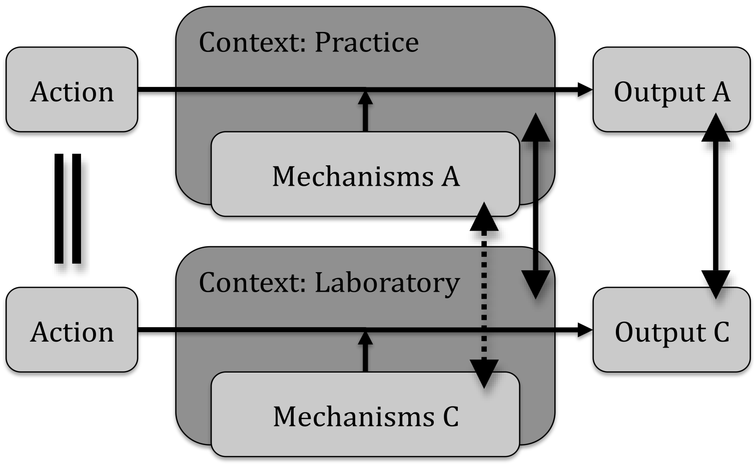

Figure 4.2: Building implicit mechanism comparisons

At this stage it is important to note that when comparing complex systems it is necessary to use a common reference frame. In this case, the key common feature was the designer. As such, the means for exploring the different mechanisms and characterising the outputs were explicitly built upon the designers' behaviours and activities. Specific behaviours and activities were used to give tangible metrics that could subsequently be used to characterise any system involving people – the major common factor throughout all the examined systems. The schema for characterising these behaviours and activities is examined in more detail in Chapter 6.

With a basis for comparison established, it is then possible to repeat the process described in Figure 4.2 for several action/output systems. Repeating this comparison for multiple actions allows strong links to be established between the two systems (practice and laboratory). Repeating comparisons also supports the generalizability of the results and helps to bound their scope. However, in order to validate the identified links (essential for effective research – Section 4.3.1), it is necessary to examine a third system situated between laboratory and practice – the intermediary system.

Research Question 2

What is the relationship between designer behaviour in practice and laboratory-based critical design situations?

In order to establish and validate the relationships established between laboratory and practice during the first two studies (Section 4.3.2), it is crucial to adopt a third perspective (Section 4.2). In this case an intermediary study between laboratory and practice (Section 4.4.3). Using this intermediary system a second set of links can be established between both practice and the laboratory, thus, providing an alternative route between the two. Figure 4.3 shows how this third perspective gives an alternative validation route for the relationship between practice and laboratory.

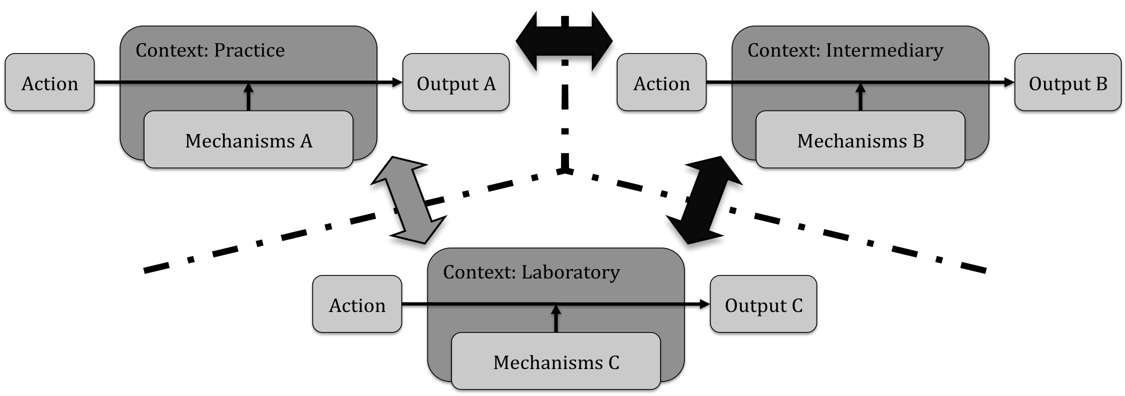

Figure 4.3: Direct practice-laboratory relationship validated via intermediary

For validation, the intermediary system was selected to have comparable mechanisms and context to practice while using the laboratory action. Combining the different aspects in this way allowed the validation of the contrived action (laboratory) as an adequate approximation of that observed in practice. This in turn validates the comparison between practice and laboratory, which relies on the input actions being analogues in both systems as discussed in Section 4.2.

The next step in developing the relationship between practice and laboratory is specifying appropriate studies able to support the various empirical elements outlined in this section. As such, the next section outlines each of the major studies and details how they relate to the requirements discussed in this section.

4.4 Studies

As discussed in Section 4.3.1, there are four main stages that research must go through in order to validate its findings, namely: research clarification, DS 1, PS and DS 2. Research clarification has already been addressed through the literature review described in Chapters 2 and 3. As such, this section outlines the specific methods used for each of the major studies (DS 1, PS and DS 2).

4.4.1 Observation of Practice

The observation study of practice is a descriptive study (DS 1). The objectives of DS 1 are to describe both the wider context of practice and also detail a number of specific action/output systems. As such, an ethnographic approach was selected as most appropriate. This was based on similar approaches discussed in Chapters 2 and 3 and was guided in particular by the works of Robinson (2010), Ball and Ormerod (2000), and Kitchenham et al. (2002). The technical aspects of the study were developed from the work outlined in Chapter 5. The study involved three practitioners who each completed an acclimatization/training period before completing one full week of complete observation. This was supported by a number of questionnaires and concluded by an interview. The specific methods are described in Chapter 6. The outputs of the first study are as follows and were used to inform the laboratory study:

- Characterisation of the wider context of practice.
- Detailed identification and characterisation of three action/output systems for further comparison (the critical design situations).
- Evaluation of the metrics and methods used.

4.4.2 Laboratory Study

The laboratory comprises a prescriptive study (PS). As the objective of the PS was to develop specific relationships with the three action/output systems identified in DS 1, a laboratory based experimental approach was selected. Each of the three systems was incorporated into an experimental brief, which was then used on a number of teams composed of postgraduate or undergraduate students. Using a direct approach such as this was considered most appropriate based on literature, particularly the works of Adelman (1991), Shadish et al. (2002), and Dyba and Dingsoyr (2008). The specific methods are described in Chapter 8. The outputs of this study are as follows and were formed the basis for the design of the intermediary study:

- Detailed characterisation of the three selected action/output systems in a laboratory context.
- Subsequent characterisation of the relationships between the laboratory and practice systems.

4.4.3 Intermediary Study

The intermediary study fulfils the role of a final descriptive study (DS 2). In this case an intermediary study is a study that uses the tasks from the laboratory study but places them in a practice context and uses practitioner participants. As the objective of DS 2 was to validate the relationships identified in the PS step, an intermediate approach was selected. This allowed the validation of both the identified relationships and the actions used for the laboratory systems. Using the experimental brief developed for the PS, a number of teams were formed from the original population of practitioners. In addition, the setting for this study was at the practitioners own workstation – mimicking the context of DS 1 as closely as possible. The development of this intermediary experimental approach was guided by the literature, particularly the works of Cook et al. (2008), Levitt and List (2007), and Edmonds et al. (2005). The specific methods are described in Chapter 9. The outputs of this study are as follows and were used to validate the identified relationships between laboratory and practice:

- Detailed characterisation of the three selected action/output systems in the intermediary context.
- Subsequent validation of the actions used in the laboratory system.
- Subsequent validation of the relationships between the laboratory and practice systems.

4.5 Summary of Research Methodology

This chapter described the process, through which the specific methods have been selected and linked together through the development of an overarching methodology. This took a grounded approach, starting with the identification of an appropriate research philosophy – critical realism. Based on this philosophy, a theoretical model was constructed to contextualise the overall research system. This theoretical foundation was then used as the basis for developing a methodology, linking the various research questions and objectives to appropriate studies and methods. The methodology was grounded by building upon the existing work of Blessing and Chakrabarti (2009). In addition, the specific study methods are introduced along with their outputs and contributions to the thesis. Figure 4.4 summarises the three studies and their associated methodological stages as well as the chapters where they are reported in detail.

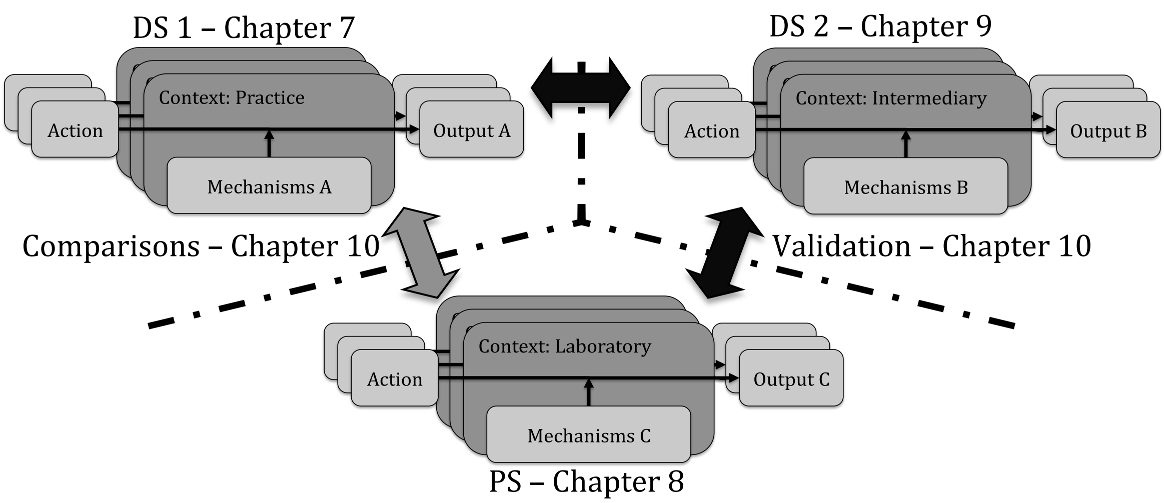

Figure 4.4: The methodological steps and their associated chapters

Finally, this section summarises the various research questions and their associated objectives. This includes methods used as well as the outcome for each stage.

Research Methodology

Research Question 1

How can designer behaviour and activity be characterised to enable comparison between design situations?

Objectives:

6. To create a methodology for investigating the relationship between practice and laboratory-based studies.
    a. **Method**: Literature review and scoping study.
    b. **Outcome**: Research clarification.
7. To review and devise a technology strategy for capturing designer behaviour and activity.
    a. **Method**: Scoping study including observation, interview and questionnaires. Supplemented by review.
    b. **Outcome**: Strategy clarification.

Research Question 2

What is the relationship between designer behaviour in practice and laboratory-based critical design situations?

Objectives:

8. To create an empirical method to capture, code and analyse designer behaviour and activity.
    a. **Method**: Empirical study of practice.
    b. **Outcome**: A characterisation of designer behaviour in practice.
9. To identify and characterise designer behaviour and activity for critical design situations.
    a. **Method**: Laboratory and Intermediate experiments.
    b. **Outcome**: A characterisation of designer behaviour in the laboratory and intermediary contexts.
10. To characterise the relationship between practice and laboratory-based studies for critical design situations.
    a. **Method**: Combination of the previous studies.

b. **Outcome**: A characterisation of the relationship between the three contexts.

4.6 Concluding Remarks

This chapter has detailed the research methodology and established the research questions and objectives. Each question is addressed by a number of chapters. Chapters 4, 5 and 6 focus on answering Research Question 1 while Chapters 7, 8, 9 and 10 focus on Research Question 2. The next step in addressing Research Question 1, now an overarching methodology has been established, is to identify appropriate capture strategies and supporting technologies, addressed in the next chapter.

"The mind moves the mass"

Virgil

5

Technology Selection

Chapter 4 has identified the need for effective characterisation of designer behaviour and activity in the various contexts studied in this thesis. Nonetheless, in order to effectively utilise these studies one other aspect must be considered – their technical implementation. This falls into three stages: capture, storage and analysis. The selection of appropriate capture technologies and analysis techniques is critical to the successful conduct of any study. Due to technical advances over the last decade storage is not an important issue unless extremely large datasets are generated (Grochowski and Hoyt 1996; Caulfield et al. 2009). As such this chapter focuses on capture and analysis technologies.

Two key aspects affect the work reported in this thesis in particular. Firstly, the need to allow for conducting and analysing both lengthy field studies (DS 1) and also short laboratory studies (PS and DS 2). Secondly, the need to capture a wide range of information, situations and media (both physical and digital) and also support both detailed and general analysis whilst retaining appropriate contextual information, the importance of which is highlighted in Chapter 2.

As such this chapter firstly examines the available capture approaches and state of the art technologies. Section 5.2 then examines various analysis approaches that could be used before; finally, Section 5.3 brings these together in a scoping study, which is used to define the technologies and analysis approach for this work.

5.1 Capture Requirements

This section examines the approaches and technologies needed to capture the various aspects of the design process and designer behaviour required for analysis and comparison. This review covers the technological demands of laboratory and fieldwork settings and subsequently identifies capture requirements.

Although specific capture approaches are many and varied, there is a common issue affecting each of them – inappropriate extent of capture. Figure 5.1 characterises this issue as encountered in the literature. The overlapping circles represent the information embodied in the design activity, the information captured empirically and the information revealed to the researcher about the design activity. It should be noted that Figure 5.1 is intended to demonstrate changing proportions rather than relative amounts as the scope of the design activity is clearly vast compared to even the most thorough study. Given the relation in Figure 5.1 two common adverse situations arise:

a. Insufficient appropriate information captured.
b. Excessive inappropriate information captured.

Insufficient information capture (Figure 5.1a) can be characterised as a lack of appropriate data concerning either the design activity or the relevant contextual factors. This is caused by factors such as lack of resources, access, planning or understanding of appropriate techniques. Examples include failures to capture or control certain empirical aspects such as the six areas identified by Kitchenham el al. (2002) (experimental context, experimental design, methods, analysis, presentation of results and interpretation of results), or factors such as self-reflection, intensity and richness as discussed by Ball & Ormerod (2000).

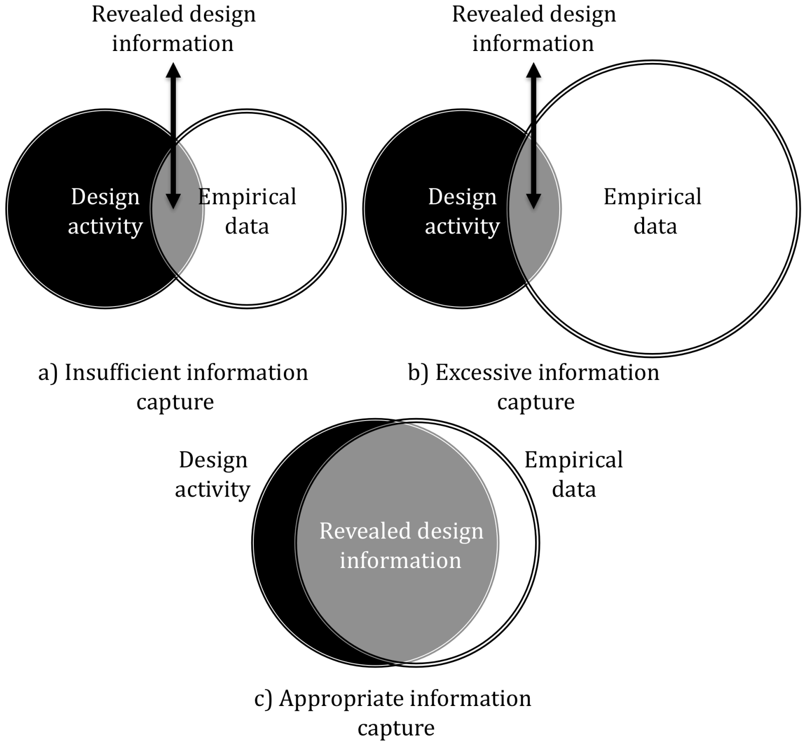

Figure 5.1: Technical issues affecting empirical capture

Excessive information capture (Figure 5.1b) can be characterised as excessive inappropriate data being captured. This can be caused by factors such as lack of planning or understanding of the requirements of the study. Lloyd et al. (2007) highlight this as a critical problem in studies where excessive data increases complexity, resulting in confusion. Kitchenham et al. (2002) note the importance of focused experimental design in order to guide statistical analysis and the potential to damage statistical validity in some analysis regimes.

Finally, Figure 5.1c represents the ideal for empirical data capture. This has been characterised as 'appropriate' capture and represents a study that gathers accurate information focused on the design activity while also providing sufficient information relating to the context, methods, environment and other factors required for reuse. This is a technical perspective of the ideal scenario described by Kitchenham et al. (2002) and Goetz & LeCompte (1981). In addition to the high-level requirements outlined in Figure 5.1, the selected technologies will need to be able to operate effectively in the context of fieldwork and the laboratory. As such the limitations and requirements of these two settings are examined next.

Fieldwork

Fieldwork covers a range of empirical studies. These can vary from non-interventionist ethnographically informed studies (Baird et al. 2000; Robinson et al. 2007) to direct experimentation in practice (Howard et al. 2010). Within this range, there are numerous approaches that can be adopted such as the 'work sampling' method developed by Robinson (2005; 2010; 2010), capturing own activity (Pedgley 2007) or diary studies (Sohn 2008; Wild et al. 2010). These are characterised as first, second or third degree – as discussed by Lethbridge et al. (2005). A core approach underpinning the study of fieldwork is that of ethnography (researchers being present and making notes on a subject within the system) (Baird et al. 2000; Button 2000). However, this has begun to be supplemented or replaced by technological and other approaches (Cunningham 2005; Coley et al. 2007). Examples include: technologically facilitated diary studies (Schmitz and Wiese 2006; Kellar et al. 2007), diary-assisted interviews (Sellen 2002; Hyldegard 2006) and technologically facilitated combinations of methods (Zimmerman 2008).

Whatever strategy is adopted, the core of fieldwork is to develop an understanding of practice with as little artifice as possible. There are several ways to achieve this: diary recordings (Bolger et al. 2003) and direct or indirect participant observation – see Lethbridge et al. (2005), who offers a discussion of the advantages and disadvantages of various approaches. From the work of Lethbridge et al. and others (Luck 2007; Morrow 2007) it becomes apparent that the capture approach has a large effect on what can be captured and how it can be used or reused.

Two other factors play an important role in the capture of fieldwork studies – the complexity of the situation and the non-replicability of any given event – highlighted in Chapters 2 and 3. Examples of this complexity can be found in the work of Balogun & Johnson (2004) – dealing with a large organization with multiple divisions and complex internal relationships – or Douce et al. (2001) – discussing the examination of complex programming situations over long periods. Combining this with the issue of variable capture approaches, it becomes apparent that there are three major demands of any technological approach:

1. It must be flexible enough to capture the full range of participant activities within the working context including distributed working (Bellotti and Bly 1996).
2. It must have as little disruptive impact as possible on both the participants' perception of their work and their physical activity.
3. It must provide as complete and unbiased a record as possible including the capture of situational context.

Laboratory

The central difficulty for fieldwork-based design research is that authentic design situations in a practice context are complex, non-replicable and difficult to manage as the parameters that define them are interconnected and jointly define the situation (Salomon 1991; Edmonds et al. 2005). These non-replicable, non-repeatable factors have led some researchers to adopt quasi-experimental approaches such as Arikoglu et al. (2010) and others (Cai et al. 2010; Lemons et al. 2010). This has generally followed the aim of limiting or controlling the experimental variables while maintaining an analogous situation to practice and are typically carried out in '*Design Observatories*' (Carrizosa et al. 2002; Milne and Winograd 2003; Ju et al. 2004; Hicks et al. 2008). Recent examples of this include Correman's (2009) work on design methodology, Stones and Cassidy's (2010) study of sketching and others (Lopez-Mesa et al. 2009; Collado-Ruiz and Ostad-Ahmad-Ghorabi 2010).

Design Observatories are the design researchers laboratory and are capable of flexibly capturing experiments while also offering some degree of control over the ambient conditions and experimental context. One such example is the Centre for Design Research at Stanford University, which used the *observe-analyse-intervene* approach (Tang 1989; Jung and Leifer 2011; Lande et al. 2011). Examples of laboratory based design experiments include: Schueller and Basson's (2001) case study of collaboration in distributed design, Marin's (2007) study of multi-disciplinary design and Prudhomme's (2007) study of knowledge dynamics in a design situation. Further, various aspects of design can be isolated and examined, e.g. interactions between designers (Smith 1998), design evolution during meetings/projects (Martin et al. 2006) or distributed and co-located teams (Larsson et al. 2005).

Although the flexible laboratory setting eliminates most of the technical issues associated with fieldwork there are still two key requirements stemming from the wide scope of activities undertaken in the laboratory, which are:

1. It must be flexible enough to capture the full range of participant activities.
2. It must provide as complete and unbiased a record as possible.

5.1.1 Capture Technologies

There are two main sources, from which most information about designer activity is drawn (McAlpine et al. 2011): formal and informal information. Combining these sources together can offer a rich record of designers' activities and interactions. As such, the next section examines what capturing these sources entails and what existing technological solutions entail.

Formal Records

One of the main situations where substantial information is generated in a difficult to capture setting is when the participant is working away from their desk in a meeting. Engineering design work (including collocated meetings) typically involves multimodal interactions, where participants use gestures (Bekker et al. 1995), sketches (Henderson 1991; van der Lugt 2002), electronic resources and physical or virtual objects (Kato et al. 2000) to communicate in a collaborative environment. Formal structured information from collocated or distributed meetings is normally in the form of written documentation produced during the meeting by a designated participant. This not only limits the ability of that participant to be active within the meeting, but can also result in a biased, incomplete or inconsistent record. In a fieldwork scenario, the researcher may take this role (Atkinson and Hammersley 1994). However, many limitations such as completeness of record and the potential for biased recording still persist. Thus, to be useful and reusable, it is important to capture not only fractions of the information generated, but to embed the information in the process in which it was generated, as highlighted in Chapter 3 and specifically emphasised by Petroski (1998).

It has been shown that documentation of this type is a typical problem found by engineers working in a distributed environment (Torlind et al. 2005). It was found that meetings and design reviews were poorly documented with major discussion issues overly summarised if recorded at all. The design rationale – the actual reasoning behind important decisions – was commonly not documented at all (Subrahmanian et al. 1997; Bracewell et al. 2009). Thus, as this research focuses on the activities and behaviour of designers in different situations, a more complete record than that provided by conventional meeting recording is vital.

A study by Jaimes et al. (2004) found that the four most common strategies for reviewing meetings were: distributed documents (88%), own notes (82%), meeting notes (79%) and asking someone (75%). Meeting recordings in the form of video or audio tracks were seldom used and designers in general are more interested in collapsed summaries or highlighted points in the form of meeting notes in this context. Other studies (Whittaker et al. 1994; Huet et al. 2007) have shown a general satisfaction with note taking from meetings but critically it is was found that 70% of participants still reported occasions when they wished they had written better notes. Thus, although handwritten notes are not ideal, they form an important record used by the designer and as such need to be recorded.

Comprehensive recording in this context is also critical in the capture of design intent, which is not normally recorded using conventional methods. A clear example of this information loss is in computer-aided design where, although relationships between parameters of geometric models are recorded, the rationale describing why these relationships were defined – the design intent – is typically not captured (Klein 1993; Ault 1999). Examples of other information types that are created and used during the design process are:

- Best practices –optimal solutions for typical engineering problem.

- Lessons learned – experiences gained and errors made during a project whose application in other projects can greatly improved their performance (Haas et al. 2000).
- Technical know-how – often documented and stored in digital repositories.

While enormous efforts have been put into documenting the design process this information is often difficult to use due to a lack of context. In this case information has been found to be difficult to interpret for users that were not involved in the process that created it. It is important that documentation can be re-examined within the context of the original communication event – i.e. the reprocessability of the information (Torlind et al. 2005). It has also been found that due to this reliance on interpersonal exchange, access to experts is often preferred over static documents and further, that users often need to find knowledgeable people who can help them apply the information to the current situation (Ackerman et al. 2003). Thus, in addition to written notes it must be possible to capture impromptu meetings between individuals away from their normal working environment.

Informal and Personal Records

Informal unstructured information is a common artefact of meetings, where, for example: several discussions can exist at the same time – side conversations (Larsson et al. 2002); there is shared sketching on whiteboards; post-its and other non-logbook media are used; and discussions can focus around physical objects (Bergstrom and Torlind 2005; Bergstrom et al. 2005). This is in addition to further personal information captured in logbooks, notes or sketches (McAlpine 2010). There is also a wide range of information used in meetings and discussions that is not recorded and accessed asynchronously such as Internet resources, personal libraries and old logbooks.

It has been shown that this personal information is an important factor, enriching and complementing the data collected from other sources (Badke-Schaub and Frankenberger 1999). Currently several tools are available that can capture white board information but other information sources still require manual collection and categorisation. Again, capturing this information demands a flexible approach able to record visual information both at the participants' desk and away from it.

5.1.2 Technology Requirements

Due to the complexity and scope of formal/informal information generated during the design process it is essential to consider a approach, using multiple complementary systems with a lower level of complexity and a higher degree of cumulative coverage. Cumulative coverage is used here to describe the idea of multiple synchronous capture sources covering overlapping perspectives of the same situation. For example, two cameras and a recorded logbook can be used to capture designer expressions, work activity and notes for the same situation – cumulatively capturing more than any single source.

Table 5.1: Technical comparisons between fieldwork and laboratory

	Description	Contrivance	Technological demands	Technological issues
Fieldwork	Ethnographic or fully embedded study of practice, typically observational	No contrived elements – equipment or researchers are fully embedded	Must capture wide range of activates without major disruption or privacy issues	Typically very large amounts of data generated by many varied sources
Intermediary	Experimental studies using practitioners, varying little from normal practice	Few contrived elements – usually limiting variation to a few aspects such as task or participants	More focused capture, can be designed with regard to specific experimental variables	Typically falls between fieldwork and laboratory in terms of data gathering
Laboratory	Experimental studies typically not using practitioners, in a custom environment	Numerous contrived elements – usually using students, different environments or methods	Highly focused, capture and analysis designed for specific experimental variables	Typically large amounts of specific data generated but over much smaller time scales

Although there are significant differences between fieldwork and laboratory, there are many similarities in terms of their technical demands. Table 5.1 describes the range of studies to be covered in this work and briefly compares the level of contrivance associated with each type, the subsequent technical demands and common issues. It should be noted that this represents a spectrum with each row highlighting the extremes.

In order to cope with this wide range of demands, the technical approach must be as flexible and as unobtrusive as possible. In addition, large amounts of multimodal data will be generated and, as such, analysis and organization must be considered when designing the capture protocols. It is also important to note that no existing system has either the flexibility or practicality demanded by this work. These issues can be distilled into a number of technology requirements. The selected technologies have to be able to allow the following:

- Capture a wide range of activities as well as detail depending on situation.
- Capture designer behaviour and activity.
- Capture contextual information beyond the specific focus of capture.
- Be unobtrusive and easy to use – preferably with no participant input.
- Be flexible enough to be installed in several different environments.
- Be able to operate over time periods of over 2 weeks of continuous use.
- Analysis must be able to deal with large volumes of data generated from multiple sources.

5.2 Analysis

The approaches and technologies discussed in Section 5.1 allow the level of information capture to be increased almost exponentially. However, without effective reuse, this data can become unwieldy to analyse or even meaningless in extreme circumstances. Thus, analysis and categorisation is an essential factor in eliciting understanding from the data generated in design observation and experimentation.

5.2.1 Content Analysis

There is a wide range of information sources that can be captured during the design process including both formal – e.g. CAD files, reports, results of analysis – and informal sources – e.g. whiteboards, post-its, logbook notes, sketches, diaries (McAlpine 2010). The ability to analyse this information is essential to support the cumulative coverage approach outlined in Section 5.1.

The most basic level of analysing this type of information often takes the form of a simple classification of the information properties (textual, pictorial, etc.) or the extraction of keywords. However, there is a variety of more advanced information based approaches for analysing design rationale (Kim et al. 2005), shared understanding (Dong 2005) and the management of documentation, collaboration and process (Lowe et al. 2000; Moreau and Back 2000). Patterns of activity have also been examined, for example: observing interaction with a CAD system to reason about the nature of the task (Campbell et al. 2005; Jin and Ishino 2006; Campbell et al. 2007). A final example is the wide range of tools and methods developed to model decision making e.g. modelling the decisional environment (Norese and Ostanello 1989) or the decision process during new product development (Montagna and Norese 2008).

Methods such as semantic analysis and other Natural Language Processing (NLP) techniques have been widely used to analyse and subsequently annotate verbal and textual information. There is a wide range of NLP techniques such as latent semantic analysis (Dong 2005) and a number of software implementations e.g. Infonic (2009). Other types of annotation or mark-up are also widely used to aid the interpretation and reuse of other structured and unstructured information sources such as CAD models or logbooks (McAlpine et al. 2006; 2008).

5.2.2 Indexing and Organizing

In contrast to analysis – providing understanding – indexing is concerned with determining how to classify the information based on this understanding, i.e. what metadata is required to categorize the document to enable effective reuse. Törlind & Larsson (2006) describe three approaches to indexing captured information: manual indexing, passive indexing and fully automatic indexing. Despite the substantial time commitment required, manual indexing is still the most commonly used with a large number of classifications for various information types. In terms of effort (and cost), such manual indexing activities are rarely scalable to the large volumes of information generated during a design review meeting (Cash et al. 2010). Automatic indexing is, however, often quite simplistic, indexing by time only. An example of this is the Quindi tool, which captures and provides automatic analysis support for meetings (Rosenschein 2004). More sophisticated systems offer the ability to index against a range of metadata produced from semantic analysis and other statistical methods (Infonic 2009; Virage 2009). Crucially, however, there is little guidance, or consensus relating to good practice for indexing criteria and little commonality between criteria for indexing different types of information.

How to store and present this information and its relationships is also critical for its reuse. Many types of database exist for organizing multiple types of information, including specialized product data management systems such as *PTC* (2009) or multi-faceted classification approaches such as Waypoint (McMahon et al. 2004). However, as with indexing, there is little consensus on how best to organize a single type of information (e.g. sketches), let alone multiple types of information in multiple formats including metadata.

Recent works (Boujut et al. 2009) show the importance of semantic annotation in the product design process and particularly during collaborative sessions. User defined and semantic annotations (i.e. annotations that carry a shared meaning and convey a certain amount of knowledge) are a means for structuring and indexing informal information by eliciting elements of context. This context, as already discussed, is particularly relevant from a design rationale perspective.

5.2.3 Manual v. Automatic

In summary, Sections 5.2.1 and 5.2.2 identify a wide range of techniques that could be applied to this project. However, there is a clear split between manual and automatic approaches for analysis and organization. In terms of analysis it becomes apparent that, in order to identify and effectively compare patterns of activity, automatic coding or analysis systems such as NLP are not currently effective for complex studies. As such, the manual approach must be adopted in order to give the required level of flexibility. This also becomes apparent when considered from an organizational perspective. Current automatic systems do not have the sophistication necessary to be able to deal with highly variable and complex datasets such as those likely to be encountered. The key tradeoff outlined in these sections is the ability to analyze well-defined, highly specific situations automatically or analyse complex situations flexibly at the cost of a much more labor-intensive process. As the studies outlined in this thesis, by necessity, cover a wide variety of situations and activities manual coding and analysis becomes the only viable option.

5.2.4 Synchronisation

A final consideration, once the data has been captured, is the synchronization of the different sources such that they can be analyzed in a cohesive manner. Synchronization in this context is critical in facilitating the 'cumulative coverage' described in Section 5.1.1. The issue of synchronizing multiple audio and visual channels is discussed by Törlind et al. (1999; 2009) who highlight many of the technical issues surrounding the subject. In addition, it is important to create a complete and accurate record in order to effectively apply the analysis techniques discussed in this section. Based on these two primary issues, technological and methodological, it was decided to synchronize the various sources using a core feed (provided by Panopto software (2011)) to which all others could be added. This approach was adopted in the scoping study and allowed all the sources to be added to a single timeline complied in the VCode (2011) video analysis software. The specific approach used for the final practice-based studies is discussed in more detail in Chapter 6.

5.2.5 Summary of Identified Technologies

In summary there are a number of available technologies that could be used to address the requirements discussed in this section. These are outlined in Table 5.2.

Table 5.2: Possible technologies

Tool /Technology	Advantages	Disadvantages
Pocket video camera *1920x1080 24fps Mp4*	Can capture a variety of settings, can be worn for all working hours	Can be obtrusive and difficult to synchronise with other sources
Video camera *1920x1080 24fps Mp4*	Can capture informal information	Obtrusive and limited setup, standalone recording
Webcam *320x238 15fps WMV*	Can be synchronised with other sources and is unobtrusive	Limited setup options and is tied to a base computer
Mobile phone	Ubiquitous and present in a variety of situations	Difficult to capture information via this source
Video Conference *Variable setup*	Can capture distributed meetings	Limited scope for capture and can be disruptive
Skype *Variable setup*	Can capture formal and informal distributed communication	Limited scope for capture
LiveScribe Pen *Proprietary format*	Can capture formal and informal logbook records	Limited to a specific logbook and requires participant input
Microsoft OneNote *Variable setup*	Can capture a range of computer based activity	Is disruptive and limited to specific computers
Keyword search	Is simple can be used on any computer	Extremely limited in scope
Tablet PC *Screen res. 3fps WMV*	Can capture a range of computer based activity	Is extremely disruptive and limited to specific computers
ManicTime	Automatic and unobtrusive	Limited scope of capture
Xobni	Automatic and unobtrusive	Limited scope of capture

In order to assess the identified technologies, a scoping study was undertaken, which is described in the following section.

5.3 Scoping Study

The purpose of this study answers was to identify the most appropriate or optimal set of tools/technologies for recording varied practice-based fieldwork as well as laboratories when focusing on designer behaviour and activity? This was addressed in two parts:

- Establishing the capabilities of various existing capture technologies in a range of design situations.
- Establishing the potential of the information provided by these technologies for giving insight into designer behaviour and activity.

In this case capability can be defined as the degree to which each technology addresses the requirements identified in Section 5.1. Potential is defined as the extent to which each technology fulfils the different metrics identified in this section, particularly those associated with context and designer insights.

5.3.1 Method

To address the two points outlined in Section 5.3, a study was undertaken. This took the form of a participant-observer experiment covering three weeklong design projects undertaken by a researcher; in conjunction with students working on existing industrially-sponsored design projects (see Project 1, 2 and 3 at the end of this section). Three one week projects were selected in order to cover the full range of likely design situations and activities at different stages in the design process while also allowing an assessment of the technology's performance over a long timescale. This was essential to allow the effective assessment of the technologies needed for practice-based fieldwork where a wide range of activities was anticipated.

A number of off-the-shelf technologies were selected in order to capture as much information as possible – audiovisual, formal and informal. Each study consisted of a researcher undertaking a design task while self-monitoring using the selected technologies. Each study deployed the various technologies in a number of combinations, such that each of the technologies was trialled thoroughly.

The researcher-observer for this study was a final year MEng student at the University of Bath. The researcher was the same for each project and, in addition to their degree course, had one year of industrial engineering experience. Over the course of each project the researcher would be briefed on the project, carry out a number of design tasks over the course of the week and then finish with a design review activity. The projects were selected from existing final year three-month design projects to ensure that they were representative of real tasks with defined goals, success criteria and time constraints.

Each technology was assessed against a range of metrics, including the cost of deployment, ease of use, amount of 'post-processing' required and ease of analysis.

These metrics were based on the requirements outlined in Section 5.1 as discussed in Section 5.3.1. The information produced by each technology was also assessed against metrics including, level of contextual information provided and level of possible insight into designer activity and behaviour.

Table 5.3 gives a summary of the technologies used during the three studies. These include both hardware and software-based systems. Sixty-eight hours of activity were captured, generating 14Gb of data. Table 5.4 gives a breakdown of when each technology was used.

Table 5.3: Capture technologies

Category	Tool/Technology
Audio-visual	Pocket video camera, Video camera, Webcam, Mobile phone, Video Conference (VC) Facility, Skype (2011)
Text-based	LiveScribe Pen (2011), Microsoft OneNote (2011), Keyword search, Tablet PC
Computer-based	ManicTime (2011), Xobni (2011)

Table 5.4: Summary of projects

Project №	Hours Captured	Volume of Data (Gb)	Hardware Used	Software Used
1	23.5	6.61	LiveScribe, Pocket video camera, Video camera	ManicTime, Xobni
2	24.0	4.96	LiveScribe, Pocket video camera, Video camera, mobile 'phone	OneNote, ManicTime, Xobni, Keyword search
3	21.2	2.90	LiveScribe, Tablet PC, Webcam, VC	OneNote, ManicTime, Xobni, Keyword search, Skype

Three groups of metrics were used to assess the technologies: practical aspects, level of contextual information and insight into designer activity. These respectively included:

- Practical aspects: ease of use, processing, analysis, capture and storage.
- Contextual information: capture of decisions, rationale, sources of information and basic contextual information (times, locations and dates etc.).
- Designer activity: capture of working task, focus, activity and behaviours.

Each of these metrics was assessed using multiple instances of technology use – over 20 for most of the technologies. Quantitative scores were allocated based on each technology's performance to streamline comparison and to limit researcher bias. Table 5.5 summarises the different metrics and their associated scoring systems. Collectively these metrics address the various requirements identified in Section 5.1. Each metric has been selected based on the three main aspects required for these studies – practicality and flexibility, broad capture of context in addition to specified details and designer behaviour and activity. Each metric was subdivided into several quantifiable aspects each scored and the summed to give an overall score.

Table 5.5: Technology assessment metrics

Metric	**Description**	**Scoring system**
Practical aspects	An assessment of the cost, installation, autonomy, processing requirements and analysis time for the different technologies.	Scored 1 – 5 for four aspects (Table 5.6), then totalled and ranked.
Contextual information	An assessment of the amount of context captured by each technology. Also addresses the range of information the technology can capture.	0 – aspect impossible to determine 0.5 – aspect is implied 1 – aspect is explicit
Designer insights	An assessment of how much information can be explicitly recorded about the designers themselves with each technology.	Scored yes/no against a list of 26 possible designer activities. Then ranked by total score.

Comparing the specifications of the technologies and allocating a ranking from 1 to 5 determined the scoring for the practical aspects. This was assessed both qualitatively and quantitatively using a matrix of criteria to generate the final score. These are summarised in Table 5.6.

Table 5.6: Practical aspects metrics

Score	**Criteria**			
	Ease of Gathering/ Autonomy	Processing Required	Ease of Analysis	Capture & Storage cost
1	Complex – requires researcher presence	4+ processes	Complex, subjective	€500+
2	.	3+	.	€101-500
3	Some intervention	2+	Straightforward	€50-100
4	.	1+	.	€0-50
5	Instant – 'fit and forget'	Instant/no processing	Instant, un-ambiguous, no training needed	€0 - Free

In contrast, the context capture group of metrics were scored using the following system: 0 – aspect is impossible to determine; 0.5 – aspect is implied i.e. only discernable indirectly with additional information; 1 – aspect is made explicit, e.g. date stamping or project metadata.

Finally, coding a sample captured from the video and written notes was used to assess the designer activity metrics. This was then scored against a list of possible designer activities as developed and implemented by Wasiak et al. (2008), who also gives definitions for the various terms. This protocol has been applied successfully in email (Wasiak et al. 2008) and logbook (McAlpine et al. 2009) contexts. In this case scoring was carried out by a hypothesis-blind third party who was given segments of information from each of the technologies (video and written) – recorded during a project clarification meeting. The metrics used are summarised in Table 5.7.

Table 5.7: Designer insights metrics

Problem solving	**Communication processes**	**Communicative acts**	**Project/ Process-related**	**Product-related**
Goal setting	Clarifying	Agreeing	Planning	Cost
Constraining	Debating	Disagreeing	Time	Materials
Solving	Informing	Opinions		Function
Evaluating	Exploring	Orientation		Performance
Decision making	Digressing	Gives Suggestion		
	Managing	Shows antagonism		
		Shows solidarity		
		Shows tension		
		Shows tension release		

Project 1

This project explored the feasibility of different manufacturing methods for producing made-to-measure orthotics for use by basketball players. The report covered the manufacturing methods, availability of resources and production of a cost estimate. The project covered three main areas: existing orthotics, materials used in orthotics and the various possible manufacturing approaches. Figure 5.2 and Figure 5.3 demonstrate some of the capabilities of the LiveScribe pen used in this project.

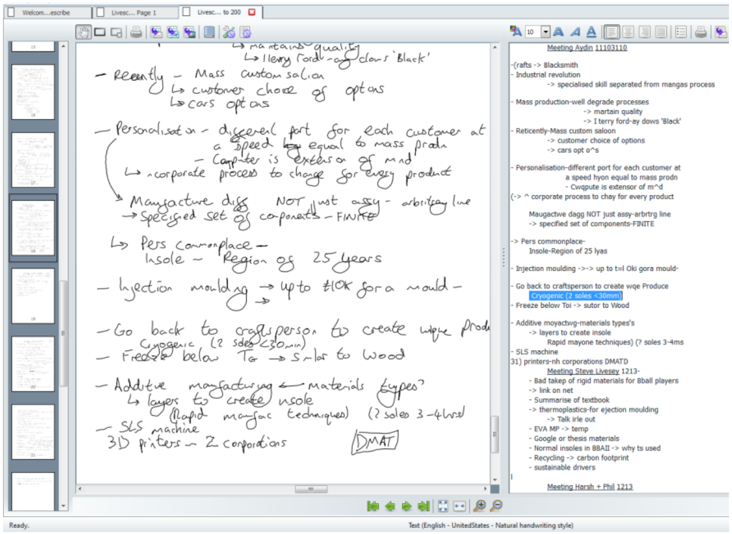

Figure 5.2: A sample of LiveScribe pen handwriting being converted to text

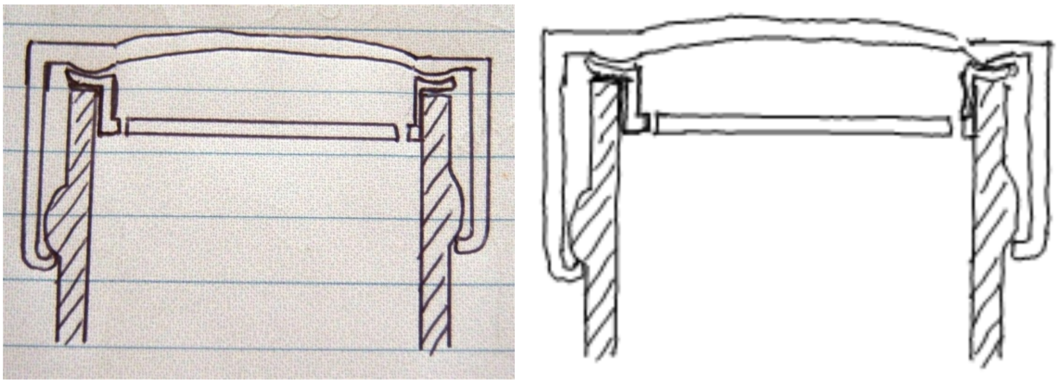

Figure 5.3: A sample of LiveScribe pen sketching

Project 2

This project investigated the feasibility of the design and manufacture of personalised shin pads. The report covered the materials suited for body impact protection, a biomechanical study of the human lower limb and an investigation of manufacturing processes suitable for shin pad materials. This project included review and testing elements as well as a discussion of the market drivers affecting shin pads and commercial viability. Figure 5.4 and Figure 5.5 show examples of the Pocket camera in use during this project.

Figure 5.4: A sample of the Pocket camera footage

Figure 5.5: Example of the Pocket camera in use

Project 3

This project primarily comprised a product-design task. The aim was to design an insert to fit into bottles to provide a 'drizzle' function for condiments and syrups. This project involved working with the manufacturer, reviewing past designs, creating and evaluating concepts. During the course of the project, distributed and collocated meetings were held to review progress and discuss design options. The final design was prototyped and a presentation made. Figure 5.6 and Figure 5.7 show OneNote (on the tablet PC) and Skype in use.

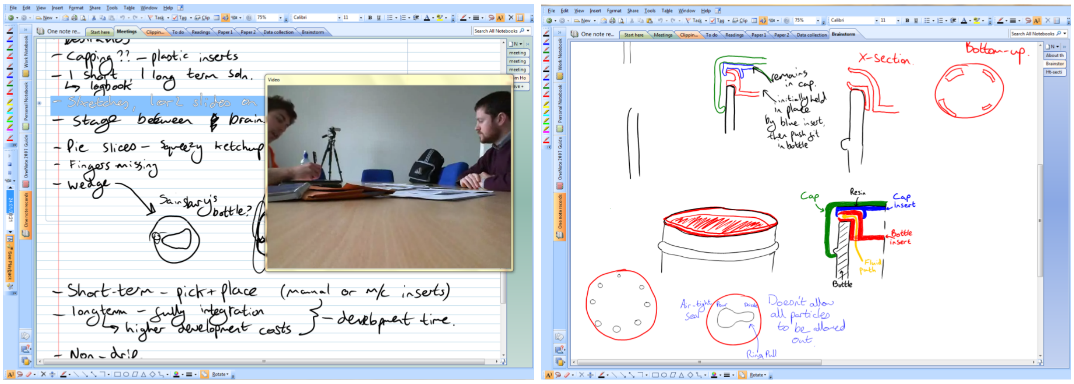

Figure 5.6: OneNote in use for making notes and sketching

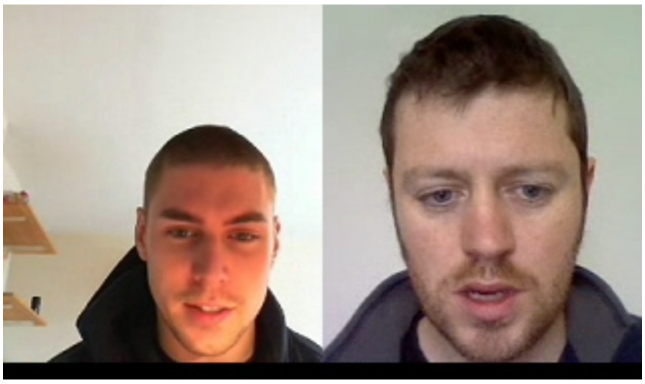

Figure 5.7: Sample footage from a Skype meeting

5.3.2 Results

This section outlines the performance of the various technologies as assessed against the three groups of metrics using the scoring criteria described in Section 5.3.1.

Practical Aspects

The scores for each of the technologies are outlined in Table 5.8. The top four technologies are highlighted in grey for clarity. These are the webcam, LiveScrbe pen, keyword searching and ManicTime, which offer a relatively complete complementary record of the designers' activity and the wider context.

Table 5.8: Practical aspects scoring (top four highlighted in grey)

Tool /Technology	Ease of Gathering/ Autonomy	Processing Required	Ease of Analysis	Capture & Storage cost	Total
Pocket video camera	3	3	3	3	12
Video camera	4	3	3	2	12
Webcam	4	4	4	4	16
Mobile phone	5	3	2	2	12
Video Conference	2	1	2	1	6
Skype	2	2	3	1	8
LiveScribe Pen	4	3	4	2	13
Microsoft OneNote	2	3	4	3	12
Keyword search	4	5	4	5	18
Tablet PC	3	2	4	1	10
ManicTime	5	2	2	5	14
Xobni	4	2	2	2	10

Contextual Information

The metrics for scoring capture of contextual information are: basic context, source, decisions and rationale. Table 5.9 summarises the scores for the various technologies, assessed against the 'impossible, implied, explicit' system described in Section 5.3.1. The top scoring technologies are again highlighted in grey. These are: video conferencing, LiveScribe pen and the tablet PC.

Table 5.9: Contextual information metrics and scoring (top three in grey)

Tool /Technology	Basic Context	Sources	Decisions	Rationale	Total
Pocket video camera	0.5	0.5	0.5	0.5	2
Video camera	0.5	0.5	0.5	0.5	2
Webcam	0.5	0.5	0.5	0.5	2
Mobile phone	0.5	0.5	0.5	0.5	2
Video Conference	1	0.5	0.5	0.5	2.5
Skype	1	0	0.5	0.5	2
LiveScribe Pen	1	0.5	1	1	3.5
Microsoft OneNote	0.5	0.5	1	1	2
Keyword search	1	0.5	0.5	0	2
Tablet PC	1	1	0.5	0.5	3
ManicTime	0	0.5	0	0	0.5
Xobni	1	0.5	0.5	0	2

Technology Selection

Designer Insights

Designer insights only compared videos v. written information, as these are the only applicable technologies in this case. As such Table 5.10 outlines the number of instances of a code for each metric group e.g. instances of problem solving activity gives 18 v. 6 for video v. written respectively.

Table 5.10: Designer insights scoring

	Problem Solving	**Communication processes**	**Communicative acts**	**Project/process related**	**Product related**
Video	18	23	7	6	13
Written Notes	6	11	0	5	6

5.3.3 Summary

Table 5.11 gives a brief overview of each technology selected from the scoping study. These technologies will be supplemented by additional techniques – as described in Chapter 6 – in order to cover the whole range of participant activity while also effectively characterising the working context. Collectively these technologies address each of the requirements outlined in Section 5.3. Table 5.11 gives a clear indication of the wide range the technologies provide in terms of both level of detail and scope of coverage.

Table 5.11: Selected technologies

Technology	**Capture content**	**Field**	**Source**
Panopto + Webcam	Participants disposition	Desk and normal working area audiovisual	Logitech HD pro webcam C910
Panopto	Participants work on the computer	Computer screen (visual) – camera coordination	www.panopto.com
ManicTime	Computer usage, activates, documents and applications	Computer activities	www.manictime.com
Mobile camera	Participants view of all situations away from the desk	Away from desk audiovisual	Samsung digital camera HMX-U10
LiveScribe pen and pad	Participants notepad use and audio	Desk/away from desk – audio and written notes	www.LiveScribe.com

5.4 Concluding Remarks

This chapter addresses two areas associated with identifying suitable technology for this research. Firstly, the technical differences between fieldwork and laboratory – and their associated capture and analysis requirements. Secondly, the selection of appropriate technologies from the scoping study based on the identified capture and analysis requirements.

Due to these constraints, it was decided that a combination of simple, flexible and readily available technologies would be combined for the final capture strategy. This has several advantages highlighted by the scoping study: They can be combined to cover a wide spectrum of situations; they can be deployed at relatively low cost; they come with existing support structures and are less lightly to disrupt the participant due to their unobtrusive 'off-the-shelf' appearance.

The scoping study identified and tested a number of technologies which could be used in both laboratory and fieldwork situations. Those finally selected formed a combination able to capture: computer work, designer activity, written notes and activity away from and at the desk. The final selection included: the LiveScribe pen (2011), webcams, ManicTime (2011), an improved pocket camera and an improved computer recording system (Panopto 2011) which also synchronised the webcam footage.

The use of multiple overlapping cameras allows a detailed record of the designers' behaviours and activities while providing a high degree of contextual information. The off the shelf and highly automated nature of the technologies maintains a high level of unobtrusiveness while reducing participant input to a minimum. In terms of flexibility of coverage, the use of multiple complementary technologies gives maximum flexibility while keeping equipment costs to a minimum. Finally, the multiple technologies support synchronisation and manual analysis by streaming all the primary video feeds through the Panopto software.

"A small rock holds back a great wave"

Homer – The Odyssey

6

Proposed Empirical Method

Although Blessing and Chakrabarti (2009) give guidance on high-level methodology they do not discuss specific methods. In Chapters 2 and 3 the main methodological issues affecting this work were discussed, subsequently Chapter 4 outlined the overall methodology and Chapter 5 described the selection of appropriate technology. As such, this chapter builds on these findings to develop the research methods. Further, this chapter goes beyond the high-level methodology to develop a core empirical method, which specifically supports the multiple studies required by the methodology outlined in Chapter 4. Subsequently, the studies outlined Chapters 7, 8 and 9 all build on this method.

In order to effectively answer the research questions (Section 4.3.2), it is necessary to conduct a series of comparable and linked studies – practice, laboratory and intermediary (see Section 4.2). To achieve this comparison, required for the identified research questions, a high quality of system understanding is necessary – comprehensive, detailed and accurate (Chapter 3). The quality of this understanding is the accuracy with which an observational study of practice represents the practitioner, their environment and the context in which they practice. For the purposes of this work, the process of generating this understanding will be referred to as the characterisation of the experimental situation. Producing incomplete or inaccurate characterisation (comprehensiveness etc.) can have serious implications for theory development, validation and impact – all of which are based on accurate characterisation of the real situation, i.e. practice.

Further to the requirement for high quality characterisation of the experimental situation, any empirical method must also consider the core areas (Theory, context, system understanding, method implementation, control and normalisation, and critique) and associated issues identified in Chapter 3. Although Table 3.2 highlights theory it is not the place of specific methods to address this, as theory must be considered at the methodological level – which is then supported by appropriate methods. This means that the method used for each of the studies must effectively tackle contextualisation, system understanding, method implementation, control and critique.

Due to a lack of appropriate extant methods there is a need to create a new method to address these issues. Examining the review, it is apparent that a number of variations in method are required to fulfil the demands of the methodology. Therefore, this chapter defines a core empirical method, which is then added to for each specific method (Chapters 7, 8 and 9) to allow for improved standardisation, triangulation, implementation and baseline comparison – mitigating approaches highlighted in Chapter 3. Further, this core method must offer a high degree of flexibility in research focus without sacrificing rigour or detail in analysis. As such, this chapter firstly examines the current issues in characterising practice in terms of existing approaches and then uses this as a basis for synthesising an enhanced method combining the best elements of these approaches. This is then detailed in three stages – capture, coding and analysis.

6.1 Current Issues and Approaches

Before it is possible to develop a new method it is key to understand existing issues. As such, this section briefly summarises and reviews extant methods by comparing them to the core issues identified in Chapter 3. Although there are many different approaches used to characterise practice, the core issues affect them all as discussed in Chapter 3. These are: theory deficit, insufficient contextualisation, system clarity, method variability, experimental control and closing the loop.

Based on these issues, it is possible to review the limitations of existing methods used to characterise practice. This can be achieved by examining each approach with regard to each of the issues and then identifying where the gaps are (Section 6.1.2). However, before this is possible, it is first necessary to introduce and summarise the main types of observational approaches.

6.1.1 Observational Approaches

There are many different approaches that attempt to characterise design practice including diary studies (Bolger et al. 2003) and ethnography (Ball and Ormerod 2000) (these were explored in detail for design research in Chapter 2 and for the associated fields in Chapter 3). Each of these approaches attempts to give an accurate representation of practice, using various technical or methodological techniques. Table 6.1 summarises the most commonly used observational approaches as identified from the reviews outlined in Chapters 2 and 3. Table 6.1 also includes an example reference for each. It is important to understand these approaches capabilities/limitations before any possible improvements or new methods can be proposed.

Table 6.1: Observational approaches for characterising practice

Approach	**Description**
Work diary	Participants report events either as they happen or reflectively e.g. (Bolger et al. 2003)
Work sampling	Participants report events as prompted – can generate large data sets e.g. (Robinson 2010)
Ethnography	A combination of observation interviews and studies e.g. (Atkinson and Hammersley 1994)
Auto-ethnography	Focusing ethnographic techniques on the self e.g. (Cunningham 2005)
Shadowing/ observation	A researcher follows the participant and captures their activities e.g.(Singer et al. 2010)
Instrumented systems	Participant activity is automatically captured e.g. on the computer (ManicTime 2011)
Fly on the wall	Participants capture themselves using video or audio e.g. (Cooper et al. 2002)

6.1.2 Limitations of Existing Approaches

Using the issues identified in Chapter 3, it is possible to critically assess the limitations of the different approaches, listed in Table 6.1. Table 6.2 brings these approaches together and relates them to the issues. This table also outlines a specific example of the issue associated with each approach.

Based on the limitations highlighted in Table 6.2, it is possible to imagine a combination of approaches that could reduce or even eliminate many of the limitations. This combinatorial concept and its implications for the core empirical method is the focus of this chapter and is introduced in the next section.

Table 6.2: Limitations of current approaches

Approach	**Limitations**	**Relation to the core issues (see Table 3.2)**	**Example of relation to core issue**
Work diary	Difficult to account for bias introduced through self reporting or contextual information	Difficult to account for bias (issue 5), difficult to validate, replicate of generalise (issue 6)	Relies on self report which can affect behaviour
Work sampling	Difficult to account for bias introduced through self reporting or contextual information	Difficult to account for bias (issue 5), can lack wider characterisation of the system (issue 3)	Still relies on self report, can be disruptive to normal working practice
Ethnography	Difficult to effectively code and report the full dataset and can be affected by bias	Difficult to account for bias (issue 5), difficult to validate, replicate of generalise (issue 6)	Extremely time-consuming and resource intensive
Auto-ethnography	Difficult to account for bias and typically of a limited sample size	Affected by issues 5 and 6 but can also be linked to issue 3 due to the limited perspective	Only appropriate in limited situations, not typically suitable for practice
Shadowing/ observation	Difficult to account for bias and typically of a limited sample size	Issues 5 and 6 play a large role in studies of this type due to possible bias and difficulty in replication	Difficult to accurately capture action on the computer or detailed working
Instrumented systems	Difficult to address contextual information or effectively characterise the whole system	Difficult to effectively contextualise system use (issue 2) and its relation to other work (issue 1)	Difficult to draw meaningful information from this type of data
Fly on the wall	Difficult to account for bias introduced through self reporting	Issues 5 and 6 lead to possible bias and difficulty in replication	Large amounts of data generated difficult to use with only one camera

6.1.3 Methodological Problems

In order to effectively describe practice, there are several method-related concerns that must be considered. Dyba and Dingsoyr (2008), amongst others (Kitchenham et al. 2002; Blessing and Chakrabarti 2009), highlight a number of problems that researchers must address when designing a study. Table 6.3 provides a detailed description of how these issues manifest in the context of observational methods, summarising the findings of Chapter 3 and expanding those issues specifically related to the method. In this context, the issues they are no longer referred to as such, instead being described as specific problems – as they are related to a specific method.

Table 6.3: Methodological problems

№	Problem	Description
1	Describing context	Characterising context to support generalization and links to theory (Dillon 2006)
2	Sampling design	Avoiding sampling bias to effectively represent the population (Torgerson and Torgerson 2003)
3	Clear research design	Designing and reporting the research to support replication and validation (Dyba and Dingsoyr 2008)
4	Data collection	Avoiding bias and information overload whilst giving a rich dataset (Hicks et al. 2009)
5	Reflexivity	Managing the research/participant relationship to minimize bias and other experimental effects (Verstappen et al. 2004)
6	Data analysis	Minimizing bias while giving results that can be effectively interrogated (Kitchenham 1996)
7	Value of findings	Defining the validity, nature and role of the findings in the wider context (Gorard and Cook 2007)

6.2 The Proposed Method

To develop the method, it is necessary to effectively mitigate limitations identified in Table 6.2. This section describes how this core empirical method builds upon existing methods to address the issues and limitations associated with current methods.

Three key pieces of research have formed the foundation for the development of this core empirical method. Of particular note is the accuracy and multi-level analysis strategy of Robinson's approach (2010), the numerous capture sources highlighted by the work detailed in Chapter 5 and the multiple perspectives on engineering work enabled by Wasiak et al.'s approach (2010). Technical elements of this prototyping work are detailed in Chapter 5 and comprise the detailed analysis and selection of capture equipment. Further to this, the whole method including coding and analysis was developed using a prototype study – an important part of the research cycle (Gorard and Cook 2007).

The proposed method addresses the problems specifically described in Table 6.3 (and more generally in Chapter 3) by combining the positive characteristics of existing works, in conjunction with further refinement and novel additions.

In order to develop the core method and provide sufficient information to allow subsequent third party analysis, replication, validation or generalization, it is critical to couch the method in a wider framework and thus effectively link to theory. As such this method can be used to address phases 5 or 6 of Gorard and Cook's (2007) seven phase research cycle (Table 3.1): (5) field study and (6) definitive testing. As with Blessing and Chakrabarti (Blessing and Chakrabarti 2009) the discussion of Gorard and Cook is general, and as such, this work goes to the next level of granularity in developing specific methods. It is critical that this method can be adapted to both phases 5 and 6 as these form the basis for the empirical studies described in Chapters 7, 8 and 9. As such, the core method is the primary element in answering Research Question 1.

The proposed core method is characterised by an integrated three-stage approach – capture, coding and analysis. Although combining capture, coding and analysis into a single method is not in itself novel, each stage draws on unique elements that contribute to a more effective overarching method. The core empirical method integrates these components to deal with multiple research foci for characterising design practitioners' behaviours and activities whilst maintaining standardisation (of method, coding, analysis and technical implementation) and also addressing the identified methodological problems. Each of the three stages has a number of sub stages:

- Stage one is the capture strategy (Section 6.3), which deals with the capture of context, technical setup and data collection. This addresses problems 1 – 5.

- Stage two is the coding strategy (Section 6.4), which introduces the five levels of coding. This addresses problem 6 and enables the analysis stage.
- Stage three is the analysis strategy (Section 6.5), which uses increasing levels of detail to give macro and micro levels of analysis. This addresses problems 6 and 7.

The three major stages and each of the main sub-stages are illustrated in Figure 6.1. Based on this outline the next section deals with the capture strategy.

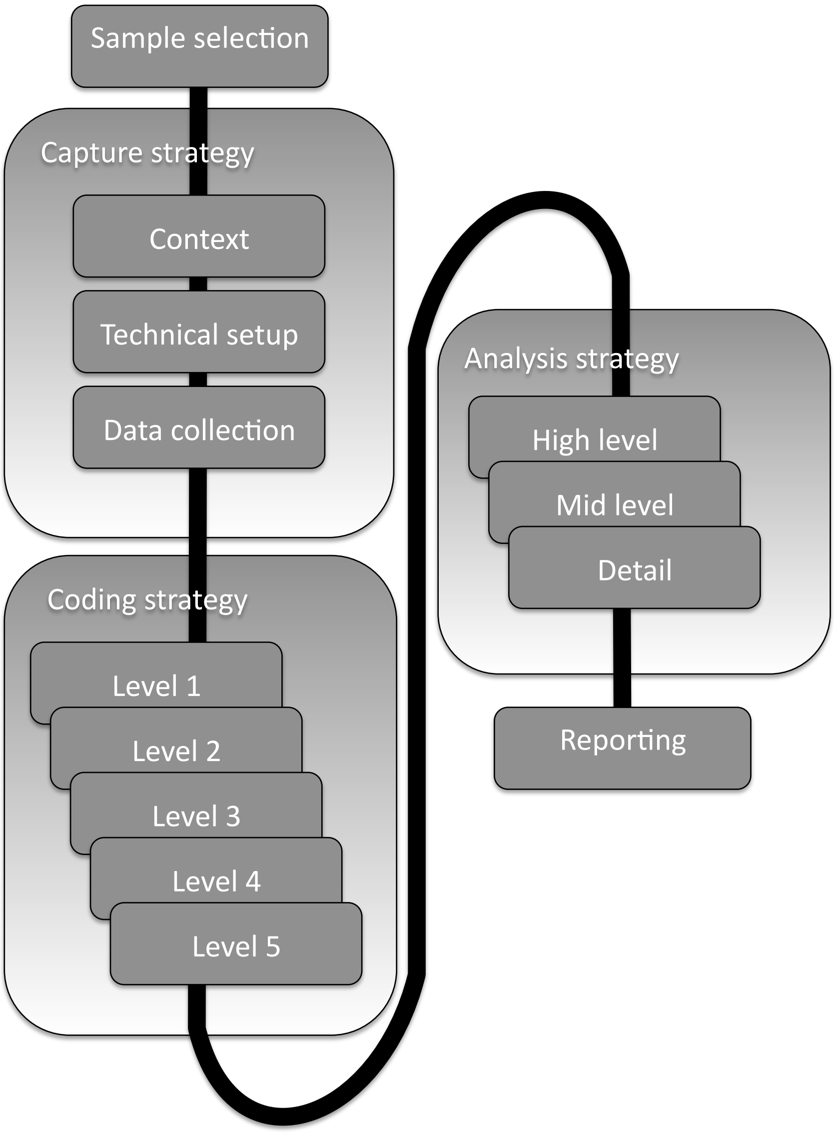

Figure 6.1: Core method diagram

6.3 Capture Strategy

There are three major aspects of the capture strategy: capturing contextual information, technical setup and data collection. These are dealt with in this section.

6.3.1 Capturing Context

This section covers the capture of various types of contextual information. Context is essential in order to develop the relevance and external validity of a study (Kitchenham 1996; McCandliss et al. 2003; Allard et al. 2009). Indeed, Shavelson et al. (2003) state that '*coupling scientifically warranted knowledge and rich contextual information in some narrative form might lead to increased understanding and use of scientific research in practice*' (p. 28). Further to this Ahmed (2007) highlights the specific relevance of contextualising various factors for observational methods.

Although context is an important element affecting research, there are no clear, widely accepted measures for characterising it in detail. A number of key terms do, however, emerge from the literature: activity, organizational, cultural, social and historical (Wildemuth 1993; Klein and Myers 1999; Malterud 2001; Dym et al. 2005). Comparing the meanings of these various terms, it is apparent that organizational and cultural are similar. 'Organizational' is commonly used to express the company culture, while 'culture' is more commonly used to describe broader, participant related aspects of culture such as national culture or the cultural background (Janssen et al. 2004). As such, by considering each factor from both a company and participant perspective, four main factors emerge: activity, social, cultural and historical. Each term is explored in more detail in this section. For the purposes of this method the various contexts were captured through a series of meetings and questionnaires based on the work of Dyba and Dingsoyr (2008) and Dillon (2006).

Activity

The context of the participants' activities is explored in greater detail in each study; however, there are several important factors that are relevant here – particularly with respect to the practice-based study detailed in Chapter 7. Firstly, the normal activities of participants can vary greatly, ranging from working at their own computer to large collocated or distributed meetings. Secondly, the bulk of their work involves either their personal computer or logbook (McAlpine et al. 2011). Based on this information, it is important that any capture strategy can record the variety of activities likely to be undertaken – particularly on their computer and logbook. Also, the capture strategy must have minimal disruption on their daily activities (Section 3.5.1). As such, it is important to give time for participants to become familiar with the various technologies and tasks associated with the method, such that they become habit and thus non-intrusive. Table 6.4 summarises the recorded information for the activity, social, cultural and historical contextual factors.

Social

Factors associated with the social context of the company include factors affecting how the company operate (i.e. factors that affect job complexity, demand, challenge, autonomy and complexity) (Shalley and Gilson 2004). These include: funding, income source, market pressures, environmental factors, other monitory pressures and the composition of the company population. In addition, social factors affecting participants include: social norms (Streitz et al. 2001; Levitt and List 2007), social status (Jakesch et al. 2011), independence and interests (Shalley and Gilson 2004). These factors were captured using questionnaires given to company managers who were best placed to ascertain information on the company related factors. Participant information such as sociometric details, basic education and property ownership were used to indirectly assess the identified factors.

Cultural

The need to capture the cultural dimension is emphasised by Petre (2004) who highlights its effect on practitioner behaviour. This can be used to assess the hierarchy within the company, as well as the level of formality, level of socialising and overall homogeneity of the company. Other factors include: pride in quality of work, competitiveness, informality, type of design work (Wild et al. 2005), organizational aims or areas of support (Janssen et al. 2004), management values, authority system (Guzzo and Dickson 1996), leadership (Stewart 2006), existing projects and practices (Lewis and Moultrie 2005). From an individual perspective, the primary factor is that of national and local culture including elements such as collectivism/individualism and group homogeneity (Janssen et al. 2004; Shalley and Gilson 2004). Based on this, three company and one participant factor were identified as outlined in Table 6.4. Culture was assessed in two ways: questionnaires given to the managers and a series of meetings with the participants.

Historical

In terms of the company, most of the historical factors manifest indirectly in terms of either the current social or cultural context. As such, there is little to directly assess in this factor. Based on this, two areas were captured – annual turnover and maturity – playing a confirmatory role by complementing the factors recorded in the social and cultural elements. In terms of the participant, the key historical factor is their previous experience and knowledge (Shalley and Gilson 2004; Jakesch et al. 2011). For the purposes of this thesis, this has been assessed by recording industrial experience, qualifications, academic achievement or related experience through hobbies or other projects. Details of company and participant background were again obtained using questionnaires given to company managers and participants respectively.

Contextual Elements

Table 6.4 outlines the contextual elements recorded as part of this method. Although this information is not directly analysed in this work it is critical for allowing reuse of the dataset and in building comparisons with other studies and participant populations. As such, these elements are key to making the core empirical method rigorous, replicable and comparable.

Table 6.4: Contextual elements

Company	Participant
Activity	
Photos of pre study participant work area and local working environment	Interview assessment of home/office split, technical features of the computer/workstation
№ of people in the office	Use of resources – whiteboard, note pad, phone, bookshelves etc
Social	
The main influencing factors on the company incl. funding/income sources, market and monetary pressures etc.	Age, occupation, highest level of education, gross individual annual income, level of property ownership
The number of full time employees, the number of design practitioners, dedicated management or support staff	Postcodes used to give sociometric information on the participants using ACORN via www.upmystreet.com
Cultural	
The company's main aim(s) (product/service) and scope, its core values and mission statement(s)	National background
Expertise, engineering focus and level/type of in-house v. outsourced design, prototyping and manufacture	
Significant partners e.g. sister, parent or subsidiary companies/institutions and their role in management/direction	
Historical	
The annual turnover of the company	Education: A-levels or equivalents – subjects and grades; degree or equivalent – institution, subjects and their focus; other professional or educational qualifications relevant to their work
The maturity of the company	Professional experience: placement(s); employment over six months; current role – company, duration, description
	Stage of development within the company's structure/professional development framework

6.3.2 Technical Setup

For the core method, the equipment selection and setup was based on the findings of the prototyping study detailed in Chapter 5. This identified a range of capture technologies, which were assessed for the level of coverage with respect to data collection/analysis demands. The identified technologies are (Table 5.11): Panopto, webcams, ManicTime, a mobile camera and the LiveScribe pen and pad. The multiple capture pathways offered from this selection made it possible to cover the wide variety of situations likely to be encountered by the participants in practice.

Table 6.5: Focus of capture and associated technology

Focus	**Capture content**	**Capture technology**	**Further information**
Participant	Front view of participants face and upper body – high resolution, low frame rate, collated by Panopto	Panopto + Webcam 1	Logitech HD pro webcam C910
Workspace	Wide view of participants whole work space – low resolution, high frame rate, audio, collated by Panopto	Panopto + Webcam 2	
PC screen	Screen capture of participants' computer – high resolution, low frame rate, collated using Panopto	Panopto	www.panopto.com (Panopto 2011)
Software	Automatic recording of computer usage – usage, activities, documents and applications	ManicTime	www.manictime.com (ManicTime 2011)
Participant view	Participants view (the camera is chest mounted) of all situations away from the work station – low resolution, high frame rate	Mobile camera	Samsung digital camera HMX-U10
Written notes	Participants notepad use and audio – writing and audio playback of notebook	LiveScribe pen and pad	www.LiveScribe.com (LiveScribe 2011)

In order to guide the setup of the capture technologies, it is necessary to find out how the participant perceived their working environment. This should be used as a guide to aid placement and focusing of the capture technologies, but should not be considered limiting. For example, one participant during the practice-based study (Chapter 7) identified that they often worked from home and, thus, additional cameras were placed in this workspace such that the full range of possible activities were captured. Table 6.5 outlines the technologies suggested for the capture strategy – highlighting the focus of each technology.

From an engineering work perspective, the capture strategy ensures that at least two complementary sources capture each aspect of work. This is given in Table 6.6; the engineering work activities are taken from the literature, primarily the work of Hales (Hales 1991), Robinson (2010) and Austin et al. (2001). In this way, a robust record can be generated to provide redundancy and support triangulation of sources – a well-established method for improving validity (Chapter 3). In contrast to Table 6.5, which emphasises the focus of each capture technology, Table 6.6 highlights the overlap in technology for each area and shows explicitly, which sources were used for each capture area. This overlap is important for synchronisation and providing some redundancy as well as allowing triangulation during analysis. The overlap dimension is important (see Chapter 5) and its impact is demonstrated in detail in the practice-based study (Chapter 7).

Table 6.6: Summary of capture areas and capture technologies

Capture area	Capture technologies	Capture content
Collocated meetings and collaboration	LiveScribe pen	Meeting notes and audio of conversation
	Mobile camera	Audio and video from the participants perspective
Written communication	Panopto	E-mail and other messaging activity conducted on the computer
Distributed communications	Panopto and webcam 2	Audio and visual of phone or computer use
	Panopto	Computer based video conferencing
Individual design work	LiveScribe pen	Personal note making/working
	ManicTime	Overview of computer usage
	Panopto	Detail of work carried out on computer
Project management activities	ManicTime	Overview of computer usage
	Panopto	Detail of work carried out on computer
Participant detail	Panopto and webcam 1	Visual of participant demeanour
	Panopto and webcam 2	Audio and visual participant demeanour
Other	Daily questionnaire	Identifies events outside the office/work time related to work
	Post study interview	Identifies events perceived by the participant to have been missed

Figure 6.2 shows a plan view of a generic equipment setup at a participant's workspace and the different viewing angles for the two webcams. The entire workspace and surrounding area are captured while video of the participant and their workspace is captured from the front and side. This setup allows the capture of a participants immediate environment such as book shelves, practical work areas, notice boards or local conversations, as well as their overall demeanour. Figure 6.2 is an idealised example illustration of the key elements and will vary between situations and workspaces.

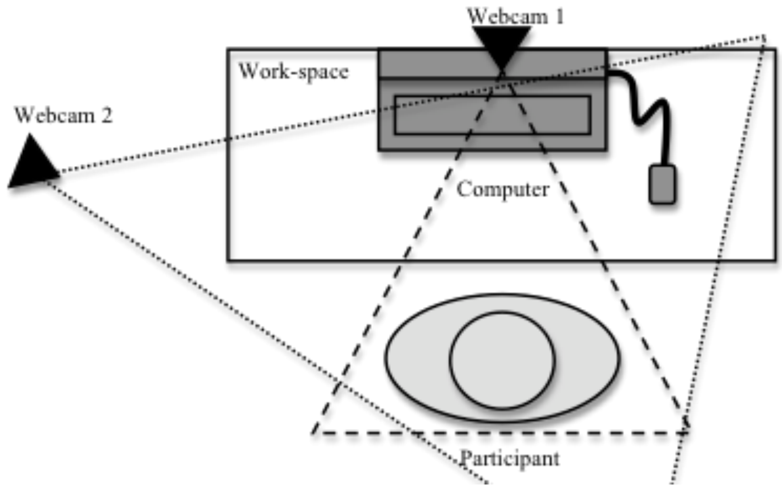

Figure 6.2: Camera setup at participants' workspace

6.3.3 Data Collection

With setup and contextualisation complete it is next necessary to collect the empirical data. Data collection took place over a period that was split into two phases; an acclimatization phase (three weeks) and a study phase.

Acclimatization Phase

It is widely accepted that a period of acclimatization is needed in situations where the study protocol is disruptive, or even known, to the participant (Adair 1984; Podsakoff et al. 2003). One of the primary reasons for this are the Hwathorne type effects discussed in Section 3.6. As such, the acclimatization period is essential for five main reasons:

1. It allows participants to become accustomed to the research equipment and procedures (such as backing up the data at the end of the day). Three weeks was considered a conservative estimate.
2. It allows participants to become accustomed to using new technology such as the LiveScribe pen (Table 6.6). Two weeks was considered the minimum for allowing this to become habit based on the study detailed in Chapter 5.
3. It allows participants time to get used to the data saving procedure required at the end of each day – backing up the video files from Panopto to an external hard drive. This reduced researcher contact to a minimum thus minimising possible Hawthorne type effects (Adair 1984; Podsakoff et al. 2003).

4. It allows the researcher time to customize the technology setup and address any issues raised by the participant. This includes checking the equipment and preliminary data – reducing problems/data loss during the study.
5. It allows the researcher to gather participant feedback on the perceived effectiveness of the capture strategy. Obtaining feedback in this way was used to improve the rigor of the study (Robinson et al. 2007).

Participants undertook at least three weeks of acclimatization prior to the main study. Three weeks was selected as it was considered a conservative estimate based on literature (Leonard and Masatu 2006) for the normalisation of Hawthorne-type effects, particularly the Halo effect in this case (Podsakoff et al. 2003; Barnes 2010). In some cases, this can be extended if the participant is unable to be in attendance for the full time. For example, during the study reported in full in Chapter 7, this period was extended to four weeks due to an absence and the need to setup additional equipment at the home workspace (in this case it was possible to use a layout similar to Figure 6.2). In all cases, the participants record data and behave as they would during the main study with the researcher checking the collected data for completeness at regular intervals.

Study Phase

With the acclimatization phase complete the study phase starts immediately – lasting as long as required for the studies aim. Before the study starts, each participant was given the opportunity to talk through any remaining issues/questions with the researcher. However, during the study itself, participant/researcher interactions were limited to reduce experimental effects (Podsakoff et al. 2003): There was no contact with the researcher; equipment was fully automated; software management and data storage were conducted using a fixed daily schedule. Once the study was completed the participants were interviewed and all the study data collected – this took place after the study phase was complete. The semi-structured interviews fulfil several important research requirements:

- It allowed the researcher to check if the participants' perceived their working practices to have been in any way unusual during the study.

- It allowed the researcher to check that participants were still hypothesis blind.
- It allowed participants to explain any incidents reported in the daily questionnaire.
- It allowed participants to relate any issues or unrecorded events encountered during the study.

With the study complete, the next stage is the organization, coding and analysis of the various data streams – organization and coding being addressed in the next section.

6.4 Coding Strategy

Due to the requirement to combine several observational approaches utilising numerous capture streams, a large amount of data can be generated (Chapter 5). As such, it is essential to be able to meaningfully and effectively code and analyse this data whilst avoiding information or analysis overload. This is compounded by the requirement to be able to analyse some sections in detail without sacrificing the wider contextual information surrounding such sections. In order to address these problems, a multi-level coding and analysis strategy was created.

6.4.1 Multi-level Coding and Analysis Strategy

The multi-level coding strategy consists of five levels of increasing detail. Five levels were selected as an acceptable balance between resolution and workload with more levels considered to be needlessly complex. This layered strategy allows the researcher to analyse detail whilst ensuring that higher-level contextualising information is also considered. In order to capture a higher level of detail without overloading the researcher, the sequential levels of coding act as a filter, isolating periods that the researcher does not wish to explore in further detail. Thus, it is possible to describe the entire data corpus at level one and subsequently remove those elements less relevant to the research – as dictated by the researchers focus.

Figure 6.3 outlines the five levels, describing the amount of detail (coding focus) and the filtering strategy at each level (filtered elements are italicized). Each level defines or guides the selection of data to be coded at the next level. Thus, reflection at each stage is essential to the strategy's effectiveness. Reflection also allows the researcher to identify and remove periods less relevant to their focus as guided by the coding strategy.

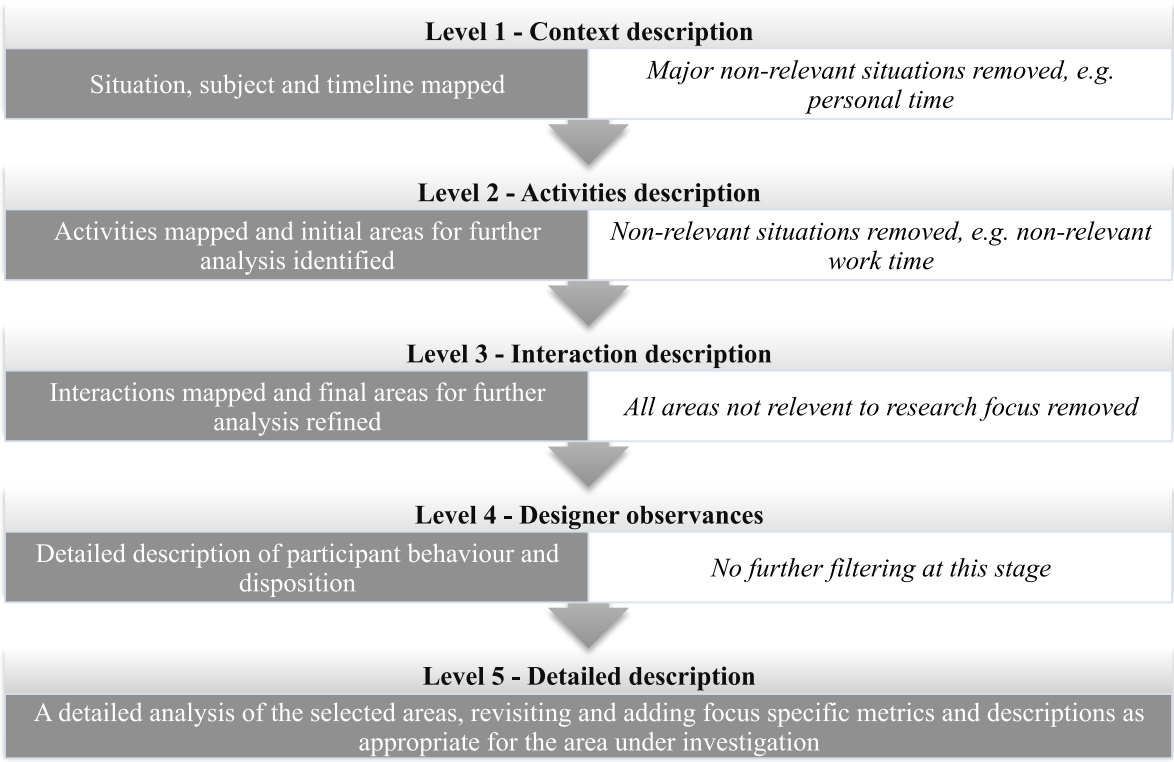

Figure 6.3: Multi-level coding and analysis strategy

6.4.2 Coding

The coding approach is based on an analysis and synthesis of a number of sources. Specifically, the coding scheme comprises both quantitative and qualitative codes, distributed over the top four levels as detailed in Table 6.7 to Table 6.10. Level 5 is included as a flexible level, allowing the researcher to either revisit existing codes with additional detail or to include detailed codes of their own depending on focus. For example, a researcher considering creativity may want to revisit Level 3 to give additional attention to the participant's interactions with physical prototypes and, at the same time, use an additional code for ideation to allow them to monitor the number of ideas generated over time. Thus, Level 5 is essential for the coding strategy to be flexible enough to be used by other researchers while retaining a degree of standardisation, a key element in developing linking theory, and study generalizability (Cross and Cross 1995; Malterud 2001).

Table 6.7: Level 1 codes: ***Context***

Group	№	Code	Type	Code options
Situation	1	Individual/ group	Binary	0 - individual, 1 - group
	2	Synchronous/ asynchronous		0 - synchronous, 1 - asynchronous
	3	Co-located/ distributed		0 - co-located, 1 - distributed
	4	Location		0 - normal, 1 - restricted
	5	Environment	Class	level of distraction: 0 - none, 1 - moderate, 2 - high
	6	Physical exertion		level of exertion: 0 - none, 1 - moderate, 2 - high
Subject	7	Design process stage		1 - brief creation, 2 - feasibility, 3 - design development, 4 - manufacture, 5 - testing, 6 - reporting, 7 - other
	8	People/ product/ process focus		focus of activity: 0 - other, 1 - people, 2 - product, 3 - process

Table 6.8: Level 2 codes: ***Activities***

Group	№	Code	Type	Code options
Problem solving	9	Goal setting	Binary	0 - not goal setting, 1 - goal setting
	10	Constraining		0 - not constraining, 1 - constraining
	11	Exploring		0 - not exploring, 1 - exploring
	12	Solving		0 - not solving, 1 - solving
	13	Evaluating		0 - not evaluating, 1 - evaluating
	14	Decision making		0 - not decision making, 1 - decision making
	15	Reflection		0 - not reflecting, 1 -reflecting
	16	Debating		0 - not debating, 1 - debating
Info. transaction	17	Recognising need		0 - not recognising need, 1- recognising need
	18	Seeking/ requesting	Class	0 - neither, 1 - seeking, 2 - requesting
	19	Interpretation	Binary	0 - not interpreting, 1 - interpreting
	20	Validation		0 - not validating, 1 - validating
	21	Using information	Class	0 - other, 1 - informing, 2 - clarifying, 3 - confirming
Management transaction	22	Managing	Binary	0 - not managing, 1 - managing

Table 6.9: Level 3 codes: ***Interactions***

Group	№	Code	Type	Code options
Audiovisual	23	Phone	Binary	0 - not interacting with X, 1 - interacting with X
	24	Videophone/ webcam		
	25	Audiovisual recording		
	26	Audio recording		
	27	Verbalisation		
	28	Conversation		
Text/ graphical	29	Logbook		
	30	Sketching		
	31	Note making		
	32	Annotation		
	33	Books/ reports		
	34	Descriptions		
	35	Charts/ diagrams		
	36	Pictures		
Computer	37	E-mail		
	38	General		
	39	Legacy		
Physical	40	Environment		
	41	Intermediary objects		

Table 6.10: Level 4 and 5 codes: ***Designer observances***

Group	№	Code	Type	Code options
Designer external	42	Axiology/ enthusiasm	Score	-1 – decrease, 0 – no change, +1 – increase – scored every 300 sec
	43	Contentedness		
Internal	44	Personality	Descriptive	acting based on personality
	45	Ethnography		acting based on social environment
	46	History		acting based on experience/history
	47	Ethics/values		acting based on specific ethics or values held by the participant
Giving/ asking	48	Opinion/ orientation/ suggestion	Class	giving or receiving: 0 – other, 1 – opinion, 2 – orientation, 3 – suggestion
	49	Agree/disagree		showing: 0 – other, 1 – agreement, 2 – disagreement
	50	Antagonism/ solidarity		giving or receiving: 0 – other, 1 – antagonism, 2 – solidarity
	51	Tension/ tension release		showing: 0 – other, 1 – tension, 2 – tension release
Level 5	X	User defined	NA	NA

Definitions

The codes were developed by synthesising the existing, proven schema of Wasiak et al. (2010), the works of Blandford and Attfield (2010) and Horvath (2004) as well as independent development (Chapter 5). The tables outline the codes used at each level and the general group that they belong to e.g. the code 'design process stage' defines a part of the 'subject' group. For example, the codes for 'subject focus' (№ 8 Table 6.7) were based on the work of Wasiak et al. (2010) and defined as: people – personnel, managing people, customers; product – prototypes, design documents, project management; process – resources/time allocation, scheduling and stage-gate management. Although not listed in the individual tables for clarity, definitions for all the codes are included in Table 6.11.

Note: In table Table 6.7 code № 7 was based on Hales (1991) and № 8 was based on Wasiak et al. (2010). Table 6.8 was based on Wasiak et al. (2010) and Blandford and Attfield (2010) while Table 6.10 was based on Horvath (2004) and Wasiak et al. (2010).

Table 6.11 gives the working definitions used for the codes in Levels 1 to 4. Each code was defined such that it could be applied to various data sources. The following key has been used to note where definitions have been adapted from existing works:

- Dark Grey (example) – Definitions based on Wasiak et al. (2010), see Wasiak (2010) for further detail and examples of use.
- Light grey (example) – Definitions based on Blanford and Attfield (Blandford and Attfield 2010).
- White (example) – Definitions based on the specific requirements of this work.

Table 6.11: Code definitions for Levels 1 to 4

№	Code	Definition
		Level 1
1	Individual	No real time interaction with any other individual or group
	Group	Real time interaction with one or more other individuals
2	Synchronous	No delays between communications
	Asynchronous	Significant delays (longer than a few seconds) between communications
3	Co-located	Working in the same location at the time of an interaction
	Distributed	Working in different locations at the time of an interaction
4	Location	The specific location of the participant in their main work site
5	Environment	The specific conditions in the current location – the level of participant distraction
6	Physical exertion	How tired/alert the participant is during the task
7	Design process stage	The stage at which an interaction is taking place in it's associated project – see Hales (1991) for stage definitions
8	People	The subject of an interaction includes: personnel, personal, managing people, customers
	Product	The subject of an interaction includes: prototypes, design documents, project management
	Process	The subject of an interaction includes: resources/time allocation, scheduling, stage gate management
		Level 2
9	Goal setting	Identifying where the design is and where it needs progressing to
10	Constraining	Imposing boundaries with requirements and desirables
11	Exploring	Discussing possibilities and ideas invoking suggestions
12	Solving	Involves searching, gathering, creating, developing solutions
13	Evaluating	Judging the quality, value and importance of something
14	Decision making	Considering key factors from evaluation and possible compromises to form decisions
15	Reflection	Reflecting upon a design decision or process already adopted or occurred
16	Debating	Discussing opposing views
17	Recognising need	Recognising a problem or deficit
18	Seeking	Finding information
	Requesting	Direct requests to another party to provide information
19	Interpretation	Assigning meaning or value to information
20	Validation	Checking the authenticity or value of information
21	Informing	Using information to inform one or more people
	Clarifying	Using information specifically to resolve issues or clarity problems
	Confirming	Using information specifically to affirm or confirm a issue or point
22	Managing	Specifically arranging, directing or instructing with regards to people, product or process
		Level 3
23	Phone	Using mobile or static phone for communication
24	Videophone/	Using any type of synchronous video for communication

	webcam	
25	Audiovisual recording	Interacting with asynchronous video recordings
26	Audio recording	Interacting with asynchronous audio recordings
27	Verbalisation	Specific verbalising of thoughts or actions
28	Conversation	Verbal communication between one or more individuals
29	Logbook	Interaction with the logbook for a purpose related to person, product or process
30	Sketching	Interacting with or producing out informal drawings
31	Note making	Producing notes made outside the logbook
32	Annotation	Notes made on existing documents or files
33	Books/ reports	The use of documents, reports, books
34	Descriptions	The use of instructional documents or prescriptive guidelines
35	Charts/ diagrams	The use of graphical representations of data
36	Pictures	The use of pictures or graphical representations not showing data
37	E-mail	Work e-mail sent or received by the participant
38	General	Work carried out on the participants computer
39	Legacy	The use of documents used by multiple users, archived or distributed
40	Environment	Interaction with the participants immediate environment – office etc.
41	Intermediary objects	Interaction with physical prototypes, models, objects
Level 4		
42	Axiology/ enthusiasm	The enthusiasm of the participant for a project, idea, task, design
43	Contentedness	The participants happiness with respect to the current task
44	Personality	Is the participant acting based on their personality?
45	Ethnography	Is the participant acting based on the social environment?
46	History	Is the participant acting based on a specific historical factor or event?
47	Ethics/values	Is the participant acting based on a specific ethic or value set held by the participant?
48	Opinion	Giving or receiving opinions: includes evaluation, analysis, expression of feeling or wish
	Orientation	Giving or receiving orientation or scene setting: includes information, repetition, confirmation
	Suggestion	Giving or receiving direction or proposed possibilities: includes direction, possible modes of action
49	Agree/disagree	The participant shows passive acceptance/rejection, understands, concurs, complies/formality, withholds resources
50	Antagonism/ solidarity	Giving or receiving support/criticism: increases/decreases others status, gives help or rewards others/asserts or defends self
51	Tension/ tension release	The participants jokes, laughs, shows satisfaction/asks for help, withdraws

It is important to note that although there are detailed protocols available for coding emotional responses the approach adopted for this research, with regard to enthusiasm and contentedness, was a basic qualitative assessment of the participant.

This consisted of the coder assessing the disposition of the participant every five minutes and noting if their enthusiasm/contentedness had increased, decreased or stayed the same. This was adopted for pragmatic reasons because it was not the primary focus of the work.

As outlined in Section 6.3.3 the next area for consideration is the analysis strategy – dealt with in the next section.

6.5 Analysis Strategy

In order to effectively analyse the large number of data sources generated by this method, there are a number of steps that should be taken to ensure rigour and completeness: alignment, analysis and reflection.

Firstly, the various data sources need to be aligned to a single consistent timeline as emphasised by Törlind et al. (1999; 2009) and discussed in Chapter 5. This allows the researcher to maximise the potential of complementary data sources in the follwoing ways:

- It allows gaps in one source to be filled by another (e.g. using mobile camera footage to follow the participant when they leave their desk – developing a more complete record).
- It allows multiple coded sources to be compared for a single event (e.g. the code track for the participant's logbook could be compared to the track for the mobile camera in order to refine the final coding – developing a more rigorous record).

Synchronisation and alignment requires a core timeline for consistency. For example, in the scoping study (Chapter 5), the primary data source selected for this purpose was the computer screen, which was then used to form a master timeline in VCode (Hagedorn et al. 2008; 2011). Although this is not prescriptive, it is recommended that whatever source be selected for this purpose, it is the most complete and comprehensive (i.e. the source covers the largest amount of the recorded period before other sources are added) – minimising the work required adding the additional sources. Figure 6.4 gives a sample screen from VCode showing the codes on the right, the multiple camera angles in the centre and the timeline at the bottom. In addition to the methodological advantages, combining the sources into a single master timeline streamlines the coding and export process - note the multiple viewing options and code timeline below the study footage (Participant obscured for ethical reasons).

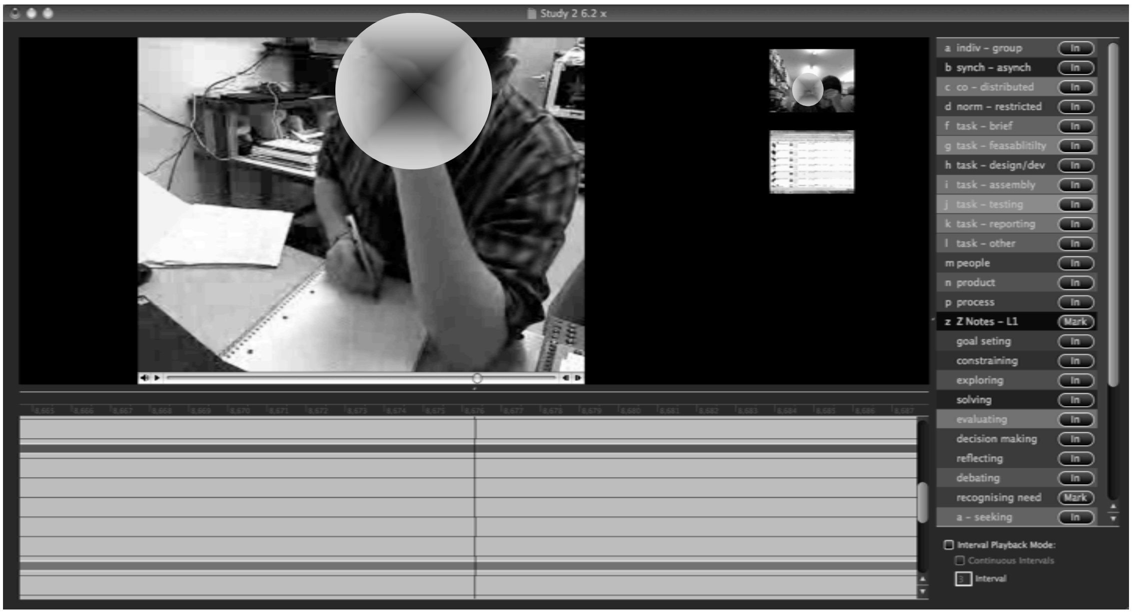

Figure 6.4: An example of the VCode interface

Once the various data sources have been aligned, the next step is to start the analysis. This can be conducted at three levels of detail and complexity.

High Level

The first and least complex level is an analysis of each individual code from the first two coding levels outlined in Section 6.4.2. This can include the time each code accounted for, the number of instances, occurrence pattern analysis for individual codes or other analysis of individual codes. This allows initial areas for further analysis to be identified.

Mid Level

Second, with the high-level analysis complete, the next stage is to consider groups of related codes. This level can be used to draw out deeper relationships between codes and to define more complex behaviours or activities. For example, groups of codes could be used to define a number of design tasks described in the design research literature – allowing an analysis of how these tasks interact and when and where they occur. This again allows pattern, frequency, total time or other aspects to be analysed for each group of codes. It is important to note that these groups of codes should be identified and defined appropriately depending on the research focus. Groups are identified based on the following stages; each stage is illustrated using an exemplar:

1. Define descriptive definitions of areas of interest – in this case tasks within the design process as defined by Hales (1991).
2. Allow groups of codes to emerge from the data for the defined areas of interest (this can include multiple groupings) – in this case, conceptual design is comprised of six combinations of codes. For example, two groups are: 'group', 'design development', 'focus – product', 'exploring' - referring to a group brainstorming activity, and 'individual, 'design dev', 'focus – product', 'exploring' referring to an individual ideation activity.
3. Reflect on the allocation of groups of codes to ensure that the selected definitions (1) are appropriate and further definitions do not need to be considered for the selected research focus. This is an important stage, as there can be large numbers of combinations for a single definition (depending on the specificity of the selected definitions). In this case, there were 151 combinations of codes allocated to 10 definitions (see Appendix A).

Detail Level

Thirdly, both of these types of analysis can be applied to subsets of codes such as those defined by the research focus at Level 5 of the coding schema. Finally, with the analysis complete, it is necessary to reflect on the validity, reliability and limitations of the data. As part of this reflective assessment, it is necessary to check for coding consistency to ensure that individual coders have not biased the analysed data and no 'drift' has occurred in coding behaviour. As such, it is suggested that when using the proposed method Kappa based inter-coder reliability checks (Berry and Mielke 1988) be used wherever possible and intra-coder checks in all other cases.

6.6 Review of the Method

The core empirical method can be applied to a wide variety of research foci whilst providing robust, rigorously comparable results. This was achieved using multi-level capture, coding and analysis strategies. Exploring these strategies further, the multi-level approach allows the detailed assessment of multiple research foci whilst also contextualising the wider body of data in a structured manner, supporting standardisation, replication and validation. Further to this, the method formalises the capture of key contextual information for companies and participants.

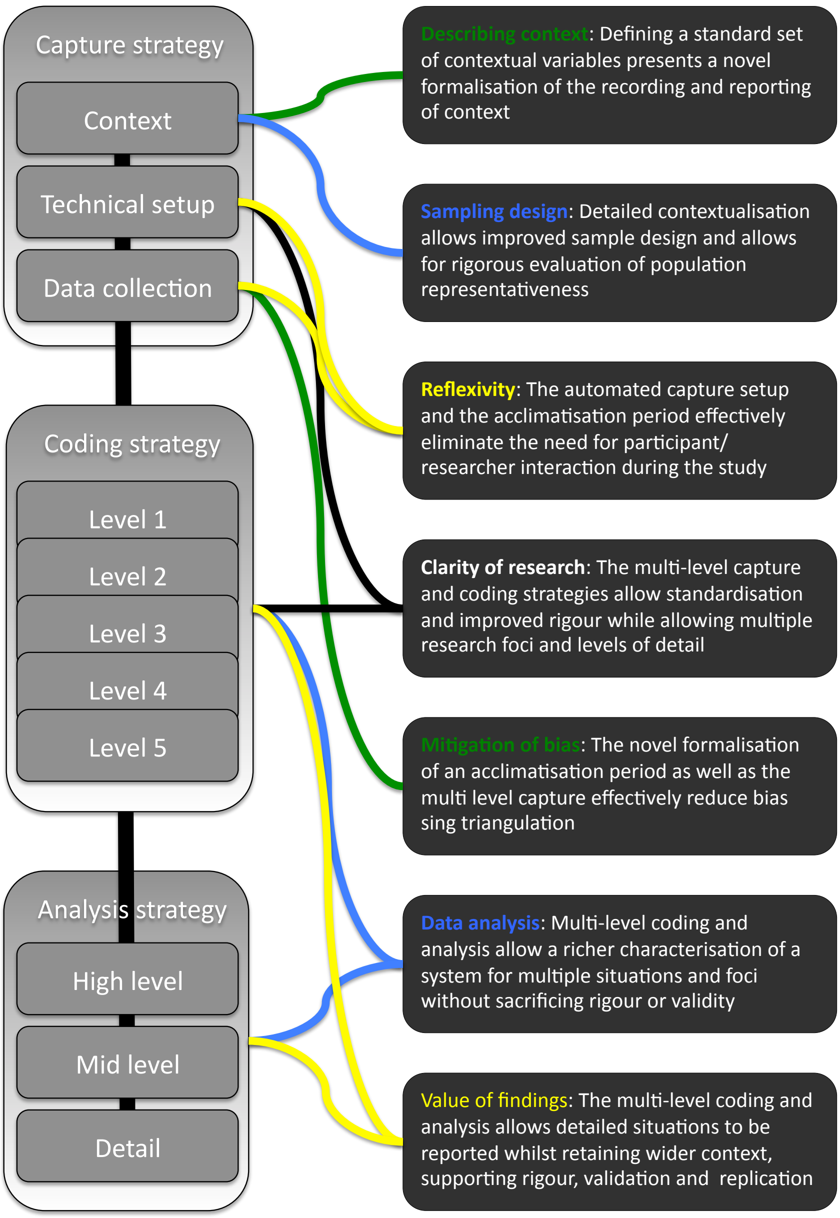

Figure 6.5: The core empirical method and the mitigation of the identified methodological problems

Re-examining the problems identified in Table 6.3 – describing context, sampling design, clarity of research design, mitigation of bias, reflexivity, data analysis and value of findings – the core empirical method addresses each by combining a number of complementary mitigation approaches. This is highlighted in Figure 6.5, which also shows the overall structure of the core empirical method and which elements mitigate each problem.

6.7 Concluding Remarks

This chapter described a core empirical method to be used as the foundation for the three studies described in Chapter 4. With the core method established in this chapter, Chapters 7 (DS 1), 8 (PS) and 9 (DS 2) outline the three studies and detail the specific modifications to the method due to population, location and study purpose. Each chapter also details elements not specified by the core method such as population selection and task design. The primary study is the observational study of practice, which forms the basis for the design of the other studies and as such is outlined in the next chapter.

"Through Adversity to the Stars"

Virgil – The motto of the Royal Air Force

7

Observational Study of Practice

In the previous Chapter a generic method was described. Building on this, this chapter introduces the specific sampling and setup requirements of the observational study of practice, however, all other aspects of the study's method correspond with the steps outlined in the core empirical method (e.g. Section 7.1 corresponds to the context step of the capture strategy). The purpose of the study is to give an overview of practitioner behaviour and activity in a practice setting including instances of deskwork, meetings and other mobile activities. This was achieved by taking a sample of three practitioners from a company of 18 people in the medical engineering and design sector. The collected data was then coded and analysed in order to identify, contextualise and validate three critical situations – forming the basis for the comparison studies outlined in Chapters 8 and 9. A summary of the studies time line is presented in Figure 7.1.

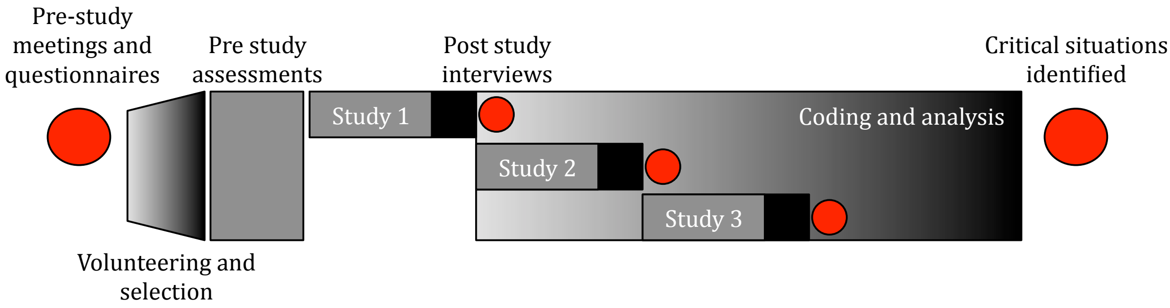

Figure 7.1: Study timeline

However, before it is possible to analyses the data, it is first necessary to contextualise the study.

7.1 Contextualisation

This section highlights key contextual information about the company and the participant population. The implications of this contextual information and its relation to the findings outlined in this chapter are discussed in Section 7.5. The questionnaires primarily used to obtain the reported data are included in Appendix B.

7.1.1 Company

The company was identified as a specialist design and engineering company in the field of medical engineering and was selected as a representative Small to Medium size Enterprise (SME), typical of a smaller design company with 10 – 20 employees. An SME was selected at this stage for two reasons – they are the typical focus for design research in the UK and they make up the majority of UK based companies, accounting for 99.9% of all enterprises and 58.8% of private sector employment (White 2011) (SME is here defined as between 0 and 249 employees).

Activity

The working area in the SME was split between two open plan offices with approximately six people in each. A personal desk area, typically used for storage or practical work, accompanied each workstation. Employees perceived themselves to work primarily at personal workstations with additional meetings and practical work taking place in one of two small meeting rooms and a large workshop area respectively.

Social

The SME employed eighteen members of staff, seven of which were design practitioners (ranging from electronic to mechanical specialists). Key influences on the company were its close links with the University of Bath and with a hospital where much of its work took place. Further to this, primary funding sources for the SME were charitable donations, research grants and income from its production unit.

Cultural

The company hierarchy was relatively flat – with junior and senior practitioners mixing and working together. There was also a reasonably informal culture with well-attended group breaks and social events. Overall, the company presented a relatively homogenous group with similar cultural backgrounds (UK education and industry) operating in an open and collaborative environment. This culture of open collaboration was further promoted by the company's aims and focus on research and design.

Historical

Historically the company was typical of many UK-based SMEs with an annual turnover of approximately £1,000,000. Further to this, the company was well established with over forty years in its current form and with deep, long-standing ties to a small group of collaborators including the University of Bath and a UK based hospital.

7.1.2 Population

This section outlines the contextual information for characterising the seven practitioners forming the target population.

Activity

Based on meetings with the population, it was clear that a small number of them worked at home for one day or more per week in addition to their normal workstation in the office. As working from home was a core part of the participants working practice it is clear that this aspect must consider this when implementing the study. Further, Windows was identified as the common operating system used throughout the company. Finally, it was emphasised that in addition to their computer, population members used whiteboards, notice boards, sticky notes, bookshelves, storage shelves and other miscellaneous artefacts in and around their workstation.

Social

The spread of practitioner ages was between 25 and 40 with all members having completed at least one degree. There was a split in property ownership with most members of the population owning property but some of the younger members renting. Based on postcode analysis all participants lived in relatively affluent areas in and around Bath.

Historical

All members of the population had attained a full set of A-levels or equivalents and had typically completed a master's level degree (see the KPMG website for a comparison between UK A-levels and their international equivalents (KPMG 2012)). It was also typical of the population to have had a range of experience in other engineering or science jobs depending on age. Finally, it was apparent that there was a relatively even spread in experience and professional development within the SME, with similar numbers of early, mid and later career practitioners.

7.2 Setup and Preliminaries

This section outlines the preliminary aspects of the study, including sample selection and setup prior to the main data collection step outlined in Chapter 6.

7.2.1 Establishing the Participants

The population was introduced to the research through a series of introductory meetings – careful attention was paid to maintaining participant hypothesis blindness (Wilkinson 1999) at this stage and throughout the study. Through the introductory meetings and the assessment of the populations' characteristics, it was found that any combination of three participants would effectively represent the overall population due to the even spread of experience and relatively flat company hierarchy (Section 7.1). As such, participants were asked to volunteer without further screening to avoid possible selection bias (Torgerson and Torgerson 2003) and due to the ethical implications of observation.

Following this, three of the volunteers from five were randomly selected for the study. It should be noted that the participants were not working on the same project and were also not explicitly working as a team at any point in the study – they were individuals working on discreet bodies of work. Thus, the final selected population consisted of one junior, one midlevel and one more senior practitioner. At this stage, it is important to note that a fully randomised selection regime would have offered the best possible approach (Torgerson and Torgerson 2003) but was not possible due to the level of observation involved. As such, although some bias may have been introduced through voluntary selection, it was the best pragmatic option available.

7.2.2 Observation Setup

Based on the context assessment, it became clear that the participants perceived themselves to be primarily based at a single workspace (a different space for each) and used their individual computers for distributed meeting activities such as video or phone conferences. Thus, although other situations were accounted for in the capture setup, the primary workspace formed the main focus. It was also apparent that a wide variety of tasks were undertaken using various types of software – which could be accounted for through an overlapping capture strategy (Section 6.3).

The technical setup used to capture the participants workspace was as specified in Figure 6.2 while the mobile camera and LiveScribe pen were used to capture local meetings taking place outside the normal workspace as described in Chapter 6.

Further to this, participants were provided with information about each technology as well as checklists for what maintenance was necessary at the end of each day – e.g. charging the mobile camera. These documents are included in Appendix C. Where work was carried out at home, equipment was again setup in accordance with Figure 6.2. Once setup was complete, the total time for data collection was twelve consecutive weeks starting in November 2010 with each individual participant being involved for four consecutive weeks including the acclimatization (three weeks) and study (one week) periods.

7.2.3 Acclimatization Period

Each participant completed three weeks of acclimatization, however this was increased to four weeks in one case due to participant absence and the need for additional setup at a home workspace. Thus, in this case additional acclimatization was deemed necessary to account for the added disruption of setup at home and the requirement for the participant to become used to the observational equipment.

Participant feedback and analysis of the gathered data from this period was used to establish whether the data capture was effective and comprehensive for each of the participants. Further to this, the assessment of the acclimatization period confirmed that the data collection procedures had become habit and that the participants no longer perceived the recording technologies as out of the ordinary – returning to their normal working/personal activity patterns. Due to this, no significant modifications were made to the technology setup defined in Chapter 6.

7.3 Study Period Data Collection

This section details the specific tasks, questionnaires, data collection and coding activities used for the observational study of practice. These are only described where they differ from the generalised method outlined in Chapter 6 and, as such, the generalised method provides the major part of the capture, coding and analysis strategies used in this study.

7.3.1 The Study

Once selected, each participant was randomly assigned a study number – 1, 2 or 3. This numbering system was used throughout this chapter with regard to coding, analysis and discussion of the results. Based on these numbers, study order was randomly determined with the studies taking place consecutively between November 2010 and January 2011. Other than this randomisation of study order, studies were carried out as prescribed in Chapter 6.

7.3.2 Questionnaires

Two paper-based questionnaires were used for the studies in order to characterise personal background and company background (Appendix B). These were collectively used to develop a detailed picture of the company and participants' social and historical context. Using these questionnaires provided a baseline against which the studies outlined in Chapters 8 and 9 could be compared.

Company Background

The personal background questionnaire was administered to the company directors during the scoping activities, prior to the participant selection. The background questionnaire assessed social, cultural and historical aspects of company context as described in Chapter 6, including: details of the workspace, influencing factors, number and type of employees, aims and scope of the company, expertise and abilities, partners, size and maturity.

Participant Background

The personal background questionnaire had been administered prior to the commencement of the study at the start of the acclimatization phase. The background questionnaire assessed the social and historical aspects described in Chapter 6, including: personal details, sociometric information, education, professional experience and personal development. Participants were given the questionnaire in paper format and were allowed to complete it in private in their own time.

7.3.3 Data Collection and Coding

This section briefly outlines the practical aspects of data collection and coding for the study described in this chapter.

Data Collection: Practical Aspects

Data collection was carried out at the end of each study phase in conjunction with the post study interview – as specified in Chapter 6. This entailed the collection of the test equipment and an external hard drive with the test data. The participant, who was given a data saving procedure to follow, saved the study data on a day-to-day basis, eliminating the need for researcher interaction. This was included in the briefing documents given to the participant (Appendix C) and formed part of the training carried out in the acclimatization period.

Coding: Practical Aspects

With data collection complete, the studies were coded in a randomly selected order (2, 3, 1) to avoid possible bias introduced through coding drift. For the study outlined in this chapter, it was not possible to use multiple independent coders. This is a common issue for design researchers and was due, in this case, to the nature of the confidentiality agreement made with the company and the participants, which limited access to the data to the primary investigator. As such one coder was responsible for the whole dataset. A possible issue in this case is coder 'drift' as they change their coding behaviour over the course of the analysis (Taplin and Reid 1973). In order to assess this 'drift', an intra coder reliability check was carried out at the end of the coding process using the VData software (2011). This involved the researcher to coding the same piece of data at the start of the coding process and again at the end of the process (6 weeks in this case). These two samples are then compared to assess any changes in how the coder tags the data. This produced a point-by-point agreement of 91% (with a 10 second range) for the same video coded at the start and end of the coding period. Kazdin (1982) sets 80% as a benchmark for good agreement and as such 91% agreement was considered acceptable – allowing the data to be analysed with confidence in its consistency. This does, however, highlight one of the main difficulties of this type of research with an appreciable difference between the samples being apparent despite being coded by the same coder. Other than this modification to allow for a single coder the rest of the coding procedure followed the method detailed in Chapter 6, i.e. the data was coded multiple times with areas being eliminated at each level.

7.3.4 Researcher Interaction

As outlined in Chapter 6, there was no interaction between the researcher and the participants during the main study period. The only interaction that took place was during the briefing of the participants prior to the study, during technical setup and during the post acclimatization and post study interviews. Each of these encounters was scripted and questions and answers outside the existing script added such that the same answers could be given for each of the participants.

7.4 Results

This section highlights the major findings of the observation studies. As detailed in the analysis strategy (Section 6.5), this section is split between high-level and mid-level analysis. The first section contextualises the overall situation, using individual codes while the second decomposes participant behaviour further, using grouped codes. Based on these results, the implications of these findings are developed in Section 7.5. It should be noted, that although all other coded activities are commented on codes five and six ('environment' and 'physical exertion') are not included in this analysis because they were purely qualitative and were not included here due to difficulties in their coding.

7.4.1 High-level Analysis

Figure 7.2 to Figure 7.4 present the high-level data (individual codes) for coding levels 1 and 2 (Section 6.4). Figure 7.2 summarises the number of times a code was used for each of the studies as a percentage of the total number of codes. This, coupled with the total time associated with each code (Figure 7.3) gives an indication of the total duration of all occurrences of any code i.e. high level information about how the participants spent their time. For example, it is possible to see that the participant from Study 3 spent more time on product related activities in comparison to participants 1 or 2. Finally, Figure 7.4 outlines the mean times and instances for each code at this basic level.

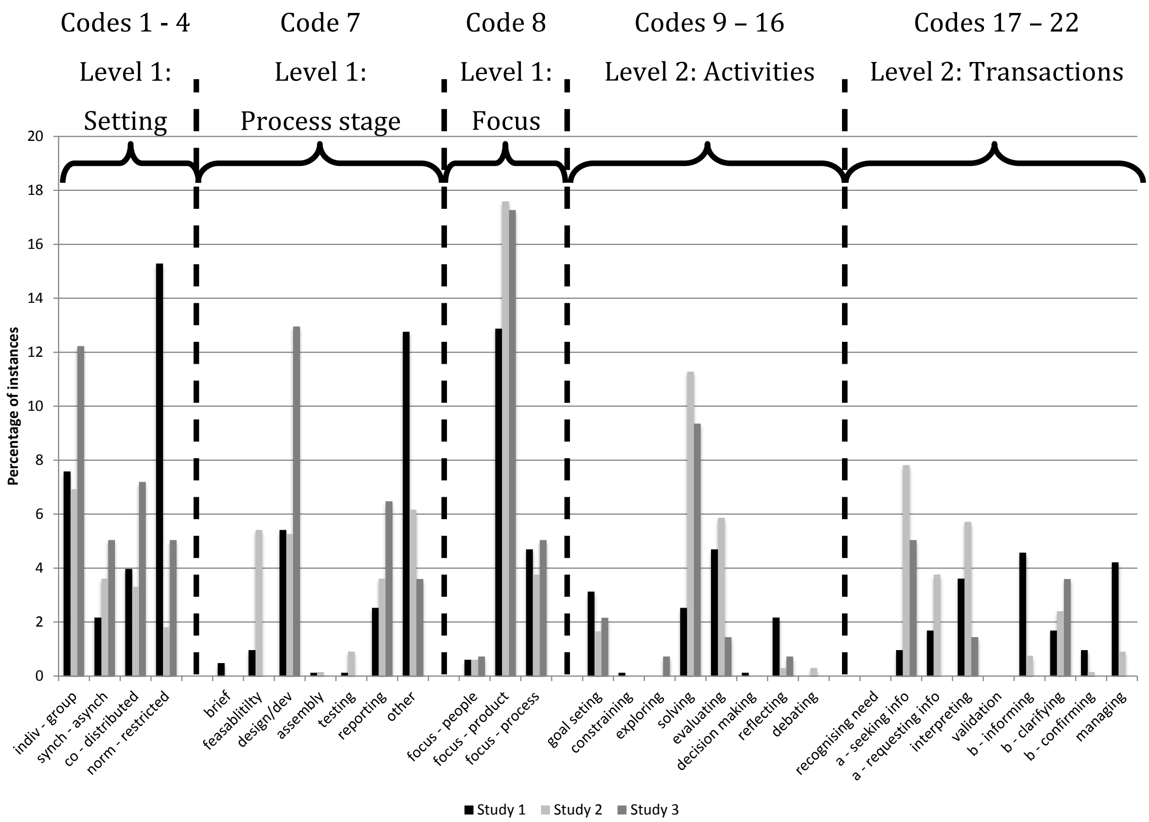

Figure 7.2: The percentage of total instances of each code for the three studies

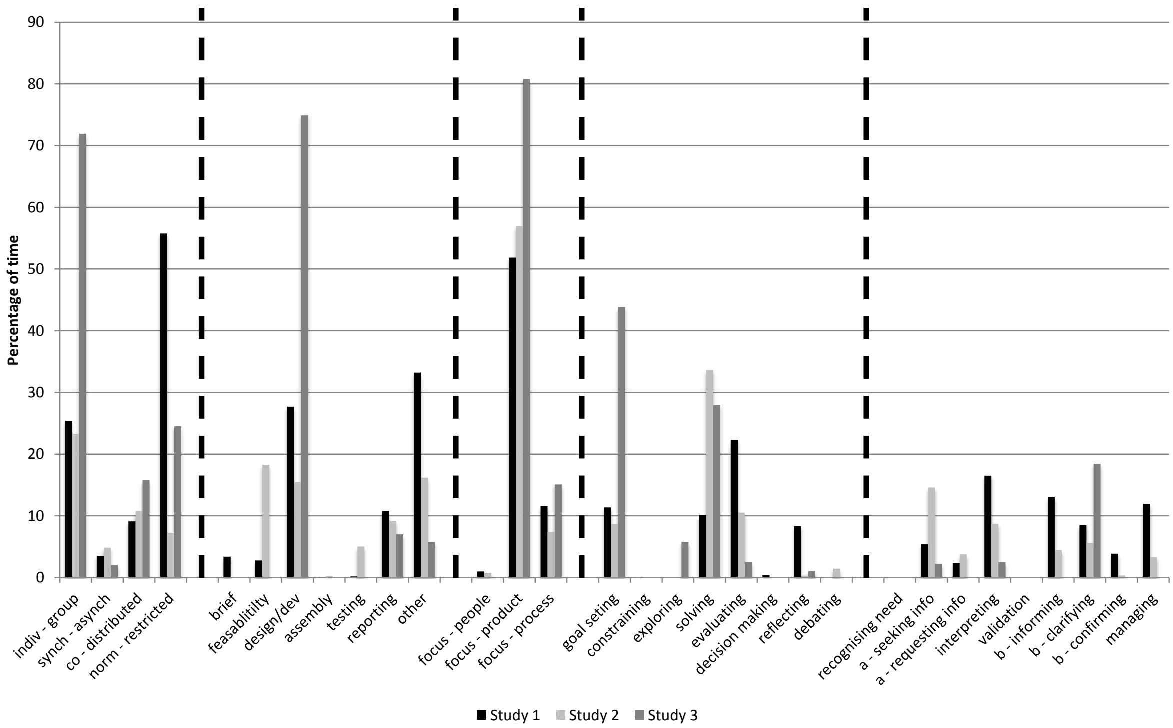

Figure 7.3: The percentage of total time for each code for the three studies

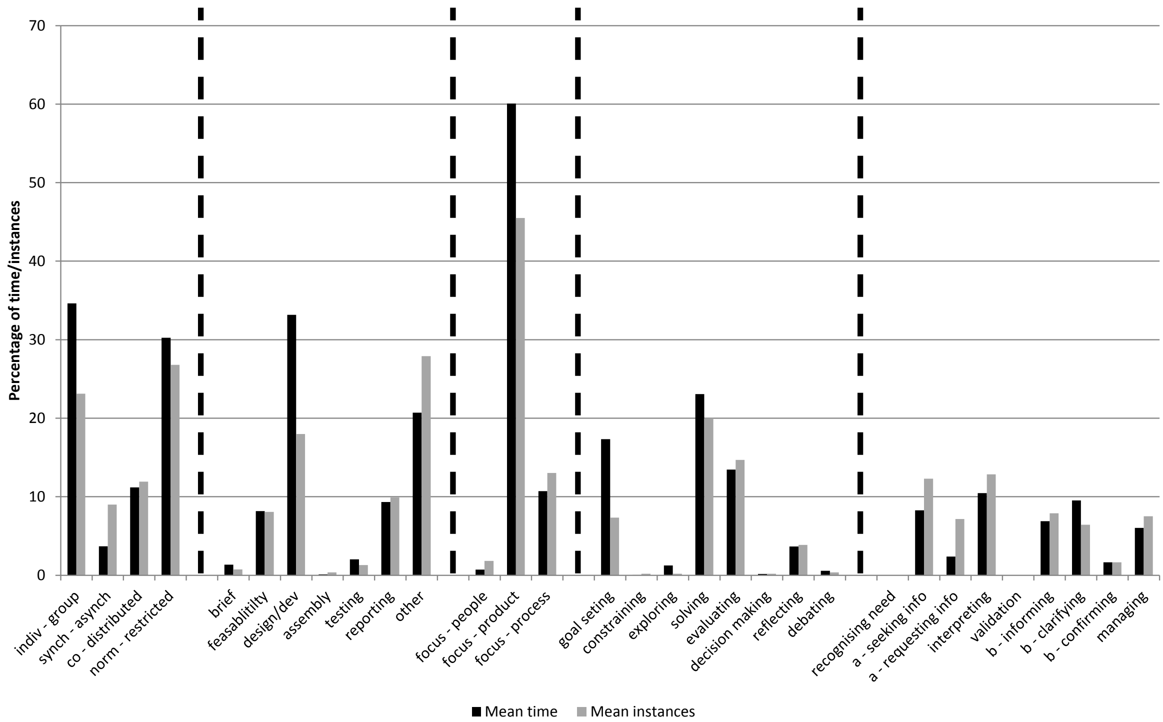

Figure 7.4: Mean percentage values for total time and total instances of each code

Key results that can be draw from these figures include the fact that 60% of the participants' time was spent with a product focus and 35% of their time was spent working with at least one other person. Additionally, 11% of their time was spent working in a distributed fashion, while 33% of their time was spent on design development. Further to this, it is possible to highlight the prominence of information seeking and interpreting as the two most significant information transactions. However, the relatively high-level perspective limits the amount of information that can be derived from this data highlighting the limitations of the high-level analysis.

Based on this analysis, it is possible to confirm the importance of group working and product focused activities as core to the participant's activities. Further, it is also possible to identify information seeking as one of the primary activities undertaken individually. As such it is logical to focus further analysis on the decomposition of these activities using grouped codes.

7.4.2 Mid-level Analysis

As highlighted in Chapter 6, deeper insight into practitioner activity requires complex tasks – described by groups of codes – to be considered. Of particular interest, from a design research perspective, are design tasks (Hales 1991). These are well established within the design research literature and as such can be used to identify suitable areas for comparison. However, before that is possible it is necessary to define the tasks. In order to effectively identify relevant groups of codes for a particular research focus, the steps: define, group and reflect, were used as outlined in Chapter 6.

Table 7.1 defines the different tasks identified for the study and provides examples of literature where these have been discussed or examined. This builds on existing definitions and was used as a template for further decomposition of the dataset. The tasks outlined in Table 7.1, have been defined based on the individual codes and as such can be described and interrogated in detail. In addition the fact that the identified tasks were also well established in the literature was key to providing a common reference frame – a core step in forming the basis of the comparison studies outlined in Chapters 8 and 9. Further, defining the tasks in this way allowed the studies reported in this work to be compared to studies extant within the literature – a prerequisite for validation. As such the tasks are summarised here for clarity. These tasks are mutually exclusive and collectively complete. Combined, the tasks 'conceptual design' through to 'administration' account for 71% of the total time recorded. The remaining non-coded time (29%) was accounted for by breaks, personal activities and periods where the participants stopped the recording for pre-agreed reasons such as confidentiality or personal time.

Table 7.1: The design tasks defined

Task	**Description**
Conceptual design	Ideation and concept development tasks incl. brainstorming, idea selection and concept exploration (Kuijt-Evers et al. 2009; Tang et al. 2010; Cash et al. 2011)
Design development	Development of a design once a final concept has been accepted incl. design refinement and problem solving (Carrizosa and Sheppard 2000; Luck 2007; Kim and Maher 2008)
Design review	Reviewing existing work or future planning incl. review activities and reflection on current designs (D'Astous et al. 2004; Bergstrom et al. 2005; Huet et al. 2007)
Embodiment design	Technical layouts and CAD configurations incl. CAD, prototyping and configuration (Chenouard et al. 2007; Scaravetti and Sebastian 2009)
Testing	Running, setting up or dismantling test hardware or software incl. technical testing and user testing activities, e.g. setting up monitors in the corridor to test equipment readiness
Project reporting	Formal collation and dissemination of structured reports incl. lessons learned, structured reports and formal presentations of findings (Haas et al. 2000; Wild et al. 2005)
Information seeking	Searching for, requesting, synthesizing and evaluating information incl. searching, interrogation of records and making notes on found data (King et al. 1994; Hertzum and Pejtersen 2000)
Dissemination	Informal distribution of decisions, work plans or progress incl. informal email, interpersonal conversations and shared workspaces (McAlpine et al. 2009; McAlpine 2010)
Miscellaneous work	Any work related tasks which are explicitly not administrative work but do not include work on a design project, e.g. office organization, tidying, sorting of components
Administration	Work relating to administration incl. personnel management, internal processes and organization of emails and filing, e.g. organization of filing system and personnel review meetings
Non-coded	Personal activities, unrecorded time and breaks incl. organization of personal activities such as course attendance, e.g. banking transactions and personal emails or phone calls

Aggregating codes to define tasks allows a more sophisticated analysis of the participant's time compared to the high level analysis (Section 7.4.1). Figure 7.5 highlights the overall breakdown of time participants spent on each task. This emphasises several key findings. Firstly, it confirms the important role of information seeking activities (e.g. Kellar et al. (2007) or Aurisicchio et al. (2010)), accounting for 16.8% of the participants total working time. Secondly, it highlights the importance of conceptual design (4.7%) and design review (6.8%) – both areas of intense interest within the design research field, e.g. Corremans (2009) and Prudhomme et al. (2007) respectively. Thirdly, it emphasises the heavy administrative (5%)/business support (12.6%) commitment facing practitioners operating in SMEs. Finally, it clearly denotes the important role reporting (7.4%) plays in the participants' working practices.

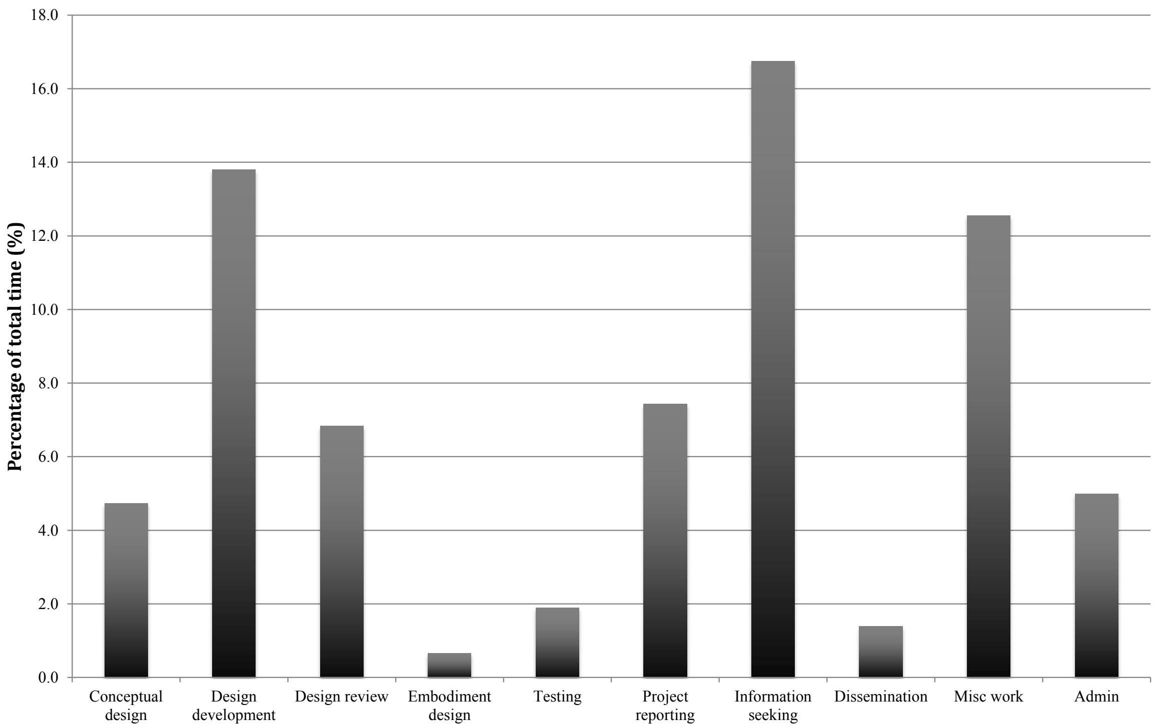

Figure 7.5: The percentage of total time for each task for the three studies combined

Figure 7.6 through to Figure 7.8 show the tasks as they occur over time for each of the three studies. This allows the identification of patterns relating one task to another. From these figures, it is possible to see that the information-seeking task plays a major role in the first two studies with a high level of activity in this area preceding much of the design development and design review activity. Further they again highlight the prominent role of conceptual design activities and design review.

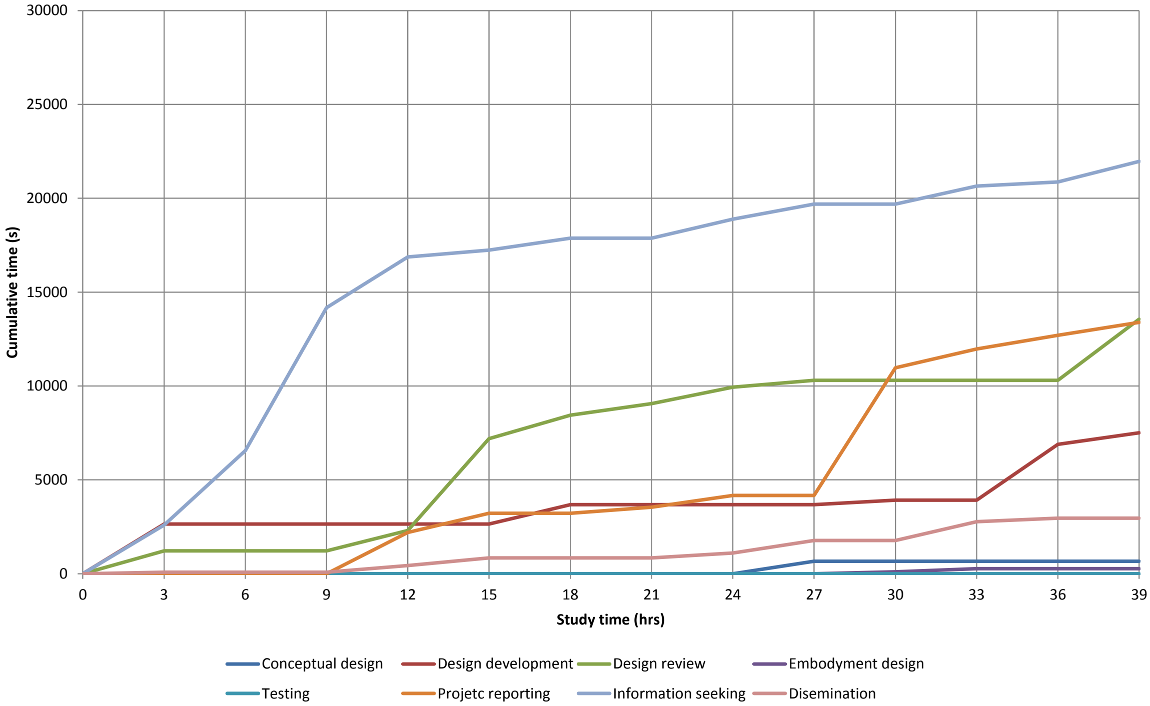

Figure 7.6: The cumulative time for each task for study 1

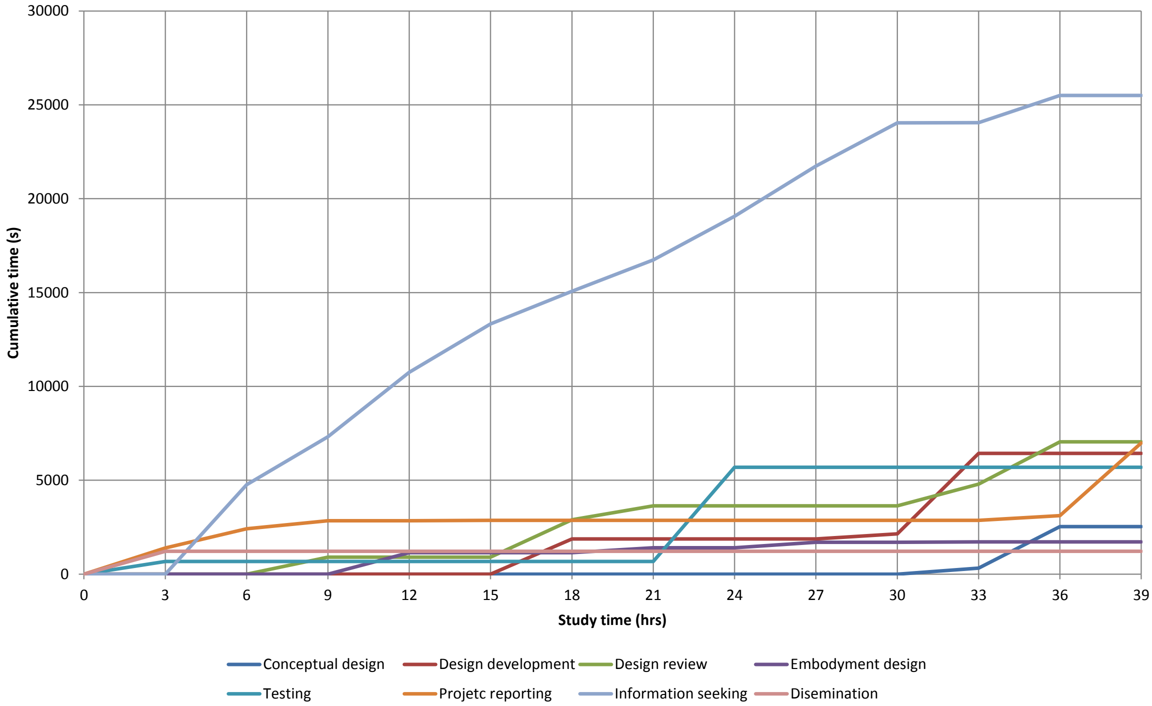

Figure 7.7: The cumulative time for each task for study 2

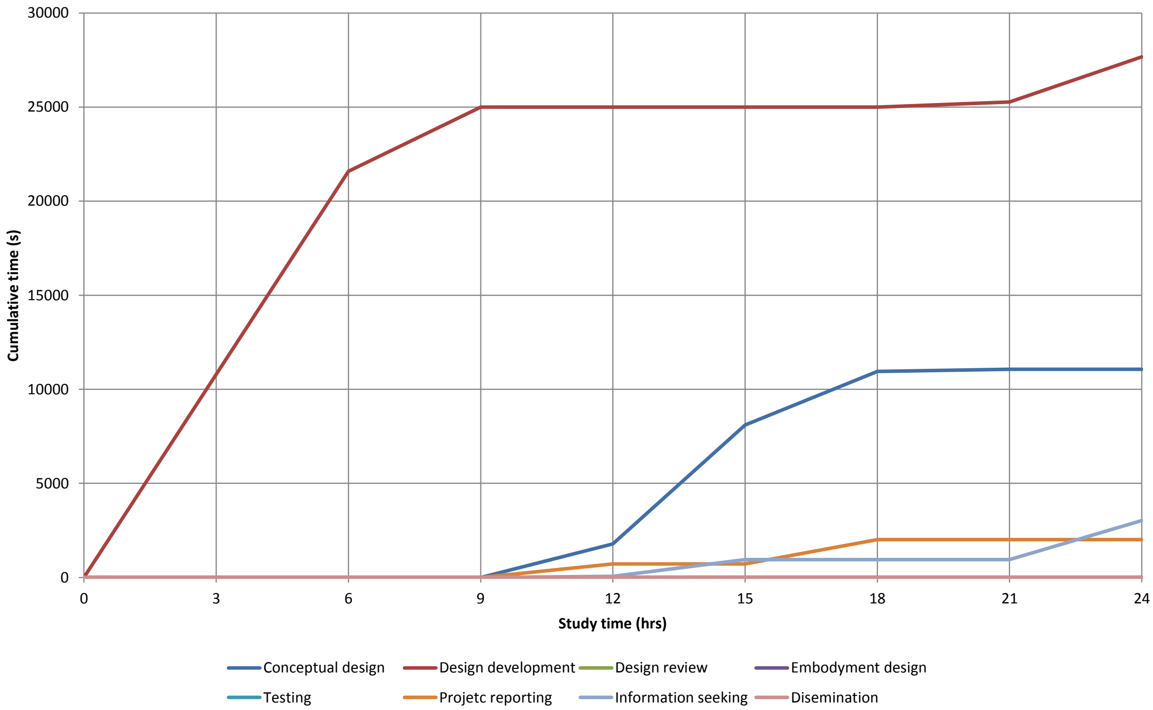

Figure 7.8: The cumulative time for each task for study 3

7.5 Discussion

This section is split into two sub-sections. Section 7.5.1 discusses the representativeness of the findings of the study outlined in this chapter. Then, Section 7.5.2 identifies and validates the relevance of the three critical situations as the basis for comparison between studies (Chapters 7, 8 and 9). Finally, Sections 7.5.3 and 7.5.4 reflect on the core method and practical issues respectively.

7.5.1 Representativeness

Section 7.4 highlighted several important tasks carried out by the participants over the course of the three studies. These included conceptual design, design development, design review, reporting and information seeking. Although these tasks are consistently the five most time consuming tasks observed from the data, their prominence for each participant varies. This conforms to the variance expected in engineering design practice and is to be expected in any study of practitioners not carried out over a very long time period (including at least 2 or more project cycles). Further, due to the small size of the SME, practitioner activity has the potential to vary considerably from week to week as project priorities change and progress. As such, the fact that these five tasks are dominant in all of the studies is a key indicator that they are core to engineering design practice within the SME. Based on this observation and the number of studies associated with each of these tasks within the design research literature (Section 7.5.2) it is possible to conclude that these tasks are, in fact, core to design practice across contexts.

In order for the methodology outlined in Chapter 4 to be effective, it is key that the core tasks identified as the basis for comparison between the three contexts (practice, laboratory and intermediary) are not only prominent in practice but also in the laboratory. Without this dual prominence, any relationship developed between the laboratory and practice would be of little pragmatic value. As such, the next section identifies three critical situations meeting these criteria and validates their relevance based on extant experimental literature.

7.5.2 Identifying Critical Situations

From the five tasks identified in Section 7.5.1, it is necessary to identify those tasks that could be used to form a suitable foundation for further comparisons. These critical design situations are defined in Section 2.4.4 as: core to the design process, commonly studied in both practice and the laboratory and with discreet elements that can be replicated experimentally. However, in order to identify these situations from the data obtained in this study the following process has been applied:

1. Identify activities that are both core to the design process and appropriate for experimental study: This is based on literature and on the various tasks described in Table 7.1.
2. Identify situations that are discreet in time and in terms of activity: This is based on the data displayed in Figures 7.5 to 7.7.
    a. Firstly, situations are characterised as an area of continuous slope for a single task lasting longer than 30 minutes – less would not allow effective comparison e.g. Howard et al. (2010) highlight that significant changes in activity (in this case ideation) take place after 20 – 30 minutes, necessitating the comparison of longer periods.
    b. Secondly one situation was selected for each of the appropriate activities (see Step 1) by identifying the period with the longest and steepest slope

across the three studies e.g. the period between hours 6 and 9 in Figure 7.5 for the activity *information seeking*.

3. Check these situations are commonly studied in practice: This uses a review of the literature to confirm the situations are critical.

Based on these criteria this section firstly eliminates those tasks not appropriate for this research before identifying three situations using Step 2 and, finally, confirming their criticality based on a brief literature review. As such, two tasks can be eliminated at this stage. These are: design development and project reporting.

Elimination 1: Design Development

The first task, design development, is fundamentally a longitudinal task ongoing throughout a project (Hales 1991; Pearce and Ensley 2004) – supported by the data shown in Figure 7.6, Figure 7.7 and Figure 7.8. Each of these figures shows a generally shallow gradient for the design development task, often in parallel with other tasks. This means that, although the design development task is ongoing, there are few discreet periods where the participants focused only on this task in a single replicable activity. This is further supported by observances of the nature of design development, where other tasks are interspersed within the development task. This emphasises the fact that design development is not commonly a discreet activity, instead being built upon multiple instances of other tasks such as information seeking, conceptual design and review. In particular in Study 2 highlights this, where the design review and design development curves were closely matched in profile, indicating an interlinked relationship. Based on these factors and the review outlined in Chapter 2, it becomes apparent that design development is too broad in scope and too embedded within the design process to be isolated in an experimental context. This is supported by the fact that design development type activity and its requirements are frequently examined via longitudinal or survey/interview type studies as part of the overall design process, e.g. Blessing et al. (1998), Court (1997) and Heisig et al. (2010).

Elimination 2: Reporting

The second task (reporting) is again embedded within the context of the process and is thus also not generally suitable for typical experimental evaluation. More often, it is assessed as part of a case study such as in the case of Hales (2004), or as an ongoing capture of rational, as proposed by Bracewell et al. (2009). Further, formal reporting is not necessarily a fundamental part of all design processes.

Based on the factors outlined in this section, it is possible to eliminate design development and reporting from further consideration as potential foundations for cross context comparison. However, three tasks still remain – information seeking, conceptual design and design review. Each of these tasks fulfils the criteria necessary for further comparison.

Information Seeking: Computer-based Searching

Information seeking forms the primary task in two out of the three datasets and, as such, can be considered core to the working practice of the participants. Further to this, Table 7.2 serves to highlight the large amount of research in the design literature concerning information seeking in various forms. Finally, although information seeking activity takes place over an extended period, there are distinct elements within this as the participant focuses on individual topics. Based on these three conditions, it is possible to confirm information seeking as a critical situation. However, before comparisons can be made it is necessary to identify a suitable discreet period for comparison.

In order to identify the period of the most intense information seeking activity, the area with the steepest curve for this task was selected from Figures 7.5 – 7.7. This identified the three-hour segment between hours three and six in Study 2 (Figure 7.7). This period selected as the seeking activity was also focused on a single subject and source (the computer) for the entire time and can therefore be considered a discreet situation. Other areas of intense information seeking activity were eliminated as they were less focused and comprised multiple activities in addition to computer use, e.g. the period between six and nine hours in Study 1 (Figure 7.6), which included a conversation with colleges, ordering via telephone and an impromptu meeting in the office.

Based on the selected case codes: 7 (design development stage), 8 (product focused), 12 (solving), 18 (seeking/requesting), 19 (interpretation), 31 (note making) and 38 (computer use) were used to specify the situation (see Section 6.4.2 for coding labels). This details a setting in which the participant had access to computer-based resources (as well as additional sources within the office) and spent their time split between solving, seeking and interpretation whilst making notes. Using this code based specification, it is possible to create a comparable laboratory situation and as such, computer-based information seeking forms the first critical situation.

Conceptual Design: Ideation

Conceptual design, although playing a relatively minor role in Studies 1 and 2, was the second largest task in Study 3. Further to this, it accounted for over 4% of the total activity of the three participants. Conceptual design and in particular group ideation are extremely prominent within the design research literature as evidenced by the larger number of examples published since 2000 (see Table 7.2). Finally, conceptual design can clearly be separated into discreet elements such as group ideation sessions. Based on these conditions, it is possible to confirm conceptual design as a critical task.

As in the case of information seeking, the steepest slope of the conceptual design task was used to identify the area of most intense activity. This area fell in the period between hours 12 and 15 during Study 3 (Figure 7.8). The majority of this time was taken up by a single 1.5-hour group ideation session. This session focused on a single distinct product-based subject and comprised a group of four practitioners, working in a collocated meeting space. The fact that this session was both collocated and product focused makes it ideal for comparison, as much of the extant literature also focuses on small team, product-focused ideation, e.g. Lopez-Mesa et al. (2009) and Howard et al. (2010). These factors, coupled with the fact that this also comprised the period with the most conceptual design from the three studies, serve to confirm group ideation as the second critical situation.

In this case, the group ideation session was characterised using codes 1 (group), 4 (in a meeting room), 7 (feasibility stage), 8 (product focused), 11 (exploring the problem) and 12 (solving the problem) (see Section 6.4.2 for coding labels). Based on these codes, the situation can be specified as a four person group in a meeting room where their time is split between exploration and solution of a product based problem at the feasibility stage of the design process.

Design Review: Review Meeting

Design review tasks played a large role in both Studies 1 and 2 and accounted for over 6% of the total coded time. Further to this, design review meetings feature heavily in the reviewed literature as exemplified in Table 7.2. Finally, design review tasks almost exclusively take the form of discreet, group meetings in either a collocated or distributed context and, as such, are readily separated into discreet situations.

As with information seeking and conceptual design, the steepest part of the design review curve was used to identify the critical situation for further comparison. In this case, the situation fell in the period between hours 12 to 15 during Study 1 (Figure 7.6). The identified situation comprised a single 100 minute collocated review meeting involving two practitioners (one senior and one junior). The fact that this meeting was product-focused makes it ideal for comparison purposes. These factors, coupled with the fact that this also comprised the period of most intense design review from the three studies, serve to confirm design review meetings as the final critical situation.

In this final case, codes 1 (group), 4 (in a meeting area), 7 (feasibility stage), 8 (product focused) and 9 to 16 (problem solving) have been used to specify the design review situation (see Section 6.4.2 for coding labels). Based on these codes, the situation can be specified as a pair of practitioners based in a meeting area where their time is split between various problem solving activities during the feasibility stage of the design process.

Table 7.2: Examples of literature associated with the three critical situations

Situation	Examples of associated literature
Information seeking	Aurisicchio et al. (2010), Hertzum (2000), Kellar (2007), King (1994), Lowe (2002), Lowe (2000), Robinson (2010), Sohn (2008), Wasiak (2008), Wild (2010), Kellar (2007), Blandford (2010), Allard (2009)
Conceptual design	Kuijt-Evers (2009), Howard (2008), Yamashina (2002), Kavakli (2002), Cai (2010), Collado-Ruiz (2010), Corremans (2009), Kurtoglu (2009), Shah (2003), Stones (2010), Reinig (2008), Lopez-Mesa (2009), Arikoglu (2010), Dorst (2001), Pirola Merlo (2004), van der Lugt (2002), Cash (2011)
Design review	Prudhomme (2007), D'Astous (2004), Bergstrom (2005), Bergstrom (2005), Ostergaard (2005), D'Astous (2001), Huet (2007), Huet (2007), Hartmann (2007)

7.5.3 Reflection on the Core Method

The core empirical method was successfully implemented during this study, validating several key aspects. Firstly, the acclimatization period was sufficient for each of the participants despite differences in working habits and experience. Secondly, the results demonstrated the value of the method in contextualising the whole of the participants' activity whilst also allowing for detailed analysis of selected periods. Finally, the fact that the method allowed for the identification of important design situations that have been independently identified in literature validates the methods ability to accurately capture and represent the activity of practitioners. It is to be noted that despite the multi-level coding strategy significantly reducing the workload of the researcher there is still a substantial coding and analysis requirement. However, it is dubious whether this could be further reduced without either compromising the fidelity of the results or automation of the process.

7.5.4 Reflection on Practical Issues

Although generally successful the study encountered a number of practical issues, which should be considered. Firstly, recording data for participants who worked at home was significantly more likely to fail than when compared to recording in the office environment. This can be attributed to significantly more private periods as family members interrupt work and the much greater level of intrusion caused by home setup – requiring a longer acclimatisation period. Secondly, confidentiality issues limited this study to only one coder, which is a common issue for design research. Finally, although the coding schema was implemented successfully there is scope for further refinement of the qualitative codes in order to give more readily accessible results. This is highlighted by the length of time required to code and analyses the data, which is one of the major limitations of this type of work.

7.6 Concluding Remarks

This chapter described the core observational study of practice. This was used to identify three critical situations within the design process, which are also commonly studied experimentally – information seeking, ideation and design review. These were described in detail and contextualised within the design process in order to provide a basis for further comparison. Finally, the three situations were validated as relevant by a review of recent empirical design research literature, highlighting their core role in both research and practice. As such, the purposes of this study were not to make specific claims about designer behaviour but instead, to provided a validation of the core method and the data necessary to for the comparison studies.

In order to develop effective relationships with practice, the next step is to detail the identified situations in the laboratory and intermediary settings. As such, the three situations detailed here have been used to form the basis for the design of the laboratory-based study described in the next chapter.

"I was taught that the way of progress is neither swift nor easy."

Marie Curie

8

Laboratory Study

This chapter details the laboratory-based study – the second part of the three-stage methodology described in Chapter 4. This study differs from the observation study of practice (Chapter 7) in several ways. Firstly, it is laboratory based. Secondly, it uses students for its participant population; and finally, it takes the form of an experiment rather than a pure observational study. A summary of the overall study timeline is given in Figure 8.1.

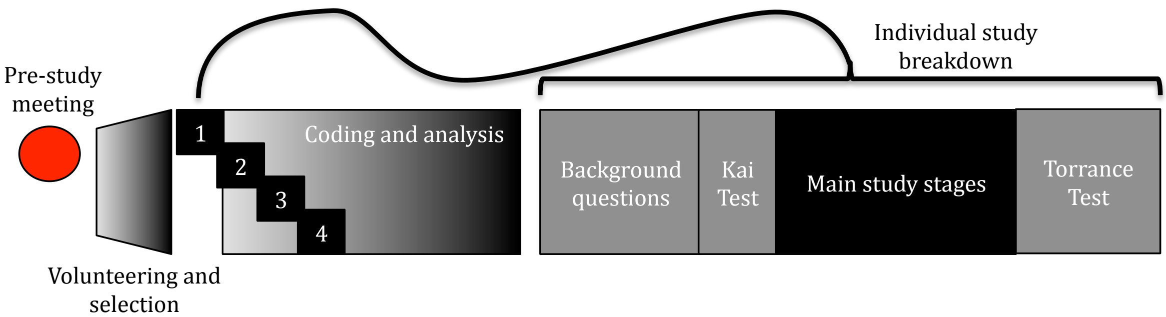

Figure 8.1: Study timeline

Using an experimental approach is necessary to describe all three critical situations (detailed in Chapter 7) such that they can be effectively compared across contexts and to existing studies in design research (e.g. the work sampling study of engineers' information behaviours by Robinson (2010), Huet et al.'s (2007) study of design reviews and Howard et al.'s (2010) practice-based study of ideation). As such the experimental approach presented in this chapter allows the examination of these critical situations during a single study. However, before the method can be detailed, it is important to outline the context in which the study took place.

8.1 Contextualisation

This section briefly outlines the activity, social and historical context of the student population used for the study described in this chapter. This information, as well as further contextualisation, data was elicited using participant questionnaires as well as data gathered from administrative sources within the University of Bath. The questionnaires are shown in Appendix B.

Activity

The study itself was split into four stages, each focusing on a different aspect of the overall design process. These stages were linked by a common design task, which was introduced to the participants incrementally at each stage – giving increasingly specific briefing information as the study progressed. This allowed the participants to be artificially moved from early to later stages in the design process – key to enabling the investigation of the three critical situations within a single study. The four stages were as follows:

Stage 1: 50 min – individual information seeking based on an initial broad brief.
Stage 2: 50 min – team ideation session based on a preliminary specification.
Stage 3: 90 min – individual detailed design development based on a detailed brief.
Stage 4: 50 min – team design review and selection session using all the given information.

The four stages are summarised in Figure 8.2.

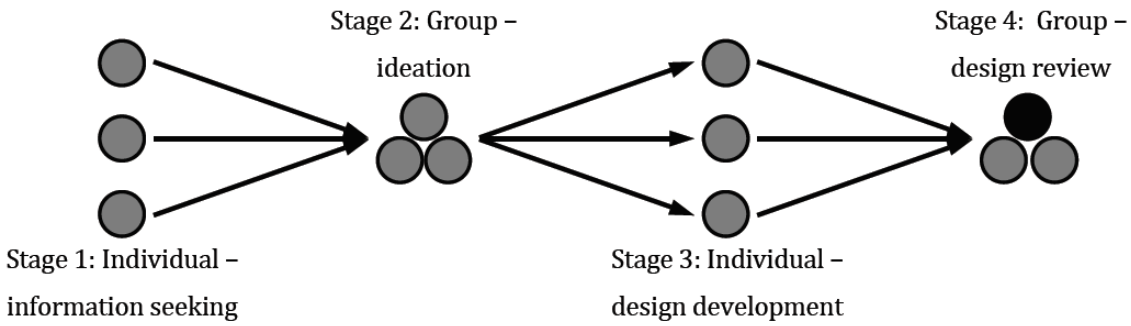

Figure 8.2: Experimental structure in four stages

The black circle in Figure 8.2 denotes a participant who was empowered as the team leader for the final stage (selected randomly). This is used to ensure that the participants stayed on task and completed the study, as well as to reflect the difference in seniority and leadership encountered during the practice based study (Section 7.5.2).

The next aspect of context deals with the technical features of the workstation used by the participant. However, due to the laboratory-based nature of this study, these factors were determined by the experimental task and equipment setup. As such, they are detailed in Sections 8.2 and 8.3.

Social

The population of students selected for this study consisted of final year students from the University of Bath, Mechanical Engineering (MEng) degree course (153 students at Master's level). A naturally occurring subgroup within this is students who have completed the Product Design and Development course (40 students). This course introduces basic product design principles and techniques, ensuring the participants were familiar with concept generation and had experience with developing products (a summary of the course's content is provided in Appendix D). This specific experience is important as participants unfamiliar with the product development process, brainstorming or review would be less able to fulfil the experimental tasks and would require significant additional preparatory training. Selecting from this subgroup of participants ensured that age, academic focus, level of education and sociometric factors were relatively similar.

Historical

The students each came from an educational background of training on the mechanical engineering course at the University of Bath and the UK education system in general. In addition to this, they had all completed the 'Product Design and Development' course and had a representative spread of industrial experience when compared to the larger student body (approximately 80% of the participants having at least one year of industrial experience). It is, therefore, not unreasonable to view these participants as representative of novice engineers (Kavakli and Gero 2002).

8.2 Setup and Preliminaries

This section outlines the preliminary aspects of the study including sample selection and setup prior to the main data collection step of the method outlined in Chapter 6.

8.2.1 Population Selection

Selecting the sample population based on the Product Design and Development course ensured that each participant's experience and background were relatively homogeneous and that the population formed an acceptable representation of the larger student body.

From the group of 40 students, twelve were randomly selected after a brief presentation of the required commitment. This group of twelve was then split into four teams of three for the study. Team composition was allocated randomly and then agreed amongst participants to ensure effective scheduling, i.e. the students' availability during the scheduled times for the study.

A team size of three was selected as it fulfilled the demands of representativeness outlined in Chapter 2, whilst also allowing for effective comparison to the activities of the practitioners that participated in the observation study (Chapter 7). This meant that for experimental Stages 2 (four participants in practice) and 4 (two participants in practice), the team size was different from that used in practice. These were changed to give a consistent team size throughout the laboratory and intermediary studies (necessary to complete one experiment with a single participant team performing a consistent set of tasks), whilst also offering comparability to the situations in practice as noted in Chapter 2.

8.2.2 Observation Setup

Individual tasks took place at an isolated workstation with access to physical catalogues, reference material and the Internet. A single camera was used to capture the participant and their desk area. This differs from the setup outlined in Chapter 6 due to the fact that there was no additional working area associated with the workstation and, thus, a second camera was not necessary. In addition, the LiveScribe pen (2011) and Panopto recorder (2011) were used as specified in Chapter 6. Figure 8.3 gives the modified plan view of the participants' individual working area. Cameras have been highlighted in red throughout.

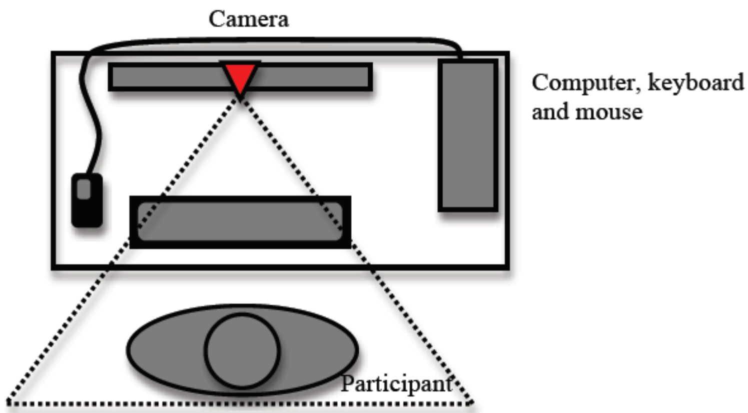

Figure 8.3: Individual setup

Team tasks took place in a working area isolated from the main research space (where individual tasks were completed). This area included seating, a table, A3 paper and a whiteboard. Activity in this area was captured using three cameras – two focused on the participants (ensuring complete coverage of their activities), while the third focused exclusively on the whiteboard. In addition, each participant was again given a LiveScribe pen and notepad to use during the session. Figure 8.4 gives a plan view of the team working area with cameras (and their orientation) denoted by the red triangles. Table 8.1 gives a full breakdown of the technologies used and what they captured during the individual and team tasks.

Table 8.1: Capture technologies

Technology	What it is recording	
	Individual tasks	Team tasks
Cameras	View of participant's face, upper body and working area	Two views of team activity incl. table and a view of the whiteboard
Panopto	Screen capture of participants' computer, plus synchronisation of screen and camera	Synchronisation of camera feeds
LiveScribe pen	Participants' notepad use	Participants' notepad use and audio

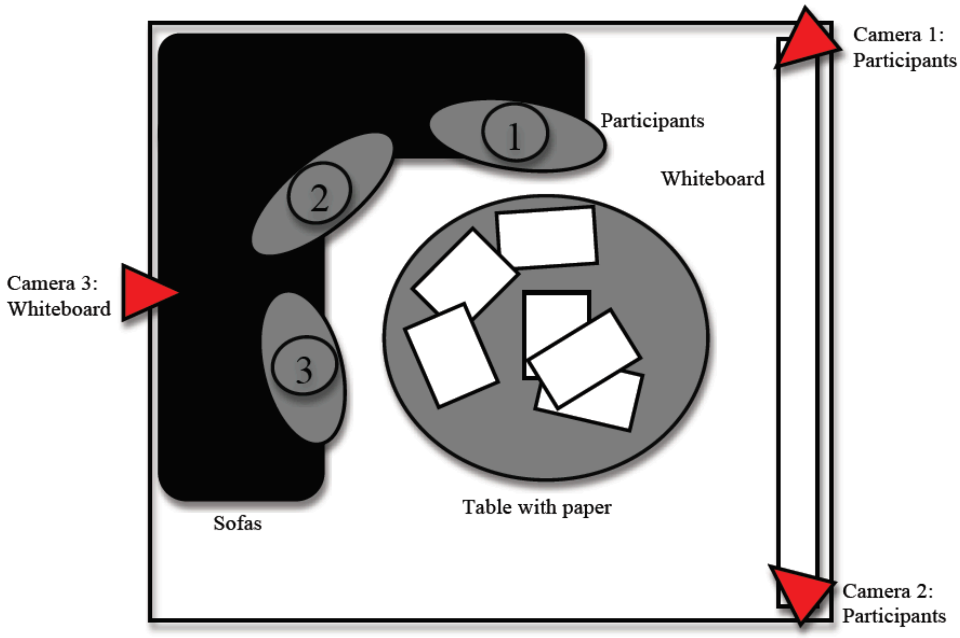

Figure 8.4: Team setup

8.3 Data Collection

This section details the specific tasks, questionnaires, data collection and coding activities used for the study outlined in this chapter. These are only described where they differ from the core empirical method outlined in Chapter 6 and, as such, the core method formed the major part of the capture, coding and analysis strategies used in this study.

8.3.1 The Task

Each task given to participants in this study was directly based on a similar task encountered during the longitudinal observational study of practice as described in

Chapter 7. As such, Table 8.2 briefly summarises the task from practice before outlining the study task and the brief given at each stage (Stage 1 to Stage 4). The briefing documents given to the participants are included in Appendix E.

Before the study began, participants were given an information sheet outlining the structure of the study. They were not made aware of the study purpose. Once the study was complete, participants were given a debriefing sheet outlining the purpose of the research and their contribution to it.

Table 8.2: Practice and experimental tasks

Critical situation	**Task from practice**	**Experimental task**	**Stage**
1. Information seeking	A representative period of individual information seeking – specifically for feasibility level technical details of an electrical component	50 minutes of individual information seeking – specifically for feasibility level technical information on camera mounting devices	1
2. Ideation	A typical 3 person ideation activity – specifically focusing on product ideas for measurement of water use	50 minutes of 3 person ideation activity – specifically focusing on product ideas for mounting a camera on a balloon	2
No critical situation	No specific period used – based on typical design development activities	90 minutes of individual design development – specifically to take one mounting concept to prototype level of detail	3
3. Review meeting	A typical 2 person review meeting (with a clear meeting leader) – specifically focusing on test results, product planning and selection for prototyping	50 minutes of 3 person review and selection – specifically focusing on selecting a concept for further prototyping	4

As Stage 3 was not based on a discreet critical situation, the results for this stage were not analysed or used for comparison purposes. As such, they are not reported or commented upon in this thesis. Stage 3 was used purely as a preliminary step in order to setup Stage 4, allowing the participants to develop individual ideas prior to the design review.

Stage 1

The brief given at Stage 1 left the participants relatively unconstrained – similar to the feasibility stage of product development. The brief was as follows:

> You are to design a universal camera mount for use on an aerial vehicle. The aerial vehicle is to be used by an amateur photographer, primarily to take still photos. Using any means available to you search for and note down information that may help.

Stage 2

The brief given at Stage 2 included an explanation of the brainstorming technique including examples, a high level specification and two explanatory pictures depicting the balloon configuration (Figure 8.5). The brief was as follows:

> During this task we would like you to brainstorm ideas to fulfil the following brief. The aim of this task is to generate as many viable ideas as possible within the time available. Please record these ideas on the whiteboard as they occur but feel free to make additional notes as necessary.
>
> Using the specification provided, develop a variety of concepts capable of mounting any camera, while slung under a helium balloon. The mount must be capable of orientating the camera to any point in a hemi-spherical region underneath the balloon, and must be operated remotely.
>
> **Specification**
>
> Total mass of camera and mount 6kg (must take a range of cameras within weight limits)

Cost (cost price) of the mount	£75
Operational life (per charge)	1.5 hours
Speed of operation – 360o pan	maximum 30s minimum 10s
Type of control	via laptop
Range of controller	100m
Range of rotation	360^{o} by 180^{o}
Volumetric size	200 x 200 x 150mm

Balloon connection	flexible
Balloon size	spherical

The design for the balloon has already been finalised, and is tolerant of any connection or interface with the camera mount. Although you should try to minimise motion in the mount where possible, you do not need to consider vibration.

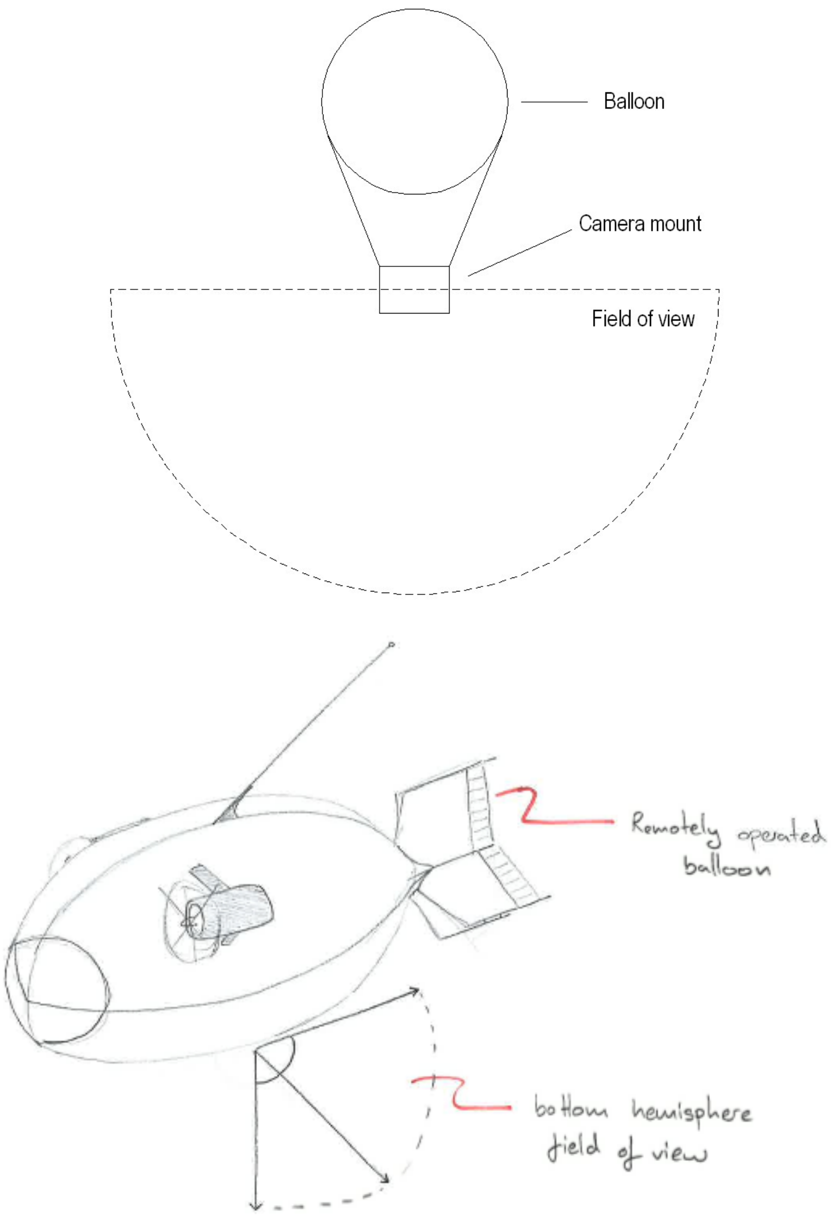

Figure 8.5: Balloon configuration pictures

Stage 3

The brief for Stage 3 contained more detailed information about the available manufacturing facilities and encouraged the participants to develop a concept in detail. This allowed the participants to develop their individual ideas further before the final review stage. The brief was as follows:

> During this task we would like you to develop one (1) of the concepts discussed during your brainstorming session based on the following brief. You are free to use the computer and notepad provided as well as any books you wish. Develop your concept to as high a level of detail as possible. Please record each action in your logbook as you proceed – Develop an appropriate, feasible, dimensioned, detailed solution.
>
> **Further details**
>
> Available machines for manufacture: lathe, end mill, injection moulding and laser cutter
>
> Assembly: By hand
>
> Your work from this stage will be given to a skilled technician, who will build a fully operational prototype. It must therefore include:
>
> General dimensions, all critical dimensions, materials to be used, a description of the mode of operation of all systems, a description of the method of assembly, a description of how the design completes its function and preferred methods of manufacture.
>
> Although unfamiliar with the project, the technician will attempt to fill in any information that they need, should you not provide it. As such complete as much work as you can, within the time allotted.

Stage 4

The final stage instructed the participants (as a team) to select and develop one final idea that could be taken forward for further advanced prototyping. This allowed the participants to select or combine the concepts developed during Stage 3. As noted in Section 8.1, a team leader was randomly designated at this stage in order to more effectively mirror the task encountered in practice. The brief was as follows:

During this task we would like you to review your designs (as developed in the previous task). The aim of this task is to select and develop one (or a combination of ideas) into a final concept to be taken forward to production. Please see the following: With your colleagues, and using your developed concepts, select and further develop a single, final concept that best fulfils the brief and specification. Please record this final concept on a single sheet of A3 paper.

8.3.2 Questionnaires

The questionnaires were used to form a baseline and to ensure that the participants were representative of the wider population. Three paper-based tests were used for this study – a background questionnaire, the Kirton Adaption-innovation Inventory (KAI) test (Kirton 1976) – measuring creative style – and the Torrance test (1968; 1998; Torrance 2007) – measuring creative thinking. The creativity tests were selected over other possible test such as Belbin (2010) as they specifically related to the critical situation – ideation. These were used collectively to develop a profile of the participants' social and historical context. Using these questionnaires provided a baseline comparison against which the studies involving practitioners could be compared – an essential step in validating any relationships.

Background

The background test was administered at the start of the study prior to the Stage 1 brief and KAI test. The background questionnaire assessed the social and historical aspects described in Chapter 6: personal details, sociometric information, education, professional experience and personal development. Participants were given the questionnaire in paper format and were allowed to complete it in private in their own time.

KAI Test

The KAI test was administered at the start of the study prior to the Stage 1 brief. The KAI test assessed the participants' creative style, allowing an assessment of their latent abilities in this area. This contributed to the characterisation of the participants' personal skills. KAI tests were given in paper format and were completed in private over a period of five minutes in accordance with KAI guidelines.

Torrance Test

The Torrance test was administered after Stage 4 and prior to receipt of the debriefing document. The Torrance test assessed the participants' creative thinking. This again contributed to the characterisation of the participants' personal skills. Torrance tests were given in paper format and timed in accordance with Torrance guidelines.

8.3.3 Data Collection and Coding

Data collection was carried at the end of the study after the participants had been debriefed – in accordance with the approach outlined in Chapter 6. However, coding of the different stages required further development of specific codes at Level 5 in the coding schema (Figure 6.3). These are non-permanent codes added to allow detailed evaluation of specific situations or research foci without making the core coding schema unwieldy. Each stage was analysed using a coding schema developed from studies extant in the literature. This ensured that the schemes had already been partially validated and allowed this set of studies to be more readily related to existing work – critical for confirming/validation of the findings. Stage 3 was not coded as this was designed as a development phase necessary for the review meeting in Stage 4 and was not based on a critical practice-based situation selected for detailed investigation (see Chapter 6). The coding schema used as the basis for each stage is summarised in Table 8.3.

Table 8.3: Detailed coding schemas

Stage	**Coding schema**	
	Description	Schema reference
Stage 1	Focused on information seeking activity – modified to include information source accessed via the computer	
Stage 2	Focused on idea generation – can give either high level or detailed breakdown of ideas and sub ideas produced over time	
Stage 4	Focused on the interactions between participants, and participants and artefacts	(Huet et al. 2007)

Stage 1 Codes

This stage used the study of Robinson (2010) as the basis for further code development. Drawing on this work, two primary codes were identified – finding source and finding information within the source. Further to this, additional codes were developed to determine the nature of the source used. This goes beyond the work of Robinson who defines the Internet as a single source. These codes were used in addition to the Level 3 codes for interactions defined in Chapter 6. Table 8.4 details the codes used at this stage. Definitions for all codes are given in Table 8.7.

Table 8.4: Level 5 codes for Stage 1 – Information seeking

Group	№	Code	Type	Code options
Searching detail	X1	Finding source/ finding within source	Class	0 – not searching, 1 – finding source, 2 – finding within source
Source detail	X2	Search engine	Binary	0 – not interacting with X, 1 – interacting with X
	X3	Catalogue		
	X4	Technology article/blog		
	X5	Supplier article		
	X6	Forums		
	X7	Expert/supplier		
	X8	Social media		
	X9	Wiki		
	X10	Patent		
	X11	Standard		

Stage 2 Codes

This stage used the study of Howard et al. (2010) as the basis for further code development. Drawing on this work, one primary code was identified – idea generation. This code was used in addition to the Level 4 codes for designer observances detailed in Chapter 6. Table 8.5 details the code used at this stage.

Table 8.5: Level 5 codes for Stage 2 – Ideation

Group	№	Code	Type	Code options
Ideation	X12	Idea	Score	A mark is placed each time an idea occurs

Stage 4 Codes

This stage used the study of Huet et al. (2007) as the basis for further code development. Drawing on this work, several codes were identified under the primary theme – artefact type. Further to this, additional refinement was carried out to ensure the codes were relevant for the study tasks and context. These codes and their definitions are defined in Table 8.6 and Table 8.7 and were used in addition to the Level 3 codes for interactions defined in Chapter 6.

Table 8.6: Level 5 codes for Stage 4 – Design review

Group	№	Code	Type	Code options
Review materials	X13	Office	Binary	0 – not interacting with X, 1 – interacting with X
	X14	Drawing		
	X15	Calculation		
	X16	Communication		
	X17	Component		
	X18	Testing/test results		
	X19	Sketching		
	X20	Logbook records		

Table 8.7 gives the definitions for each of the codes used for the three situations.

Table 8.7: Code definitions for Level 5

№	Code	Definition
Stage 1		
X1	Finding source	Searching for information relating to where specific product information is available
	Finding within source	Searching within a specific website for information related to the product
X2	Search engine	A website that retrieves data, files or documents form the whole internet
X3	Catalogue	A website that provides a list of items, specifically for sale – entries can also include technical information
X4	Technology article/blog	A website giving general commentary on products, technologies and other technical literature in an informal manner
X5	Supplier article	A website giving commentary on products or technologies written and hosted by the supplier of said product/technology etc.
X6	Forums	A website hosting a message board
X7	Expert/supplier	A specific acknowledged expert or product supplier
X8	Social media	A website hosting user uploaded and accessible content for the purposes of social interaction
X9	Wiki	A website developed collectively which allows users to add and edit content but with a specific focus such as informing
X10	Patent	A website displaying a specific patent document
X11	Standard	A website displaying a specific standard such as the British standards
Stage 2		
X12	Idea	A novel concept – not previously mentioned – relating to some aspect of the product/solution
Stage 3		
X13	Office	The use of elements in the office environment itself e.g. using a built in whiteboard
X14	Drawing	Interacting with or producing formal technical drawings
X15	Calculation	Interacting with or producing specific calculations
X16	Communication	Interacting with or producing formal communications outside of the meeting e.g. composing an email
X17	Component	Interacting with an existing physical component
X18	Testing/test results	Using data from previous testing or conducting ad hoc tests within the meeting
X19	Sketching	Interacting with or producing out informal drawings
X20	Logbook records	Interaction with notes made in the logbook previously

8.3.4 Researcher Interaction

Researcher interaction with the participants was kept to a minimum – briefings were printed onto paper and issued to the participants without verbal instruction or other interaction. During the study periods, the researcher was removed from the study area and did not interact with the participants. However, in order to answer questions and solve participant issues, it was necessary to communicate with the participants. To reduce potential biasing factors, possible questions and answers were written down beforehand. If one of these questions was asked, the answer was read aloud to ensure the same answer each time. When a new question was asked, an answer was given and both question and answer added to the list. This allowed flexibility whilst maintaining consistency across the teams.

Acclimatization

Despite it presence in the core method no acclimatization period was given to the experimental participants. There are two main reasons for this. Firstly, as this study aims to replicate typical experimental conditions (and as such help validate experimental methods) an acclimatisation period is not appropriate as it is not a typical feature of this type of study. Secondly, an acclimatization phase would be impractical and ineffective due to the highly contrived nature of the laboratory setting – it is effectively impossible to fully acclimatize participants in any reasonable time frame (it is worth noting that acclimatization required three weeks in the relatively uncontrived observational study). This second issue is the primary reason acclimatization is not a feature of experimental studies and indeed forms one of the reasons they are considered contrived in comparison to fieldwork.

8.4 Results

The main focus of this section is the examination of the results solely for the participant population used in this study. As such, the results fall into four main sections: Baseline questionnaires, experimental Stage 1, 2 and 4.

8.4.1 Questionnaires

The first aspect of the populations' characteristics to be analysed was the KAI and Torrance tests given to the participants to assess the spread in their creative style and creative level respectively. These tests gave a mean for the group of 12 participants, which fell well within one standard deviation of the standardised 50th percentile figure provided for the KAI (Kirton 1976) and Torrance (Torrance 2007) tests as outlined in Table 8.8.

Table 8.8: Summary of Kirton Adaption-Innovation Inventory (KAI) and Torrance test results

	KAI	**Torrance**
Lab Participant 1	*100*	*96*
Lab Participant 2	*104*	*108*
Lab Participant 3	*100*	*113*
Lab Participant 4	*116*	*103*
Lab Participant 5	*99*	*124*
Lab Participant 6	*98*	*125*
Lab Participant 7	*117*	*108*
Lab Participant 8	*128*	*96*
Lab Participant 9	*110*	*NA*
Lab Participant 10	*81*	*100*
Lab Participant 11	*97*	*105*
Lab Participant 12	*91*	*99*
Standardised 50th Percentile	96	101
Lab Participant mean	103	107
Standard deviation	17.5	14.2

8.4.2 Stage 1 Analysis

During each stage, there were four major areas suitable for developing an inter-comparison of the population. These were:

- The focus of the participants' activities.
- The variation in which coded activities took place over time.
- The nature of their searching activity.
- The variation in the level of enthusiasm and contentedness for each participant.

These are detailed for each study stage (Sections 8.4.2 to 8.4.4) and their implications discussed in Section 8.5.

Starting with an assessment of the participants focus during Stage 1, Figure 8.6 shows the duration of the Level 5 coded activities as a percentage of the total stage time.

This shows a spread of values amongst the participants. However, there is a clear focus on 'finding within source' and on six of the information sources – search engine, catalogues, technology articles/blogs, supplier articles, forums and wikis. Further to this, the source 'catalogues' is clearly dominant amongst the information sources (as apposed to the 'search engine' which is primarily used for 'finding source'), accounting for an average of 23% of the participants' time in comparison to the other activities, which collectively accounted for 22%. It should also be noted that participant five appeared to be an outlier doing significantly less searching when compared to the other participants. Finally, Figure 8.6 highlights the difference between 'finding source' and 'finding within source' averaging 22% and 49% of participants' time respectively.

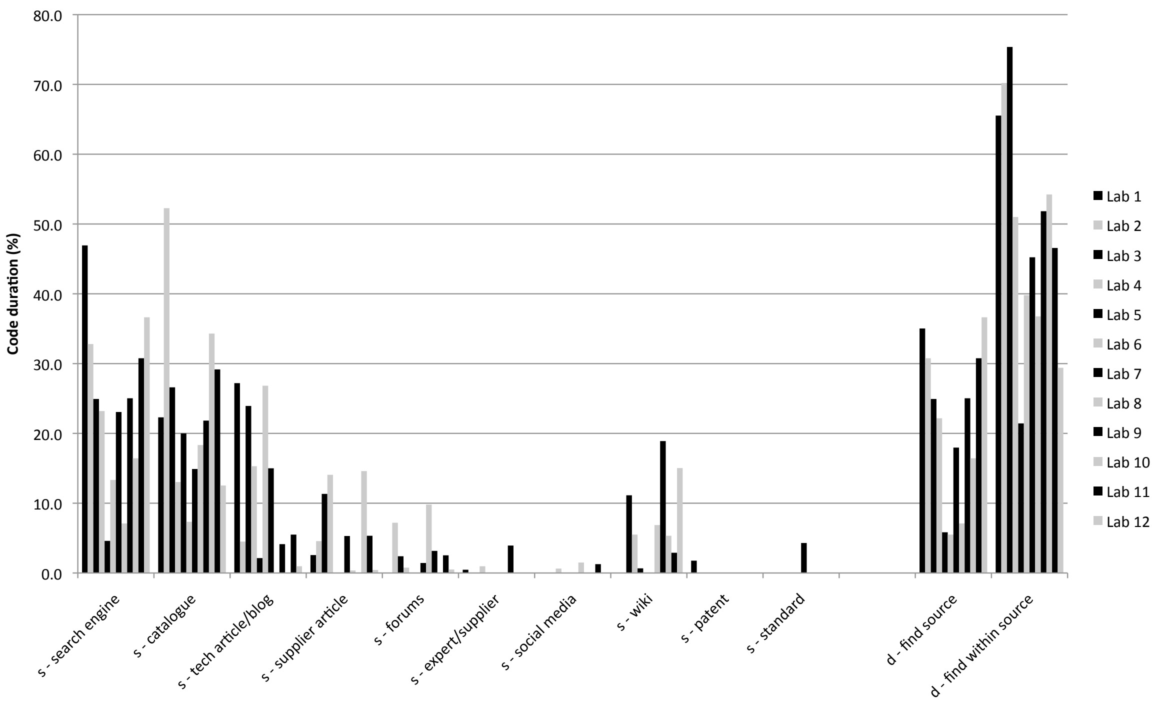

Figure 8.6: Coded activity duration as a percentage of the total stage time

Figure 8.7 shows the number of instances of each coded activity. This is a function of the proportion of occurrences as a percentage of the total number of instances per stage. This coupled with Figure 8.6 allows an estimate to be made of the relative importance of each coded activity for each participant. This again highlights the primacy of 'catalogues' as an information source accounting for 8% of the identified instances compared to the other sources which collectively account for 8% or an average of 1% each. Further, the importance of 'finding source' is emphasised compared to Figure 8.6 accounting for 8% of instances. This suggests that the participant, as a key part of their overall information seeking strategy, undertakes many short searches.

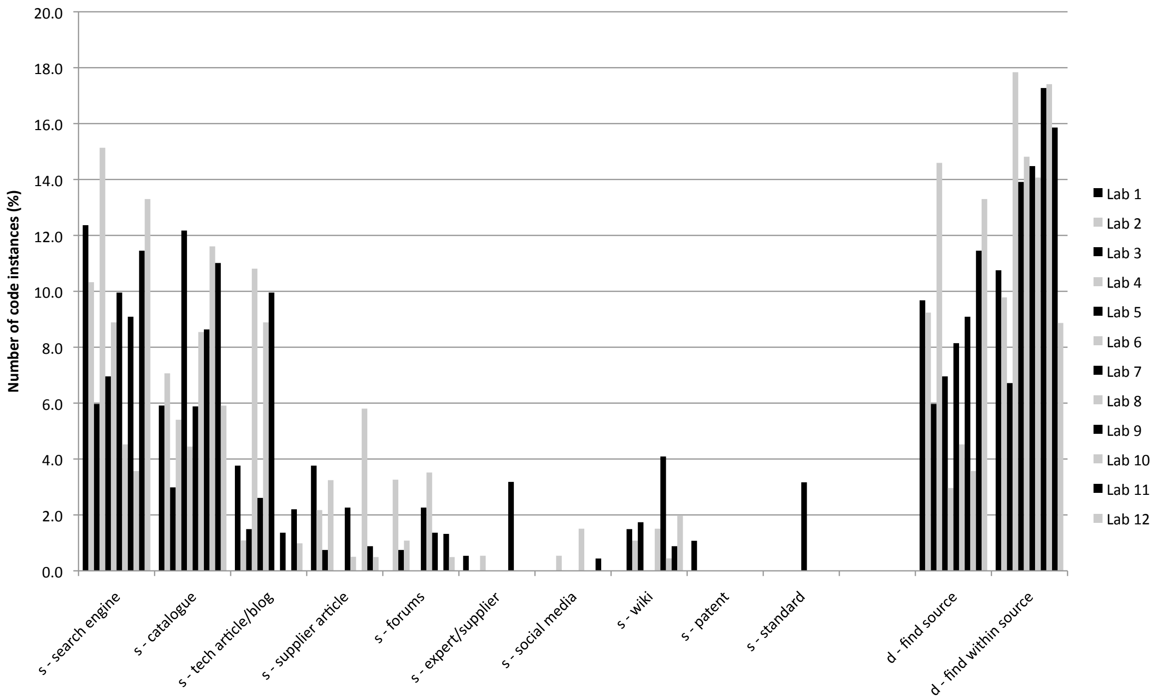

Figure 8.7: № of instances of coded activity as a percentage of the stage total

Figure 8.8 shows the average time the participant spent on each coded activity as a function of total time spent per activity divided by the number of instances. This gives an indication of how the participants were using each source – either for quick queries or for extended searching or evaluation. From this figure, it is evident that, other than in a very small number of cases, the average time spent on a single activity was short. Specifically, only seven activities had an average duration longer than 100 seconds and 70% of the coded activities average less than 50 seconds.

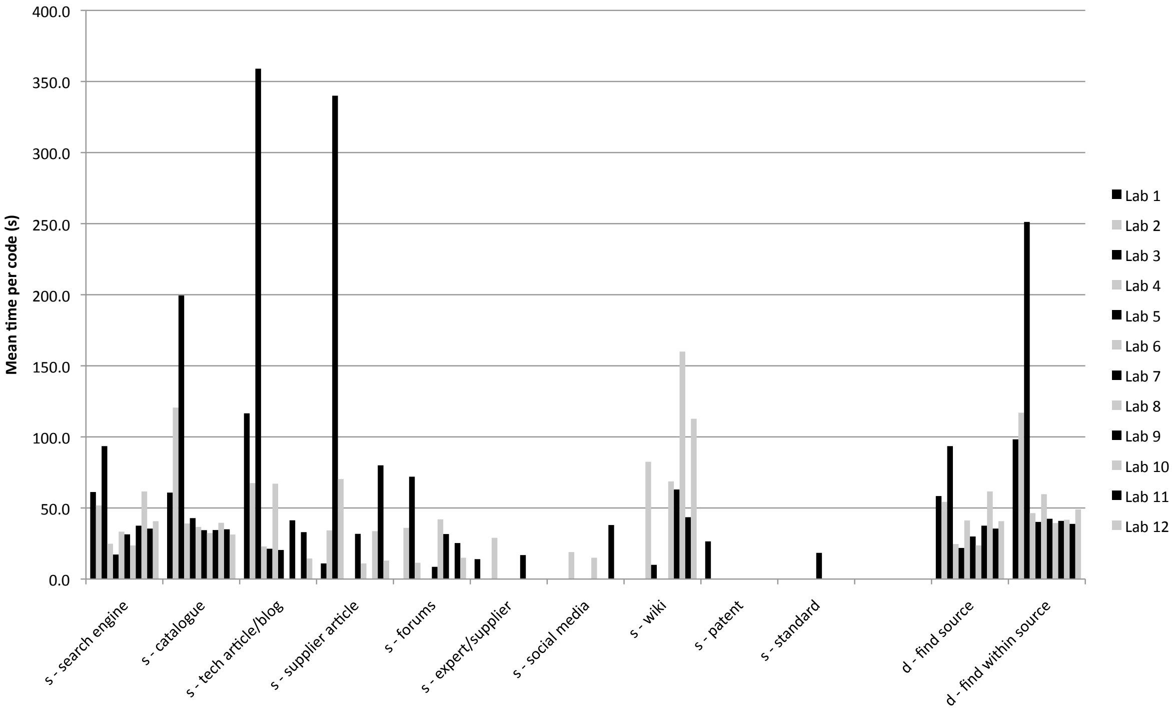

Figure 8.8: Mean time per instance

Figure 8.9 shows the spread of the major coded activities over time – information seeking, interpreting, finding source and finding within source. These display relatively little spread except for 'finding within source', where there was more variation. Specifically, 'finding within source' had a spread of 54%. In comparison, 'information seeking' had a final spread of 31, 'interpreting' had a spread of 30 and 'finding source' had a spread of 31. This is summarised in Table 8.9. Outliers were defined as participants whose final duration was more than 10% away from their closest neighbour.

Table 8.9: Comparison of the final spread in coded activity

Coded activity	**Spread (Outliers: Min./Max.)**	**Mean time (%)**
Information seeking	31 (26/NA)	60
Interpreting	30 (13/75)	40
Finding source	31 (NA/NA)	22
Finding within source	54 (NA/NA)	49

Figure 8.9 also gives a clue as to why participant five forms an outlier point for information seeking activities. Based on graphs 'a' and 'b', it appears that the

participant stopped seeking further information at the half way point and focused on bringing together the information they had already found.

In order to allow for comparison across situations of varying length, both axes are defined as percentages of the total stage time. Thus, the x-axis is from 0 to 100% while the y-axis is scaled to fit each coded activity. This format was used for Figure 8.9 and all subsequent figures of this type.

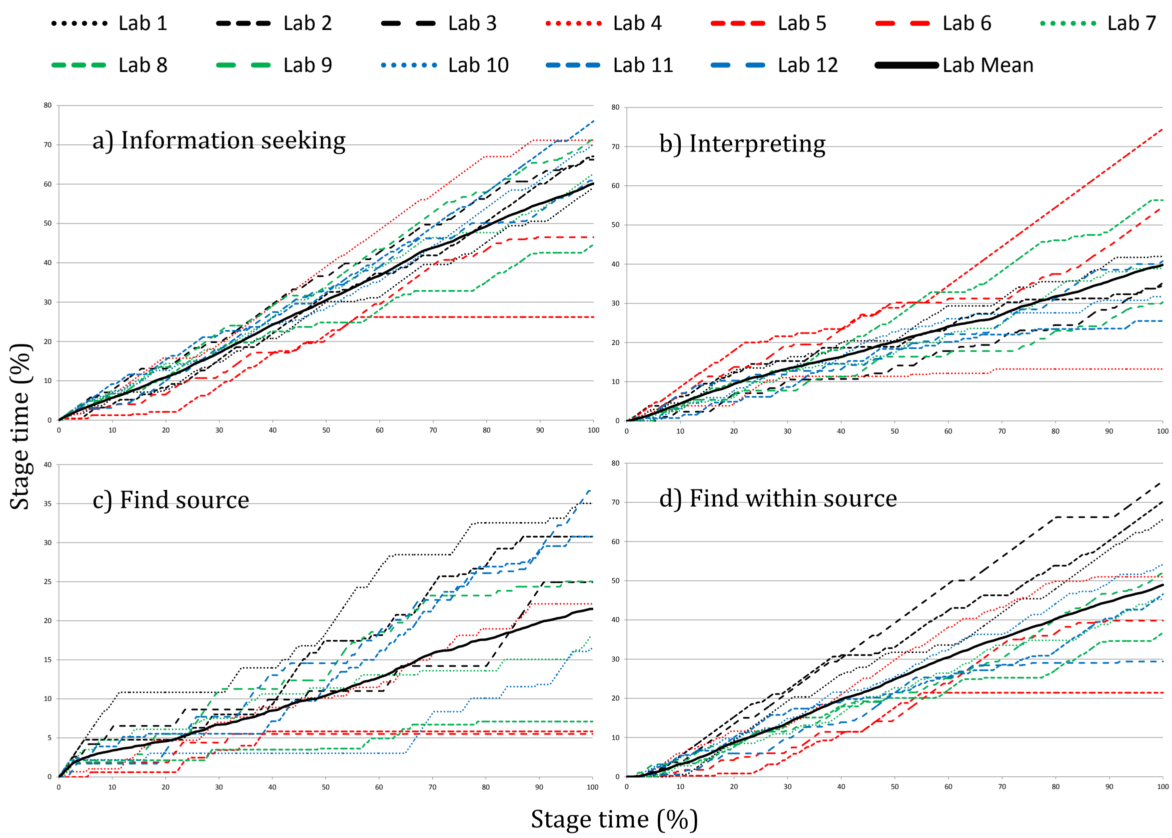

Figure 8.9: Cumulative time as a percentage of the total stage time for the high level activities

Examining the data in more detail, Figure 8.10 depicts the activities spread with respect to time for each of the six core information sources. Figure 8.10 shows a high degree of spread for graphs 'c' through to 'f', with no clear pattern of activity emerging from the studies. One finding to be noted, however, is that for each of these four marginally used sources, activity tends to be concentrated in a single continuous use (i.e. the curve goes from zero to its final value and then plateaus) with little or no activity associated with the source either before or after this event. In contrast, sources 'search engine' and 'catalogue' are more closely grouped with less emphasis on a single activity and more on a continuous usage over the course of the stage. Both of these curves show an average that can be closely approximated using a linear trend line (‘search engine’ gradient = 0.24, R^2 = 0.99; ‘catalogue’ gradient = 0.23, R^2 = 0.99), in contrast to the discreet events described in the other codes.

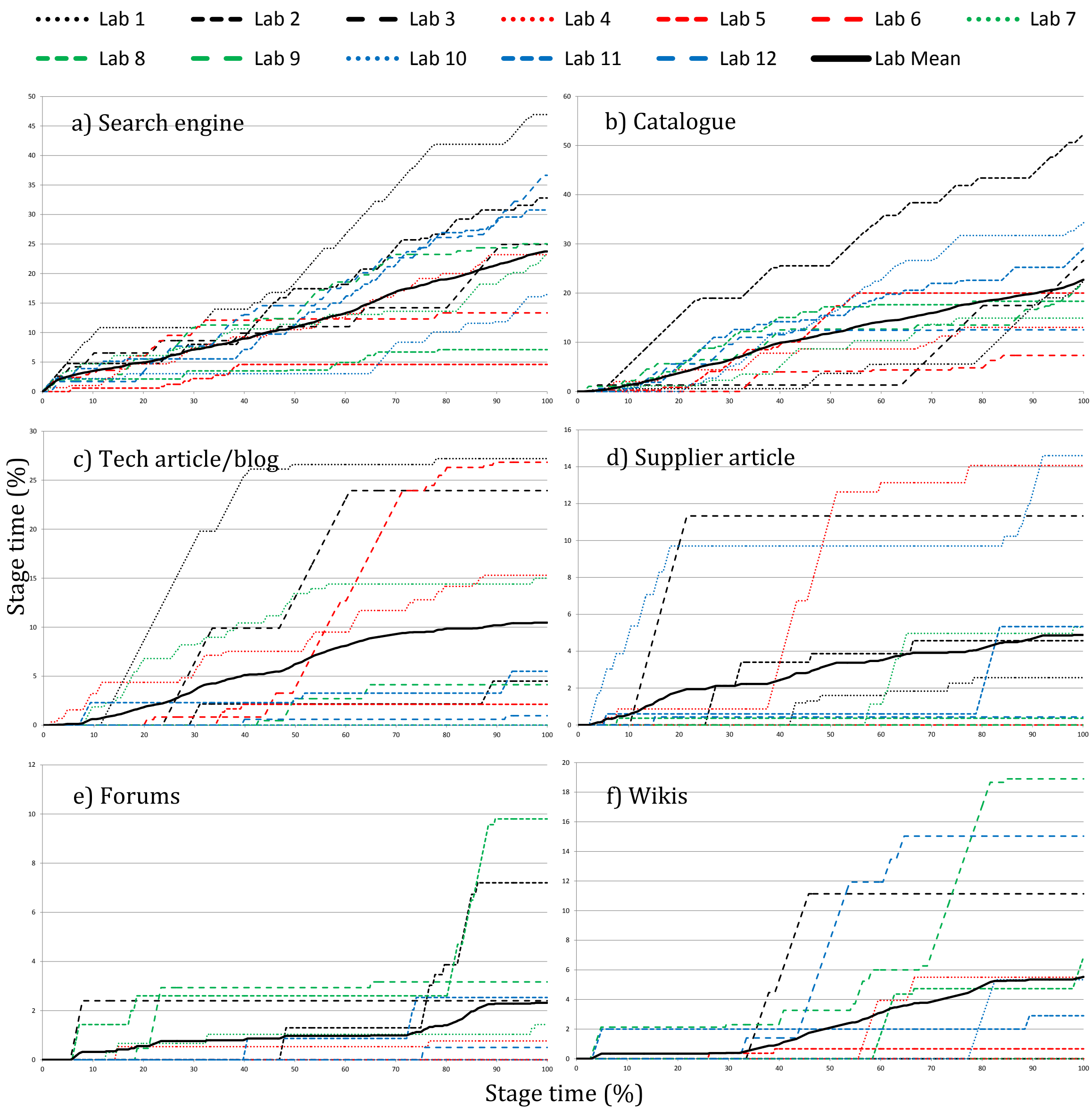

Figure 8.10: Cumulative time as a percentage of the total stage time for specific searching activities

Figure 8.10 also highlights one of the potential benefits of the core empirical method in examining the differences in participant behaviour or working practice. For example, ‘wikis’ are either used relatively heavily or not at all. Given additional data points from further studies (whose comparability is facilitated by the use of the core method) potential patterns could subsequently be established.

Decomposing participant search activity further, Figure 8.11 shows the high level of spread in the number of search activities undertaken by each participant – ranging from under 20 to over 70. This, coupled with Figure 8.8, gives an indication of each participant's search style – either favouring a large or small number of searches. This is highlighted by Figure 8.11, which gives an average number of searches of 48 for the whole group but an average of 25 for a subgroup of participants (3, 5 and 6). This is in contrast to Figure 8.12, which highlights the relatively small variation in the number of sources used by the participants – a range of 5 about a mean of 6 sources.

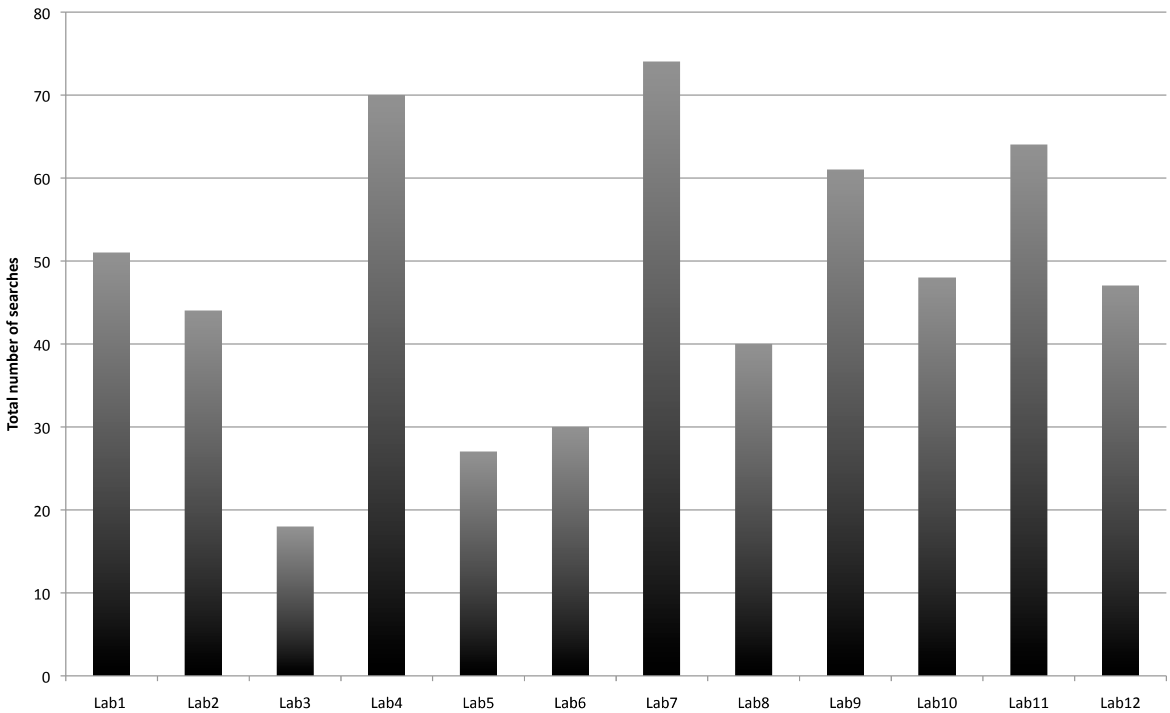

Figure 8.11: The number of searching activities carried out by each participant

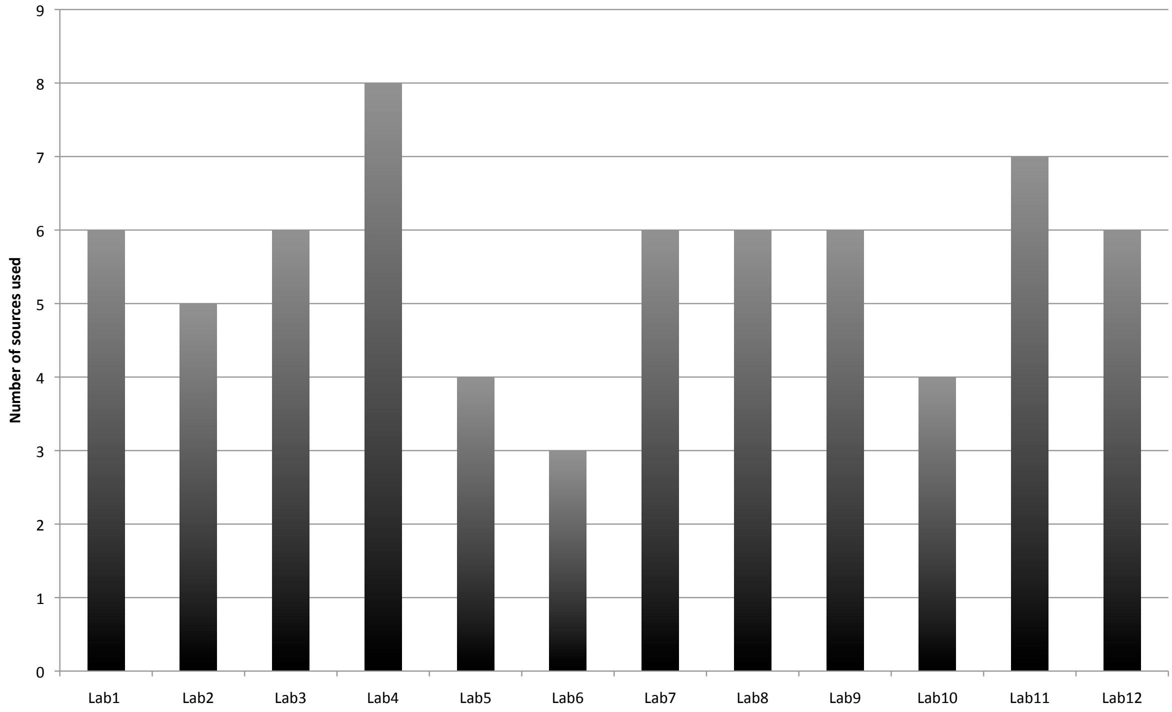

Figure 8.12: The total number of sources used by each participant

The final area of inter-comparison is that of changes in the participants' enthusiasm and contentedness over the course of the stage. Although Figure 8.13 and Figure 8.14 show a degree of variation, there is a downward trend in both cases.

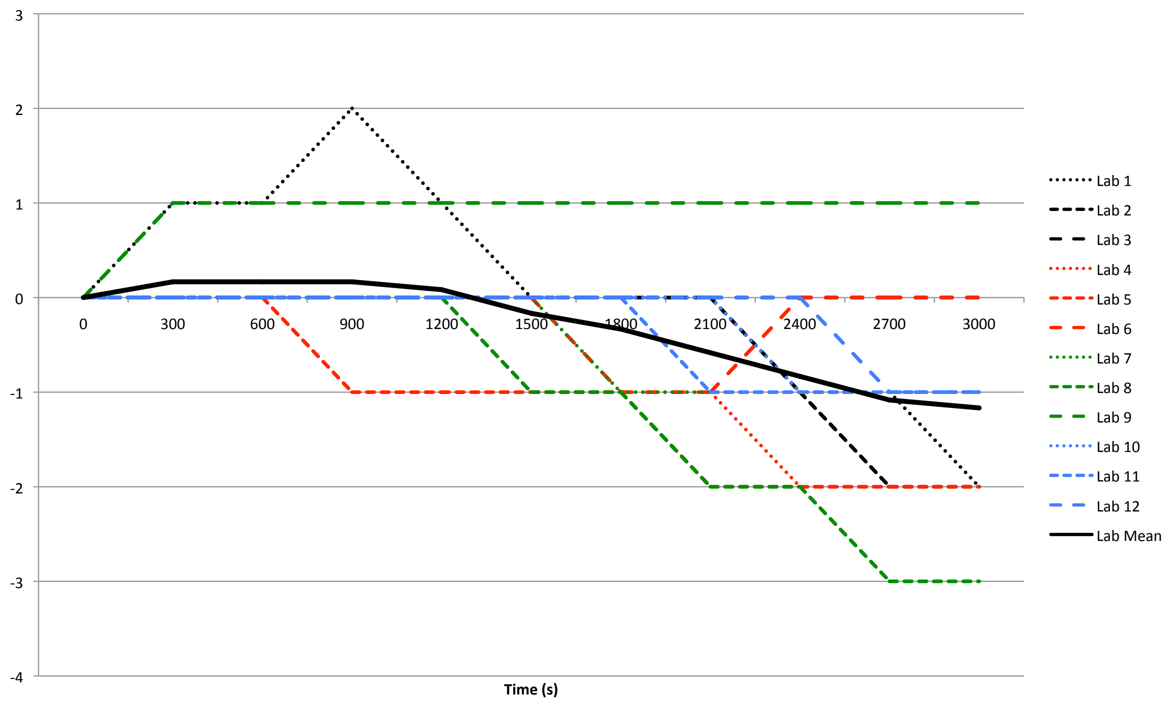

Figure 8.13: Qualitative assessment of participant enthusiasm over time

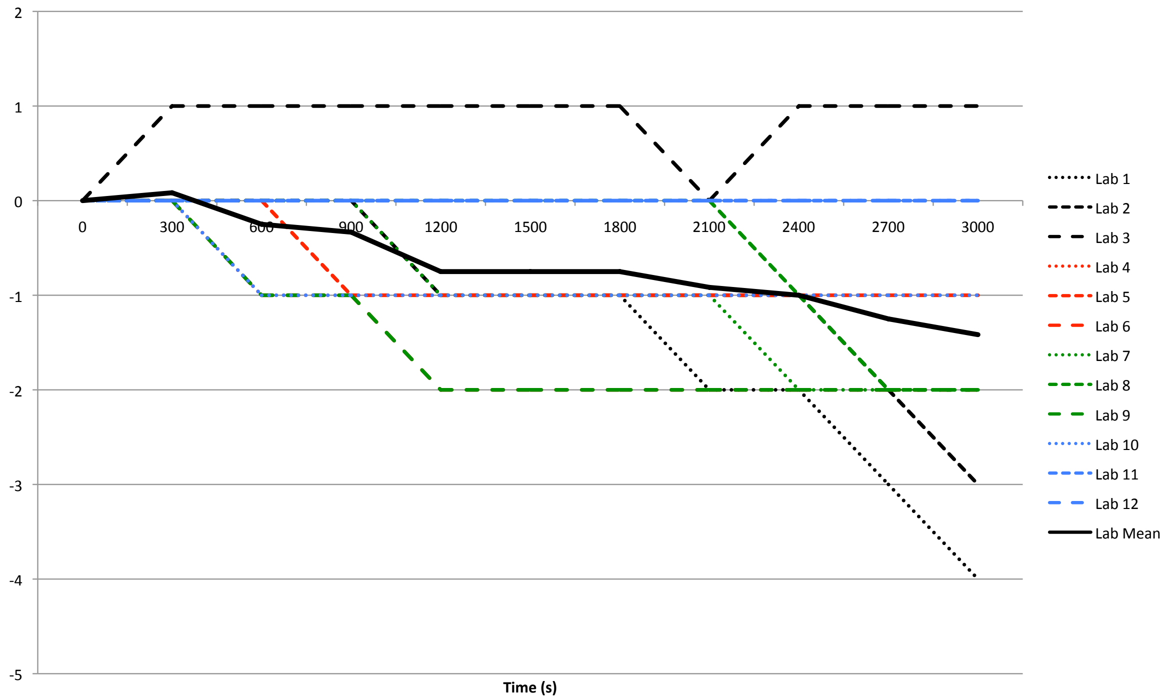

Figure 8.14: Qualitative assessment of participant contentedness over time

8.4.3 Stage 2 Analysis

As in Stage 1, the initial analysis was based on the duration as well as the number of instances of a coded activity. However, in contrast to Stage 1, this stage was team based and as such the four teams are labelled 'lab team' 1 – 4 throughout. Figure 8.15 highlights the spread in duration for each of the four teams. Based on this, it is possible to assess the level of variation across the teams and across individual coded activities. The key coded activity 'exploring' had a spread of 25 around a mean of 56%, highlighting its importance for all of the teams. Further, the conversational nature of the task was emphasised by the prominence of the coded activities 'informing', 'clarifying' and 'confirming'. More specifically, these activities account for 42, 25 and 13% of the teams' activities in comparison to the other possible activities (recognising need – validation), which collectively account for only 12% of the stage time.

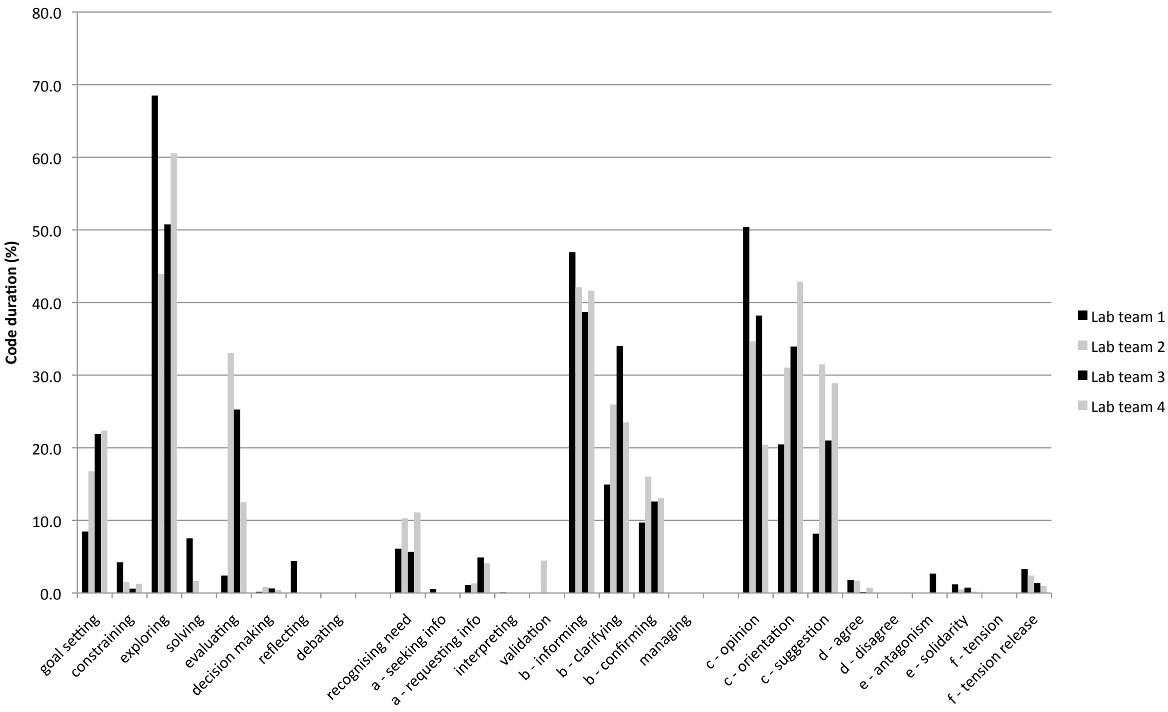

Figure 8.15: Coded activity duration as a percentage of the total stage time

Figure 8.16 shows the number of instances of each coded activity. This emphasises the conversational, discursive nature of this task in the large number of instances of: informing, clarifying and confirming. This again highlights the importance of the conversational activities ‘informing’, ‘clarifying’, ‘confirming’, which collectively accounted for 34% of the instances. However, the coded activity ‘recognising need’ was also emphasised as an important aspect of the discussions held at this stage (accounting for an average of 6% instances). This emphasises the fact that, although ‘recognising need’ did not account for a large amount of time (8% in comparison to the conversational activities 80%), it served a key role in the discussion. Further to this, Figure 8.17 emphasises the conversational nature of the discussions at this stage, with the mean time per code instance being short with only 21% of the coded activities having an average time per instance longer than 20 seconds – significant shorter than in Stage 1 (50 seconds). The two major exceptions to this were the high level activities ‘exploring’ and ‘solving’, which had averages of 66 and 41 seconds respectively.

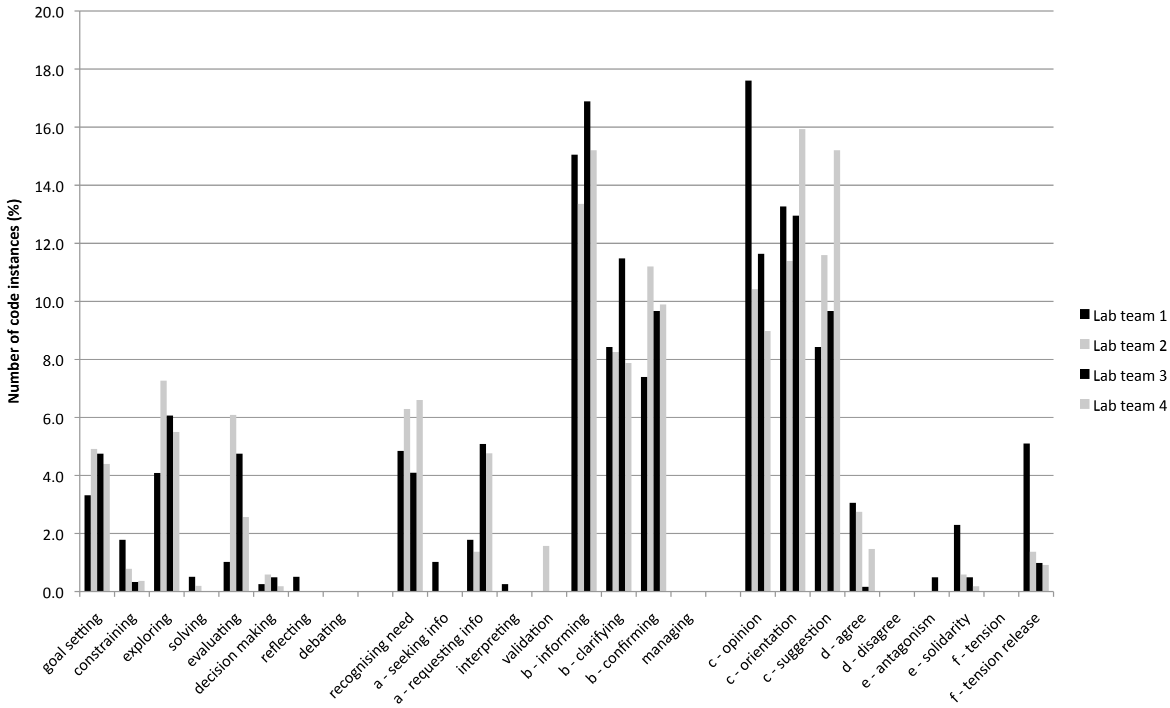

Figure 8.16: № of instances of coded activity as a percentage of the stage total

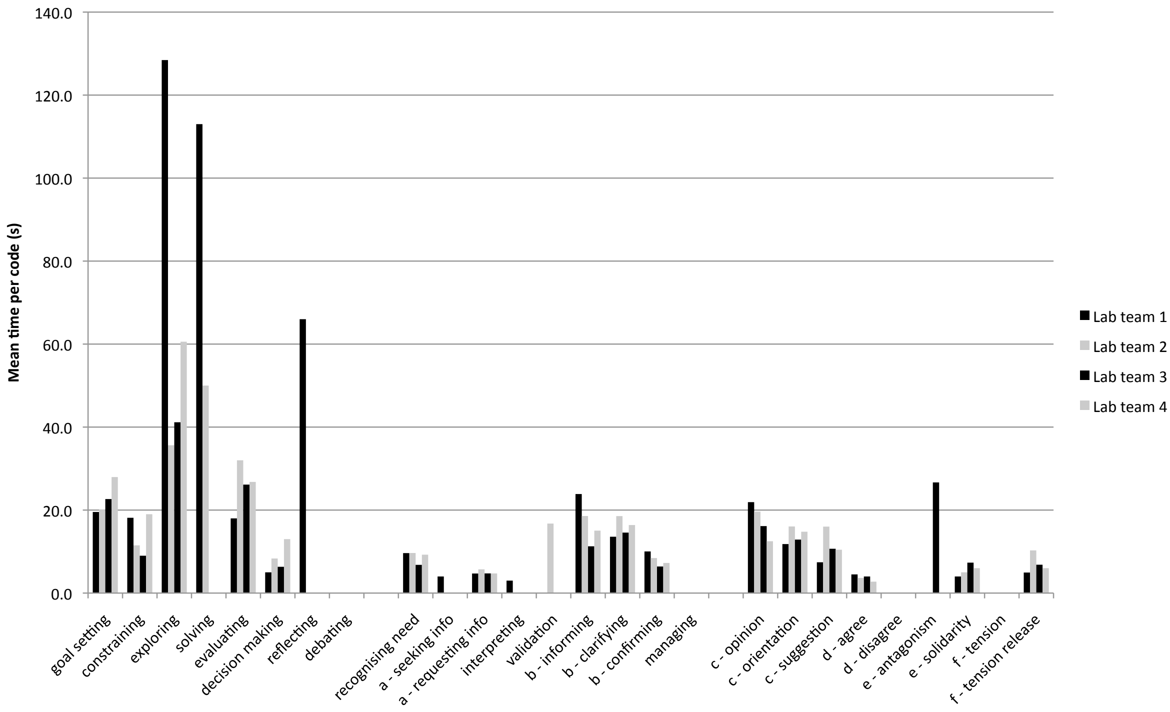

Figure 8.17: Mean time per instance

The key additional coded activity associated with this stage of the study was that of idea generation. The results for this activity are outlined in Figure 8.18, which shows ideas generated over time for each of the four teams. Both in terms of total number of ideas and in ideation rate (ideas per minute), the teams were well clustered with very little spread (14) during the first thirty minutes (min. = 54, max = 68 and mean = 60) and only slightly more spread (18) by the end of the stage (min. = 83, max. = 101 and mean = 89). This similarity was further supported by a comparison of the ideation rate for the four teams. Each of the teams can be modelled using a linear trend line which gives a very small variation in rate (0.3 ideas per minute in the first 30 minutes and 0.9 in the last 20 minutes) and a high level of conformity to a linear trend with all R^2 values being over 0.8 (Table 8.10).

Table 8.10: Ideation rate for the four teams based on liner trend line

Time (minutes)	Ideation rate (ideas per minute)		R^2 value for linear trend line	
	0 – 30	30 – 50	0 – 30	30 – 50
Lab 1	2.1	1.9	0.98	0.95
Lab 2	2.2	1.5	0.87	0.95
Lab 3	2.5	1.0	0.98	0.97
Lab 4	2.1	1.2	0.95	0.94

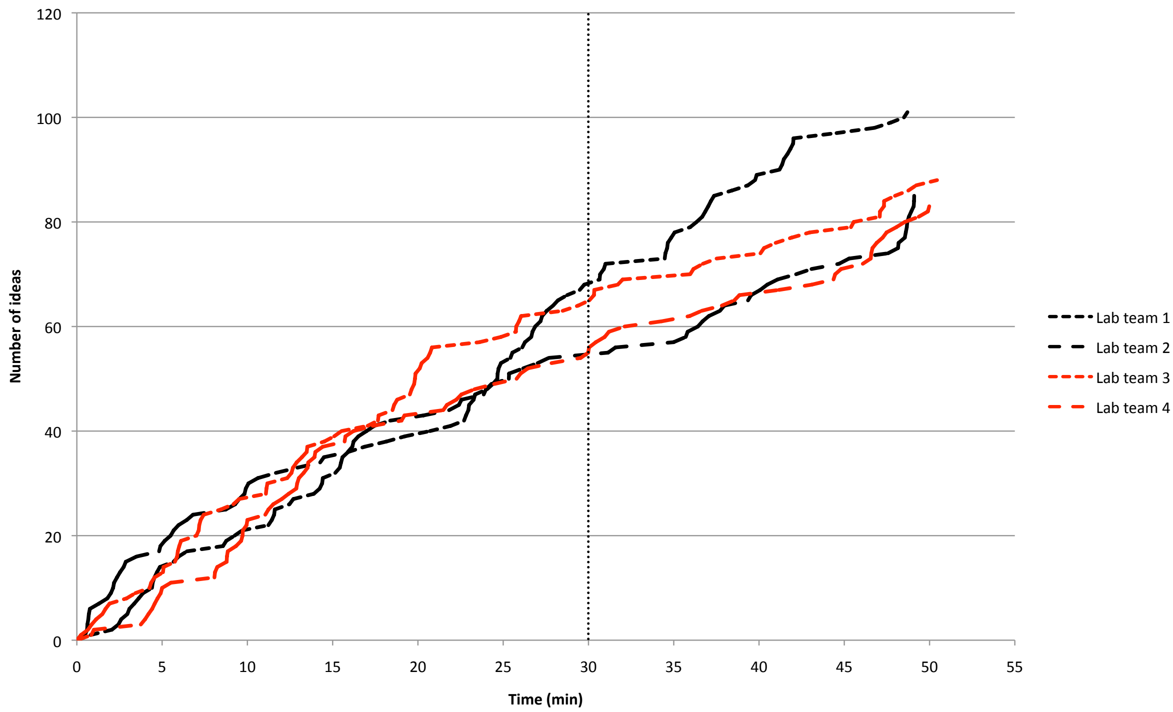

Figure 8.18: Ideas generated over time

Finally, the qualitative assessment of the participants' enthusiasm again shows a general downward trend (Figure 8.19). There was no change in contentedness – hence, no figure is given. It is worth noting here that, although there was a general reduction in enthusiasm over time this was far less clear than in Stage 1, where the participants were working individually.

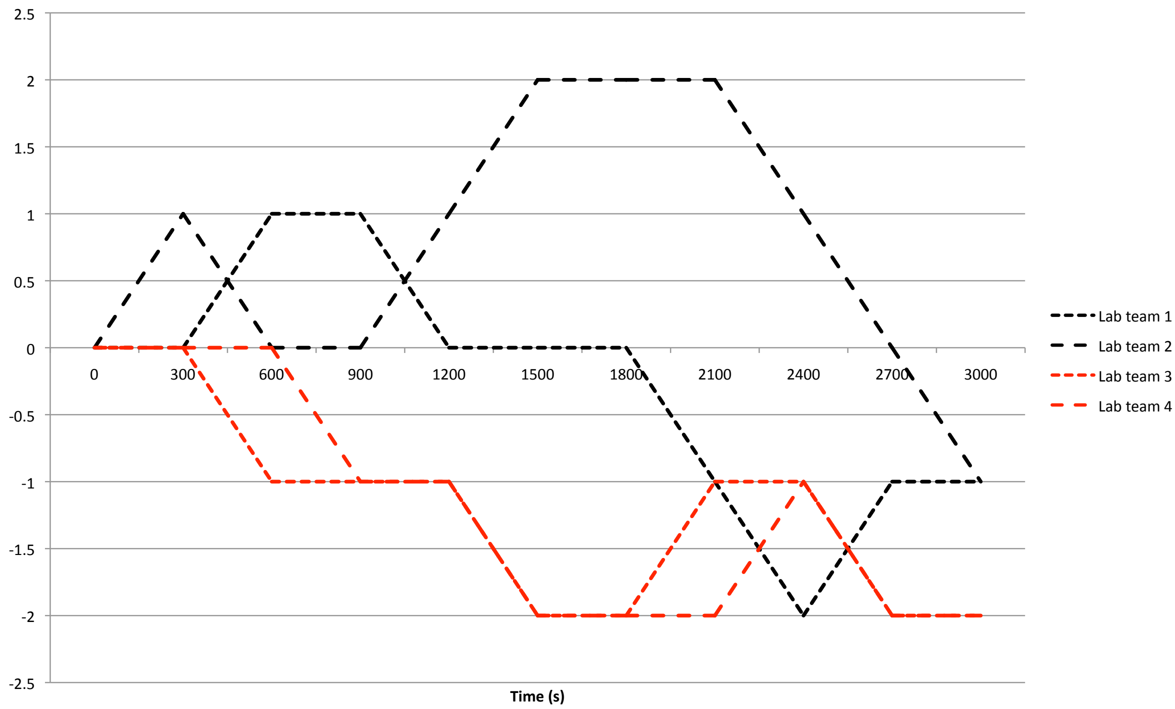

Figure 8.19: Qualitative assessment of participant enthusiasm over time

8.4.4 Stage 4 Analysis

As in the previous stages, the duration, number of instances and average time per coded activity are assessed in this section. This stage was again team based and retains the naming convention outlined in Section 8.4.3.

Although there was a spread of values for all of the coded activities, there were several trends evident across all the teams in Figure 8.20. Firstly, the primary activities stood out as 'solving' and 'evaluating' having an average total duration of 43 and 30% respectively, in comparison to the other high-level activities (goal setting – debating), which collectively accounted for only 28% of the stage time. Secondly, as in Stage 2, there was an emphasis on the conversational activities in the form of 'informing', 'clarifying' and 'confirming' – accounting for an average of 34, 35 and 11% respectively. Finally, of the specific coded activities associated with interactions, there was a focus on 'sketching' (70%), 'logbook records' (14%) and 'briefing documents' (3%) compared to the other activities. There was, however, one notable exception to this in Team 3, who showed a high degree of interaction (59%) with the office environment ('office'). This can be explained as this team, in contrast to the others, decided to focus their review and final design round the whiteboard, rather than the participants' individual logbooks or the paper provided.

The findings from Figure 8.20 are further supported by Figure 8.21, which again highlights the prominence of the conversational activities during the stage, as well as the dominance of 'sketching' as the primary Level 5 coded activity. The activities 'informing', 'clarifying' and 'confirming' account for 28% (11, 9 and 8% respectively) of the instances compared to only 10% for the other coded activities (recognising need – managing). Further to this, 'sketching' was also highlighted as significantly more prominent than 'logbook records' or 'briefing documents', accounting for 3, 2 and 1% of instances respectively.

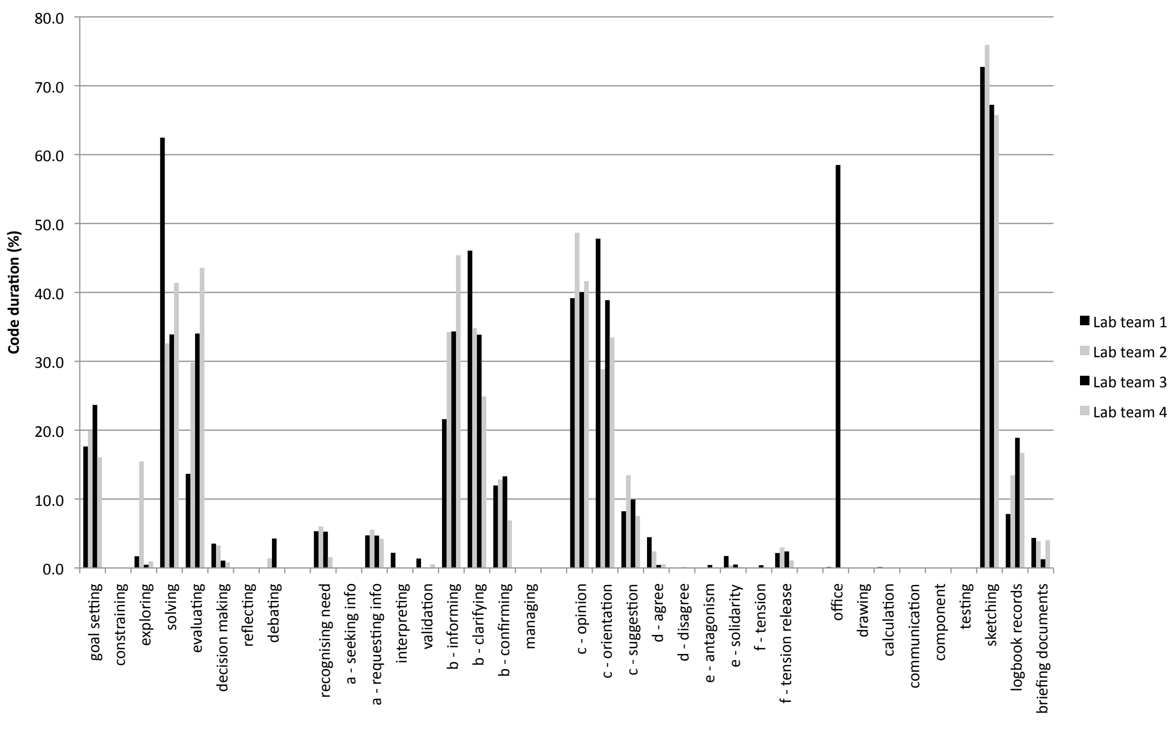

Figure 8.20: Coded activity duration as a percentage of the total stage time

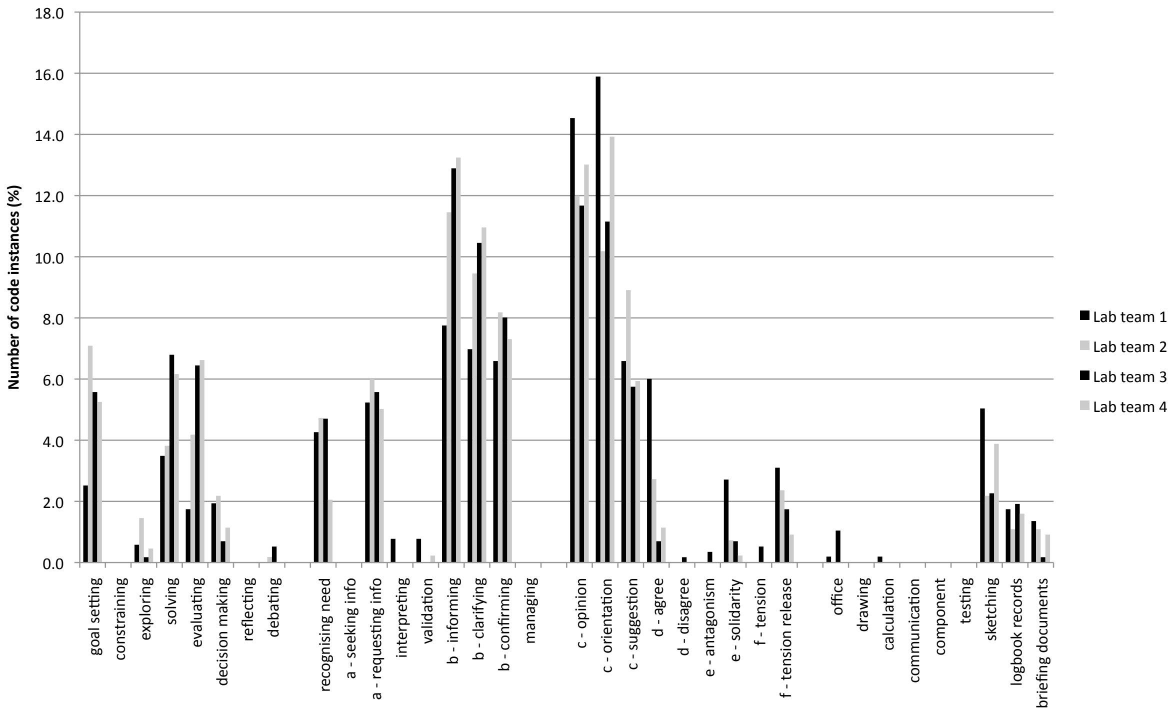

Figure 8.21: № of instances of coded activity as a percentage of the stage total

Finally, Figure 8.22 also highlights the conversational nature of the task (as in Stage 2), with only 9 of the coded activities lasting longer on average than 50 seconds and 67% of instances lasting less than 20 seconds on average (similar to Stage 2: 79% < 20 seconds). The main exceptions to this were 'sketching' (averaging 136 seconds) and 'logbook records' (54 seconds). This can be explained by the fact that these interactions often underpin conversations and, as such, tend to be much longer than the individual conversational elements such as 'informing' (18 seconds) or 'clarifying' (23 seconds).

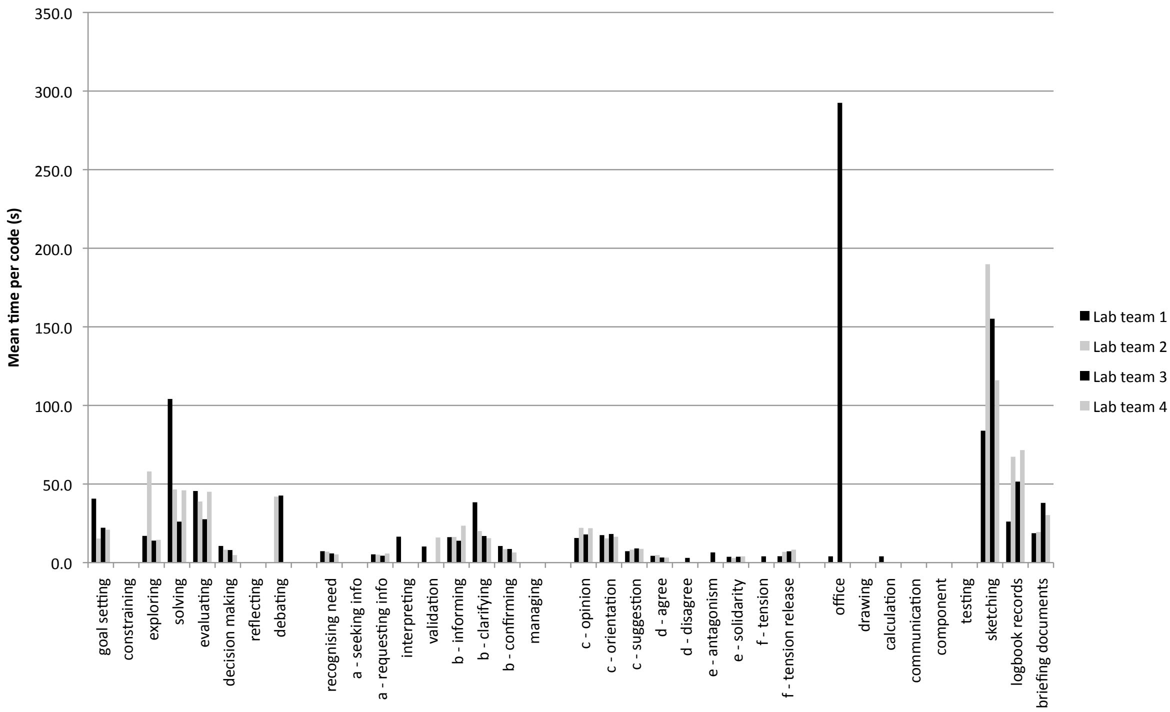

Figure 8.22: Mean time per instance

Finally, the qualitative assessment of the participants' enthusiasm again shows a general downward trend (Figure 8.23). As in Stage 2, there was no change in contentedness. Again the downward trend is less clear here in comparison to Stage 1.

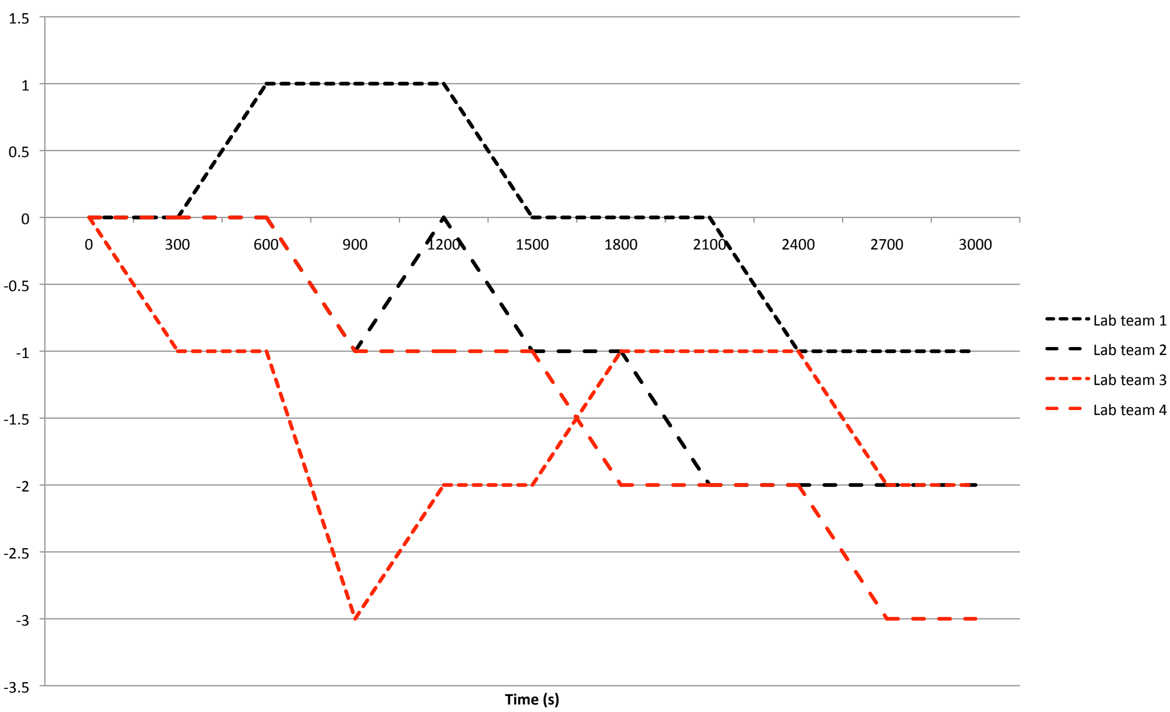

Figure 8.23: Qualitative assessment of participant enthusiasm over time

8.5 Discussion

This section aims to tackle two core issues: the representativeness of the population and data, and what data is appropriate for use in further comparison.

Building on the questionnaire data outlined in Section 8.4.1 in addition to the contextual data (Section 8.1), it is possible to assess the representativeness of the selected population. In all cases, the recorded data shows that the population form a representative sample of mechanical engineering students at the University of Bath. This is supported by the fact that the range of ages and experience amongst the selected students closely matched that of the wider population. Further, the results of the KAI and Torrance tests showed that the selected population's mean and spread of scores closely matched those to be expected for participants at this age/education level. The tests also showed the expected level of spread amongst the students with all the scores falling within two standard deviations of the defined 50th percentile value. Based on these three elements – one specific to the University of Bath and two more general – it is possible to state that the selected population of students is a fair and representative sample of the wider body of UK, university level mechanical engineering students, at least for the purposes of qualitative comparison.

The next factor to consider in assessing the data from the study outlined in this chapter is the spread of results within the student population. As with the data from the KAI and Torrance tests, the participants showed a spread of results for the measured criteria. However, in all but a small number of cases, the given results could be reasonably approximated by a mean, showing clear trends despite the relatively unconstrained nature of the experimental stages. This was highlighted by the small spread in activities such as 'information-seeking' (Figure 8.9), the number of ideas generated over time from Stage 2 (Figure 8.18) and the prominence of 'sketching' in Stage 3 (Figure 8.20).

There are, however, several counter examples that need to be explored. In particular, although the specific searching activities depicted in Figure 8.10 all showed increasing trends, there was no clear pattern in their use – this is most evident when examining the less heavily used information sources such as 'forums' or 'wikis'.

Although, there is not necessarily a trend towards behaviour patterns, the lack of patterns or clear groupings in this work can, in part, be attributed to the size of the sample. This is because it is not (and was not intended to be) sufficient to draw out more subtle patterns that might become apparent using a statistically significant sample. This can only be addressed by expanding the dataset, which is a key function of the core empirical method.

Another area where the data shows a wider spread than expected was that of participant enthusiasm during the team stages (Stages 2 and 4). This variance is clearly demonstrated by Figure 8.19, where one team bucks the normal downward trend, having a large increase in enthusiasm late in the stage. This can be partially accounted for by the fact that team interaction can naturally lead to increased enthusiasm through humour or mutual support – factors not affecting the individual in Stage 1. Further to this, it is important to note that although no clear pattern could be derived from the results for enthusiasm due to the wide range, there was a clear and consistent downward trend across all teams and all stages. Based on these findings, it is possible to state that although there was a clear spread in the results for the student participants, there were also unambiguous trends and average values that can be used as the basis for comparison. However, these must be addressed on an activity-by-activity basis.

8.5.1 Reflection on the Core Method

The core empirical method has been adapted for this experimental study by the introduction of an experimental task rather than free-form observation of practice. Apart from this modification the core method was otherwise little changed with the coding and analysis strategies implemented successfully despite the differences in task and context. This validates the core methods usefulness in various situations and highlights its flexibility in adopting situation specific aspects such as modified capture setup or additional codes at Level 5. Further, the multifaceted results produced by the layered coding and analysis strategies allowed the successful consideration of both the wider context of the participants' activities and their specific behaviour over time – key to developing an effective comparison. Finally, the results for several of the participants were significantly different from the main group – constituting outliers.

The fact that the method allowed these to be identified and investigated from a number of perspectives gave valuable insight into the nature of this outlier behaviour and validated the methods ability to deal with the wide range of results encountered when investigating human behaviour.

8.5.2 Reflection on Practical Issues

As this study was fully controlled there were few practical issues associated with setup, capture or data analysis. However, it is of particular note that, despite a group size of three, participants were seen to split into subgroups, particularly during the design review. For example, a single participant would often work on progressing the overall design whilst the other two would converse to solve specific problems. As such it was important to reflect this in the coding. Although this behaviour was not anticipated the coding strategy coupled with the flexible software support of VCode allowed parallel working to be effectively represented, suggesting that the core method is capable of capturing and processing larger teams and significantly more complex situations if required – helping to validate its efficacy as a method able to be flexibly applied to a wide range of research foci.

8.6 Concluding Remarks

This chapter described the main experimental study of students in a laboratory setting. This was used to detail the three critical situations identified in Chapter 7 for the laboratory context. These were examined in detail in order to identify common trends and assess the spread of results for the student population. This led to two key findings. Firstly, the selected student population appears to form a representative sample of mechanical engineering students typical of experimental studies – conforming to the expected results for both the KAI and Torrance tests as well as closely matching the wider population in terms of background. Secondly, the participants showed trends in terms of prominence of certain coded activities and in their activity over time. Only in a small number of cases was the spread in results such that no clear trends could be identified or a valid average obtained.

Based on these conclusions, key areas for comparison can be identified for each stage – facilitating effective comparison between the study outlined in this chapter and those outlined in Chapters 7 and 9. Table 8.11 outlines the areas selected for the final comparative analysis. These areas are primarily based on mean (including trends over time), maximum and minimum values (or other teams for Stages 2 and 4). Using these areas allows a comparison of trends, relative spread and the prominence of activities across the different studies. They will be used to compare between the studies by considering: focus of activity, activity over time, situation specific activity and participant enthusiasm and contentedness.

Table 8.11: Areas to be used for further comparative analysis

Stage	**Areas for comparison**
1	The mean values for the twelve participants The maximum and minimum values when comparing activity over time
2 and 4	The mean values for the four teams The actual values for the four teams when comparing activity over time

Based on these results and the adopted comparators, it can be concluded that the selected participants offer a sound basis for comparison against the practitioners examined in the previous study (Chapter 7). However, in order to validate any relationships with practice, the next necessary step is to detail the critical situations in the intermediary context. As such, the next chapter describes the intermediary study.

"There is a single light of science, and to brighten it anywhere is to brighten it everywhere."

Issac Asimov

9

Intermediary Study

This chapter details the intermediary study – the third part of the multi-perspective methodology described in Chapter 4 – practice, laboratory and intermediary. The intermediary study forms a bridge between laboratory and practice by combining elements of both to give a semi-contrived context. As such, this study differs from the laboratory study (Chapter 8) in two ways: it is based in a practice context and it used practitioners for its participant population.

This study used a slightly modified version of the four stage experimental approach described in Chapter 8 (to allow for the different setting). Again the stages are: Stage 1 – information seeking, Stage 2 – ideation, Stage 3 – design development and Stage 4 – design review. Of these four stages, three were identified for further examination as critical situations (Chapter 7). As such, the results in this chapter are grouped by stage, covering the three critical situations: Stage 1 (Section 9.2.2), Stage 2 (Section 9.2.3) and Stage 4 (Section 9.2.3). This chapter outlines the primary results from the intermediary study and again compares the various participants and spread of the data. However, before such a discussion is possible, it is first necessary to detail the modifications to the method used in this chapter and outline the results of the study.

9.1 Method Modifications

As the study described in this chapter forms an intermediary step between the observational study (Chapter 7) and the laboratory study (Chapter 8), much of the method and contextual information is the same. As such, this section summarises the modifications necessary for this study and refers to the preceding chapters for other aspects of the method.

Contextualisation

As this chapter builds on the studies outlined in Chapters 7 and 8, little further contextualisation is needed. In this case the participants and company contextual information (social, cultural and historical) is the same as that from Chapter 7, i.e. design practitioners operating in an SME. Further, as the study outlined in this chapter is the intermediary step, the activity is the same as that outlined in Chapter 8, i.e. the four stage experimental study.

Population Selection

Population selection was carried out as described in Chapter 7, with three participants selected randomly from the practitioner population within the SME. It should be noted that the three practitioners randomly selected for the study described in this chapter differ to those selected for the observational study in all but one case. Re-selection was carried out in order to avoid possible bias and other experimental effects that could have been introduced at this stage.

Observation Setup

Although this is very similar to the setup outlined in Chapter 8, the area, in which group tasks took place, differed slightly, as these tasks were based in the company's own meeting room in accordance with the principles of the intermediary approach. Figure 9.1 shows the modified arrangement of cameras and equipment. The area used for the individual tasks was the same as that described in Figure 8.2 in Chapter 8 and was carried out at each of the participants' normal workstation. Cameras are again highlighted in red.

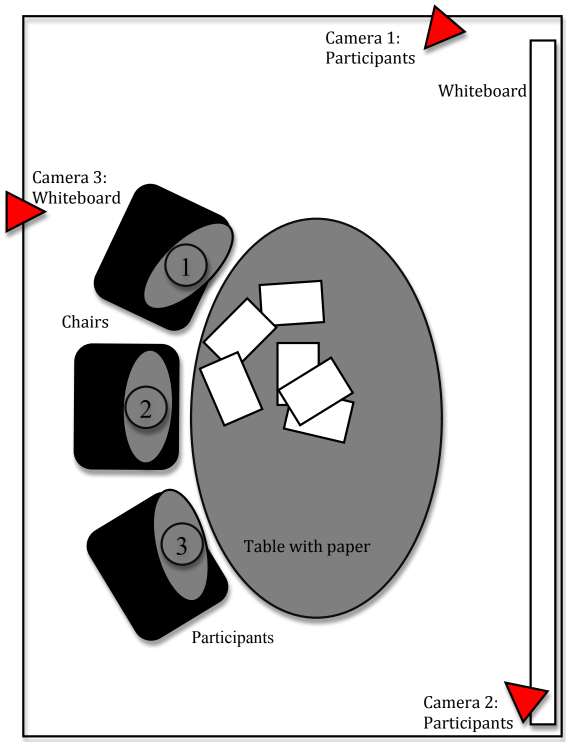

Figure 9.1: Modified group setup

Data Collection

As with the technical setup and contextualisation, the data collection procedure used has been described in detail in Chapter 8. In this instance no modifications were necessary for the intermediary study.

9.2 Results

As there were only three participants (one team) used for the study outlined in this chapter, the main focus of this section will be on an inter-comparison of the participants based on the questionnaires and Stage 1 of the study. Throughout this section, 'int' is used to denote 'intermediary' in the figures for brevity.

9.2.1 Baseline Questionnaires

As with the laboratory study, KAI and Torrance tests were used to baseline the intermediary participants. These tests gave results for the group of three, which were compared to the standardised 50th percentile figure provided for the KAI (Kirton 1976) and Torrance (Torrance 2007) tests. This data is outlined in Table 8.8. There was a wide range of values for the individual participants, but there was an overall mean value within one standard deviation of the 50th percentile figure, similar to the laboratory study (Chapter 8).

Table 9.1: Summary of KAI and Torrance test results

	KAI	**Torrance**
Participant 1	*136*	*122*
Participant 2	*106*	*103*
Participant 3	*89*	*98*
Standardised 50th Percentile	96	101
Participant mean	110	108
Standard deviation	17.5	14.2

9.2.2 Stage 1 Analysis

This section details four aspects of the participants' activities – focus, activity over time, stage specific activity and variation in enthusiasm. As such, Figure 9.2 shows the focus in terms of the duration of the Level 5 activities as a percentage of the total stage time (for comparison see Section 8.3.3). This again shows a spread of values amongst the participants. However, as in Chapter 8, there is a clear focus on 'finding within source' and six of the information sources: search engine, catalogues, technology articles/blogs, supplier articles, forums and wikis.

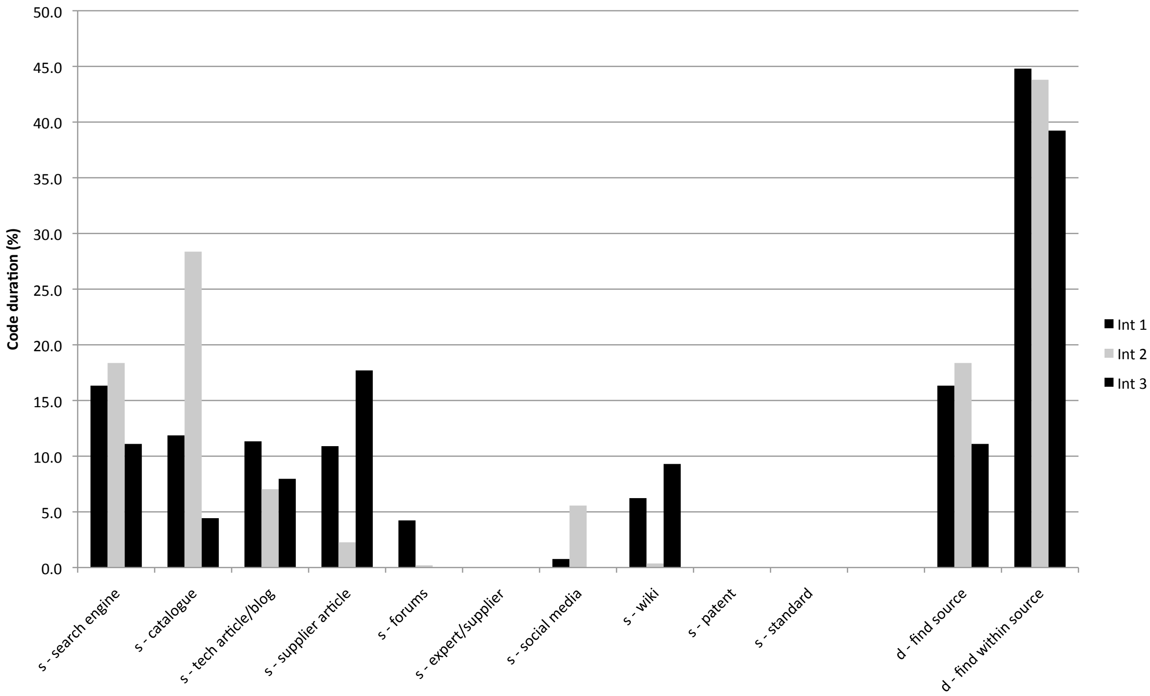

Figure 9.2: Coded activity duration as a percentage of the total stage time

Figure 9.3 details the number of instances of coded activity as a percentage of the total number of activities per stage. Figure 9.4 shows the mean time spent on each activity as a function of total time per activity divided by the number of occurrences.

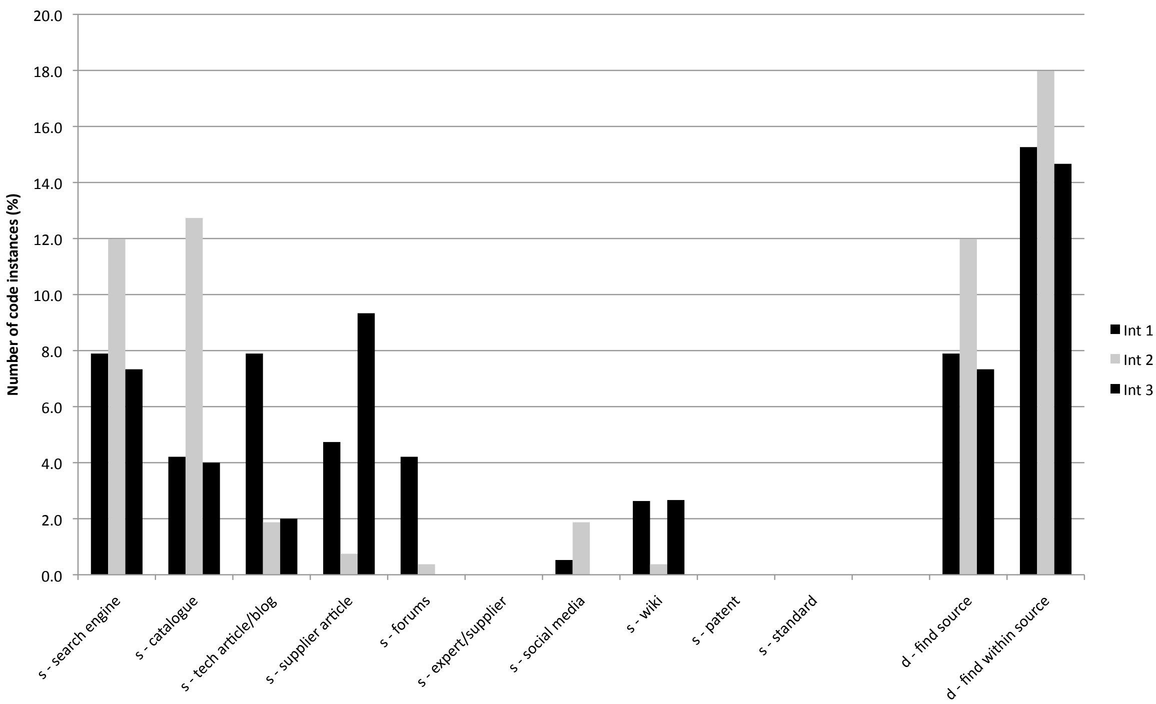

Figure 9.3: № of instances of coded activity as a percentage of the stage total

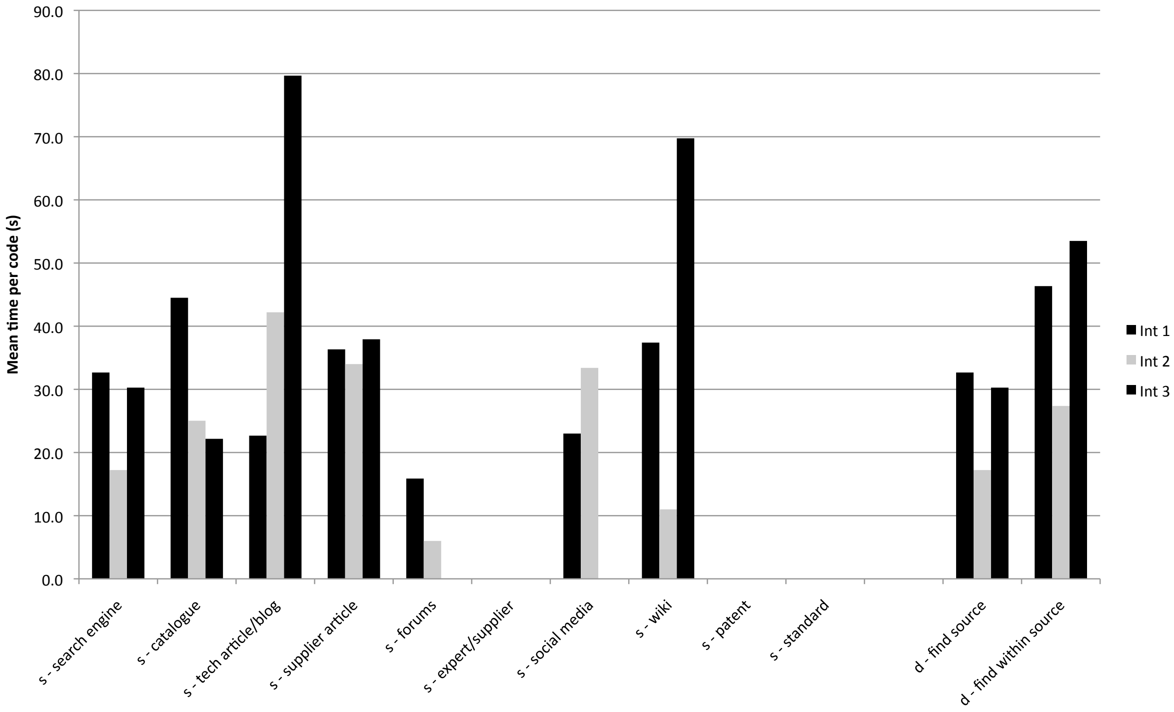

Figure 9.4: Mean time per instance

Further to the results on participant focus given in Figure 9.2 to Figure 9.4, the coded activities were also examined with respect to time. Figure 9.5 shows the tracks for the activities: information seeking, interpreting, finding source and finding within source. These activities are shown separately from the specific searching activities as they are at a higher level. The four coded activities shown in Figure 9.5 denote the overall searching behaviour of the participant, splitting it firstly into either 'seeking' or 'interpreting' and then decomposing the seeking behaviour into either 'finding source' or 'finding within source'. Figure 9.6 then goes on to detail this searching behaviour by exploring only those activities used within periods denoted as 'finding source' or 'finding within source'.

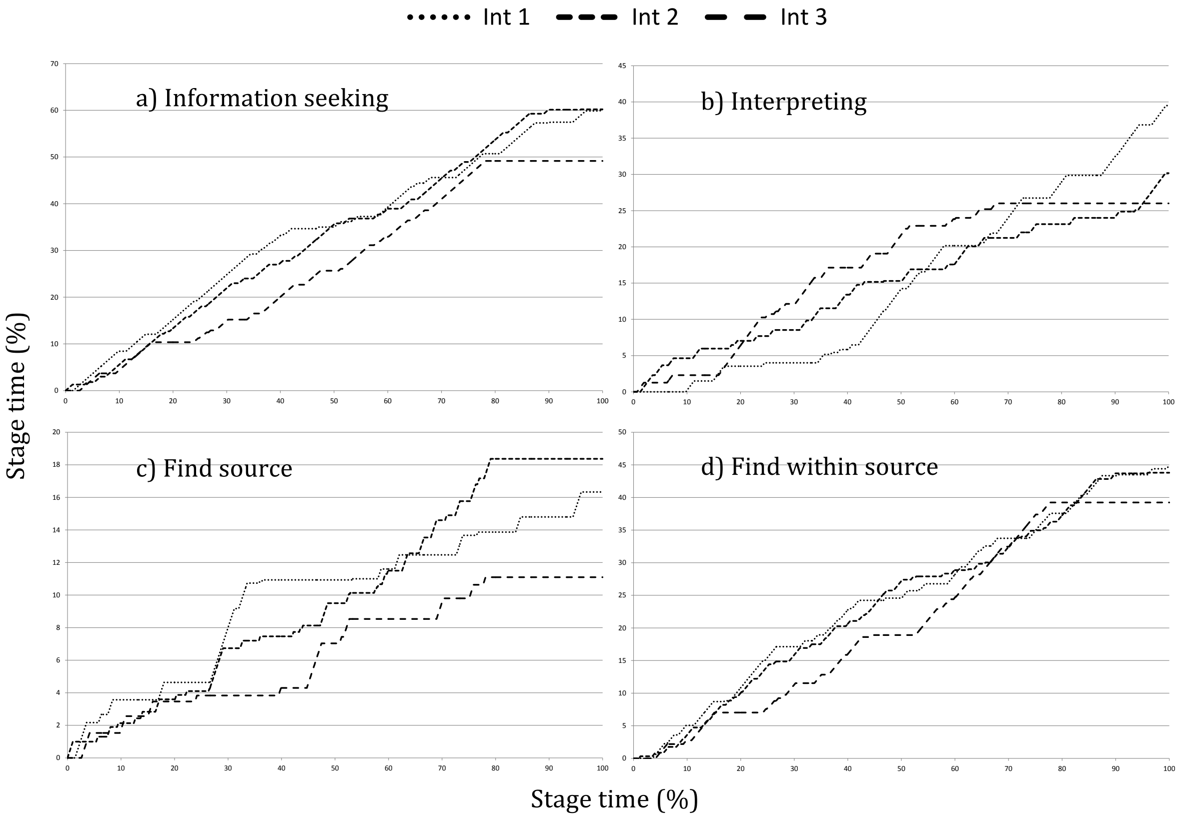

Figure 9.5: Cumulative time as a percentage of the total stage time for the high level activities

Unlike in Chapter 8, no mean value is presented in either Figure 9.5 or Figure 9.6. This is because, in contrast to the laboratory setting where there were enough data points (12) to construct a meaningful average, in this study there were only three data points. As such, a mean would not accurately represent the spread observed across the results. Therefore, in this and subsequent chapters the intermediary results are presented as three distinct points, rather than a mean value.

Figure 9.6 shows the tracks for the six main searching activities: search engine, catalogue, technology article/blog, supplier article, forums and wikis. These activities were prioritised for comparison due to their prominence in both the laboratory and intermediary setting.

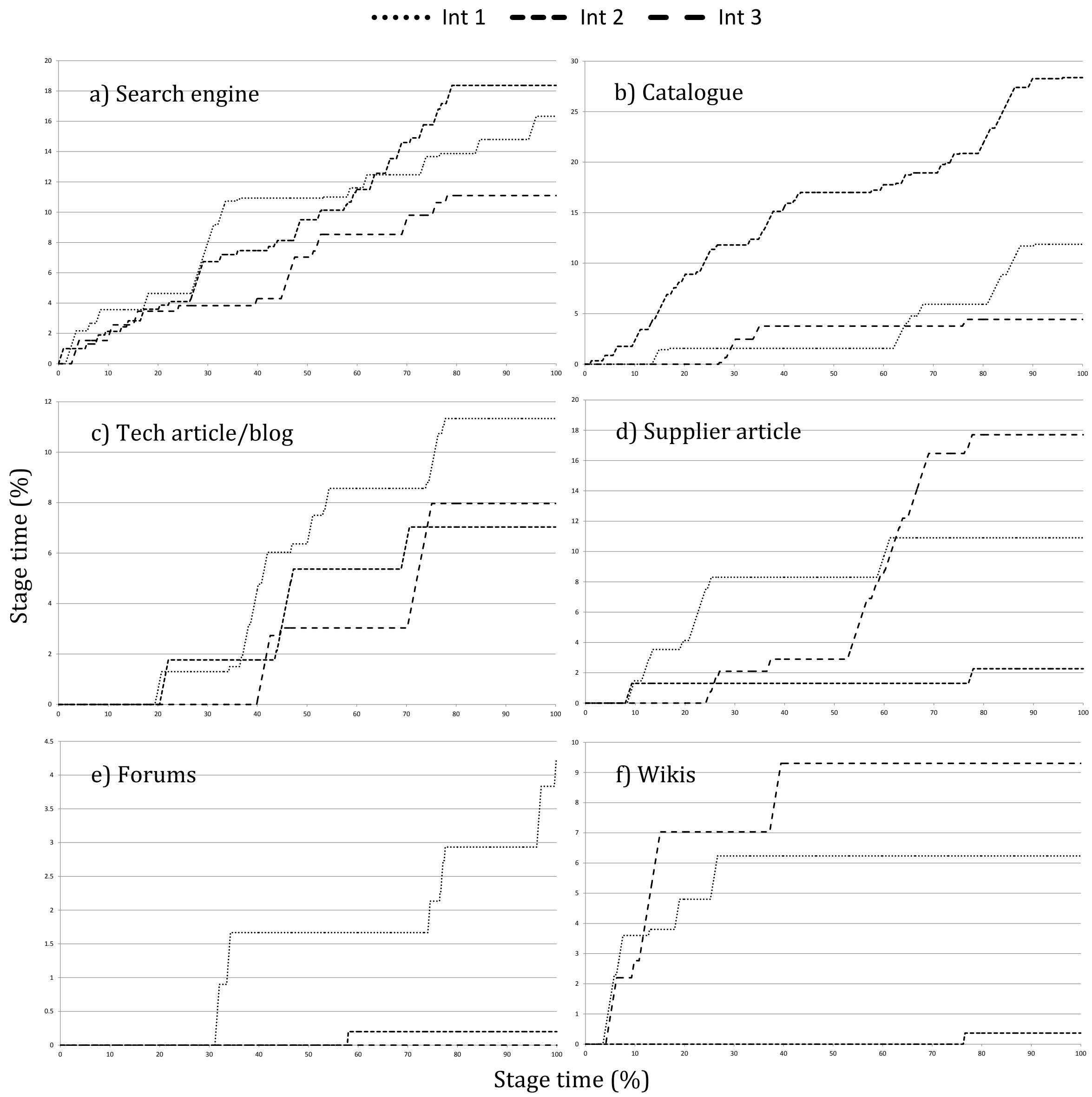

Figure 9.6: Cumulative time as a percentage of the total stage time for specific searching activities

Examining the data for Figure 9.5 and Figure 9.6, it is possible to quantitatively assess how closely grouped the participants were for the coded activities by comparing their respective trend lines. Table 9.2 gives a breakdown of the primary data and data taken from linear trend lines. In this case, the table highlights those activities that qualitatively appear to be closely grouped as indicated by the small range between the maximum and minimum values: information seeking, interpreting, finding source, finding within source, search engine and technology article/blog. The similarity in the trend line slope and R^2 values indicate that the curves were fundamentally similar in terms of shape, magnitude and closeness of fit.

Table 9.2: Similarities in trend line data

Coded activity	Min. (%)	Max. (%)	Slope of trend line			R^2 value		
Information seeking	49	60	0.66	0.55	0.66	0.97	0.98	0.99
Interpreting	26	40	0.33	0.30	0.34	0.91	0.97	0.87
Finding source	11	16	0.13	0.20	0.19	0.95	0.98	0.83
Finding within source	39	45	0.43	0.48	0.48	0.97	0.98	0.99
Search engine	11	18	0.13	0.20	0.19	0.95	0.98	0.83
Tech. article/blog	7	11	0.12	0.08	0.07	0.91	0.90	0.76

Examining the specific search activity further, Figure 9.7 depicts the number of searches by source. This gives further detail on the amount, focus and nature of the participants' searching activity. Figure 9.7 indicates participant focus by giving a measure of which sources the participants most heavily relied upon in terms of expected results – i.e. those sources most often searched, were those the participants perceived to be most likely to answer their search query/provide the appropriate information.

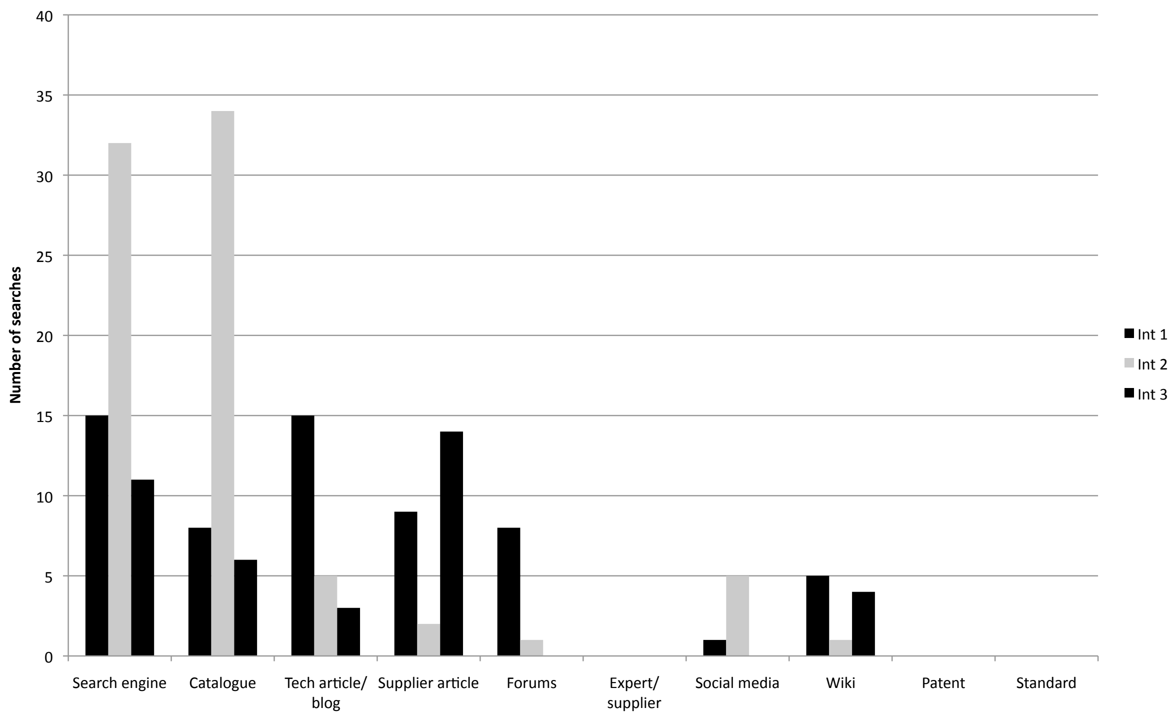

Figure 9.7: Numbers of search activities using the various sources

Further to this, Figure 9.8 shows the total number of searches carried out by the participants (based on the total number of instances) and the number of different sources used. This gives an indication of the participants' reliance on searching for information and the level of diversity in their searching activity/information sources. This is further supported by Table 9.3, which gives the primary data for each participant's primary and secondary source.

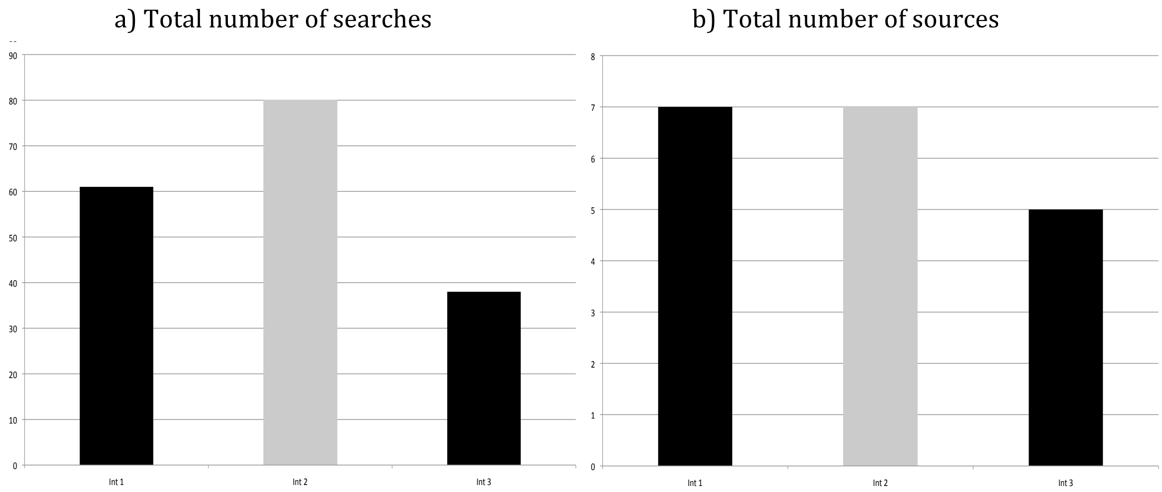

Figure 9.8: The number of searches and sources used by participants

Table 9.3: Participants preferred sources

Participant	Primary source (№ of searches)	Secondary source (№ of searches)
1	Tech. article/blog (15)	Supplier article (9)
2	Catalogues (34)	Tech. article/blog / social media (5)
3	Supplier article (14)	Catalogues (6)

Finally, Figure 9.9 and Figure 9.10 outline the qualitative assessments of participant enthusiasm and contentedness, as they changed over time. These give a relative measure of how the participants compared emotionally as they undertook the various tasks.

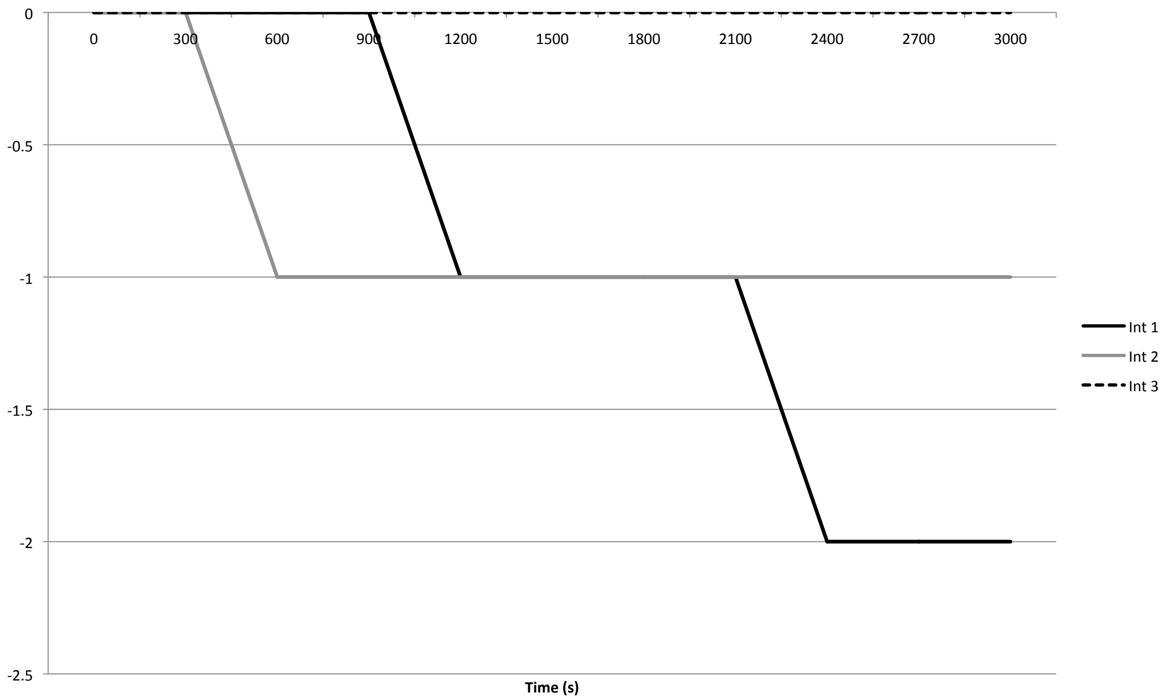

Figure 9.9: Qualitative assessment of participant enthusiasm over time

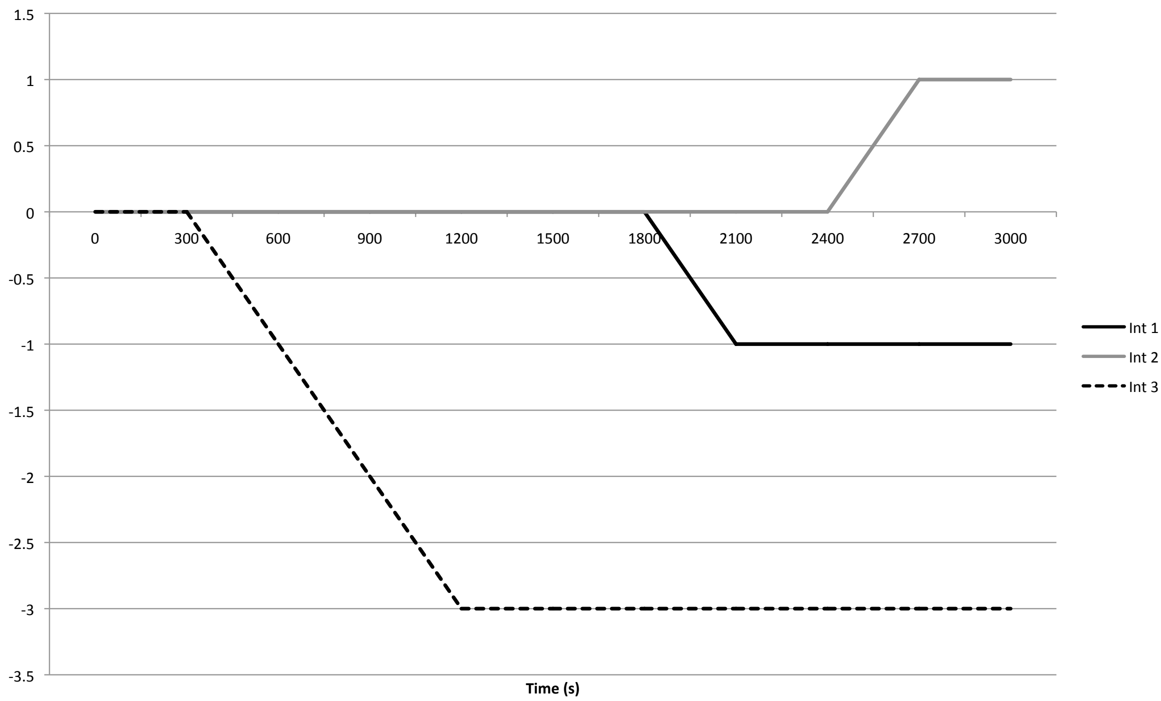

Figure 9.10: Qualitative assessment of participant contentedness over time

9.2.3 Stages 2 and 4 Analysis

Unlike the laboratory study (Chapter 8), only one team was used for the intermediary study. As such the results for Stages 2 and 4 contribute only a single data point each. Due to this, there is no possibility to perform an inter comparison of the results for the study outlined in this chapter. Therefore, as the primary purpose of this chapter is to assess the variance within the population, the results for Stages 2 and 4 are not presented here to avoid repetition. Instead they are presented in detail as part of the wider comparison described in Chapter 10.

9.3 Discussion

As in Chapter 8, this section considers two aspects – representativeness and spread of the results. As with the selection procedure described in Chapter 7, the selection of participants for the study outlined in this chapter produced a random, representative sample of the population of the SME. This assessment is supported by the similarity in the backgrounds of the participants used in this study when compared to Chapter 7. This is further supported by the results of the KAI and Torrance tests, which produced a mean for the participants within one standard deviation of the expected 50^{th} percentile figure. Finally, the three participants showed a spread of results within two standard deviations of the standardised mean. Based on these factors, it is possible to state that the selected population of practitioners is a representative sample of the population of the participating SME. Further to this, the participants conformed to the expected norms associated with both KAI and Torrance tests, as well as the background questionnaire and can, thus, be tentatively considered to be representative of a more general case within SMEs in the UK.

The next factor to consider is the spread of the results across the three participants. As with Chapter 8, it is apparent that although the participants varied, there were unambiguous trends, which were common across all the participants. This is highlighted by the figures, Figure 9.2, Figure 9.3 and Figure 9.4, which all emphasise the primacy of 'finding within source' and sources such as 'search engine', 'catalogue', 'technology article/blog', 'supplier article' and 'wikis'.

This is also supported by Figure 9.5, which shows the similarity in terms of both total usage and usage pattern for the four primary coded activities: information seeking, interpreting, finding source and finding within source. This is supported by the fact that each track can be modelled using a linear trend line which shows that the participants were tightly clustered, with similar slopes and R^2 values as well as small differences between the minimum and maximum values (Table 9.2). Although this similarity was less clear for the 'specific searching activities' detailed in Figure 9.6, there were again general trends that can be discerned as common, particularly for the activities: search engine and technology article/blog. This is supported by the similarity in the slope and R^2 values produced using linear trend lines and the small difference between maximums and minimums (Table 9.2).

Further to this, the analysis of the number of searches and search sources outlined in Figure 9.7 and Figure 9.8 shows a range of results amongst the participants. However, these results show less obvious trends with each participant favouring different primary sources. In this case, the coded activity 'search engine' is not included in the discussion as this was primarily used for finding sources rather than finding within source. As such a comparison of the three participants reveals not only different preferred sources, but also differences in the level of reliance on a single source as outlined in Table 9.3.

Finally, there was a wide range in the total number of searches being carried out (a difference of 46 searches between the highest and lowest). Finally, there is no clear trend associated with the participants' enthusiasm (Figure 9.9) or contentedness (Figure 9.10) during the study. Based on these findings it is possible to state that, although there was a clear spread in the results for the participants, there were also unambiguous trends suitable for the comparison of certain activities. However, as discussed in Chapter 7, these must be addressed on an activity-by-activity basis due to the variation in spread.

9.3.1 Reflection on the Core Method and Practical Issues

As with Chapter 8, the core empirical method has been adapted for this study by the introduction of an experimental task rather than free-form observation of practice. Further, as this study is an intermediary between the laboratory and practice based studies there were no practical issues beyond those already discussed in Chapters 7 or 8. However, it is important to note that the fact that the core method was adapted to the three contexts with no significant issues whilst maintaining the benefits of standardisation validates the core methods role as a method able to be adapted and added to for a range of research foci while retaining standard, comparable, elements.

9.4 Concluding Remarks

This chapter described the experimental study of practitioners in the intermediary setting. This was used to compare the internal similarity of the practitioner population. The data was then compared in detail in order to assess the spread of the results and to identify common trends.

Based on this analysis a number of coded activities were identified, which showed a close correlation across the population, including: information seeking, interpreting, finding source, finding within source, search engine and technology article/blog. However, a much wider spread in results was observed for the 'specific searching' activities including: catalogue, supplier article, forums and wikis. This indicates that although searching activities were fundamentally similar, the use of specific sources varied considerably across the population. This corresponds with the findings of Chapter 8 and suggests that the population used in this study is representative. This conclusion is further supported by the spread of background, KAI and Torrance results, which correspond to expected population norms.

Utilising the results of this study – and the studies outlined in Chapters 7 and 8 – it is possible to complete the three-point comparison laid out by the methodology (Chapter 4). As such, the next chapter develops the results from the three studies in order to characterise the relationships between the three contexts: practice, laboratory and intermediary. This three-point comparison will be used to identify differences between the studies and subsequently develop relationships between the contexts for each coded activity. These will then be used to establish general relationships between the contexts for key characteristics of the design situation such as the participant and setting.

"To be, rather than to seem to be."

Cicero

10

Characterising the Relationship Between Laboratory and Practice

The methodology presented in Chapter 4 laid out a three-stage approach for establishing relationships between practice and the laboratory – comparing studies in practice, laboratory and intermediary contexts. Subsequently, three studies have been undertaken. In order to effectively characterise the relationship between practice (Chapter 7) and the laboratory (Chapter 8) the intermediary study has been used to discriminate influencing factors and validate the findings from the other two studies. For example, where the intermediary result is aligned with the laboratory it is possible to determine that participant and setting are not influencing factors in any difference observed between the laboratory and practice. Further to this, the study of practice (Chapter 7) identified three critical design situations as the foundation for this comparison. This chapter is split into three parts, each presenting results for a critical design situation, identifying relationships and discussing the implications of these findings with respect to extant literature. Each section brings together the results of the three studies detailed in the previous chapters: Chapter 7 –

observational study in practice; Chapter 8 – experimental study in a laboratory context; and Chapter 9 – experimental study in an intermediary context. The differences between these three contexts are described in Table 5.2 and can be summarised as follows:

- Practice: Ethnographic fully embedded study of practice – in this case observational with no contrived elements.
- Laboratory: Experimental studies using students, in a custom environment with numerous contrived elements – in varying the task and environment.
- Intermediary: Experimental studies using practitioners, varying little from normal practice with few contrived elements – in this case varying task.

Sections 10.1, 10.2 and 10.3 bring together the three studies to examine each critical situation in turn – information seeking, ideation and review meeting. Each section presents the results using several complementary analysis approaches. As each section is based on a different critical situation, there is some variation in what is presented, summarised as follows:

Statistical Significance

As there are not sufficient data points to use statistical significance tests to determine differences between contexts, maximum and minimum values were used as a quantitative guide for the qualitative analysis. Throughout this chapter the convention of referring to a difference as significant has been adopted where values fall outside the maximum/minimum range found in the laboratory. This coupled with a comparison to the laboratory mean gives an indication of how closely related the two contexts are. However, before an overall comparison can be made, it is necessary to outline each situation. As such the next section details the results for the first design situation – information seeking.

10.1 Design Situation 1: Information Seeking

This section explores the critical design situation ‘information seeking’. As this is a comparison of the three studies, the following abbreviations are used for brevity in figures: *lab* denotes the laboratory context; *int* denotes the intermediary context; and *practice* denotes the practice context. These terms are used throughout the chapter for figures and tables.

10.1.1 Results

As with the inter-participant comparisons outlined in Chapters 8 and 9 the results detailed here will follow the form: focus of activity, activity over time, situation specific activity and participant enthusiasm and contentedness.

Figure 10.1 shows the duration of each coded activity for the three studies as a percentage of the total situation time. This highlights several important features of the participants’ searching activity. Firstly, it was possible to examine the variation in the amount of ‘seeking information’ compared to ‘interpreting’ for the three different contexts. In the case of ‘seeking information’, all three contexts fell within the range seen in the laboratory. Specifically, the laboratory minimum was found to be 26% compared to the observed value for practice of 41%, which was closer to the intermediary (57%) and laboratory (60%) means. However, a larger difference was observed for ‘interpreting’, where the practice value (6%) fell bellow the minimum value observed in the laboratory (13%) and was significantly lower than the mean values for the intermediary (32%) or laboratory (40%) contexts. Secondly, Figure 10.1 emphasises the primacy of ‘catalogues’ as the main source for information in all three contexts. For example the minimum usage of ‘catalogues’ was in the intermediary context (15%), which was still significantly greater than any other individual source and was large even in comparison to the sum of the other eight sources (28%). Finally, the figure shows the difference between ‘finding source’ and ‘finding within source’ averaging 15% and 41% of participants’ time respectively – a ratio very similar to that seen in the laboratory context (22% and 49%). An example of the discriminatory role of the intermediary results can be seen in ‘interpreting’ –

here the laboratory and intermediary results are aligned while practice is lower. As such, we can conclude that this difference is unlikely to be caused by changes in the participants or the setting and thus, must be attributed to other factors such as how embedded the designer is within the design process.

Figure 10.2 shows the results for the number of instances of each coded activity. This again highlights the difference in level of activity associated with 'interpreting' across the three contexts. Specifically, 'interpreting' accounted for 2% of the instances in practice, in comparison to the laboratory (13%) and intermediary (11%) settings. Further to this, Figure 10.2 also emphasises the importance of 'catalogues' as an information source. This was particularly evident in practice where 'catalogues' (12%) account for more instances than the other sources combined (10%). Finally, a similarity between the three contexts was highlighted by the fact that the results for both 'finding source' and 'finding within source' were tightly clustered about the laboratory mean with a spread of 2.3 and 2.5% respectively

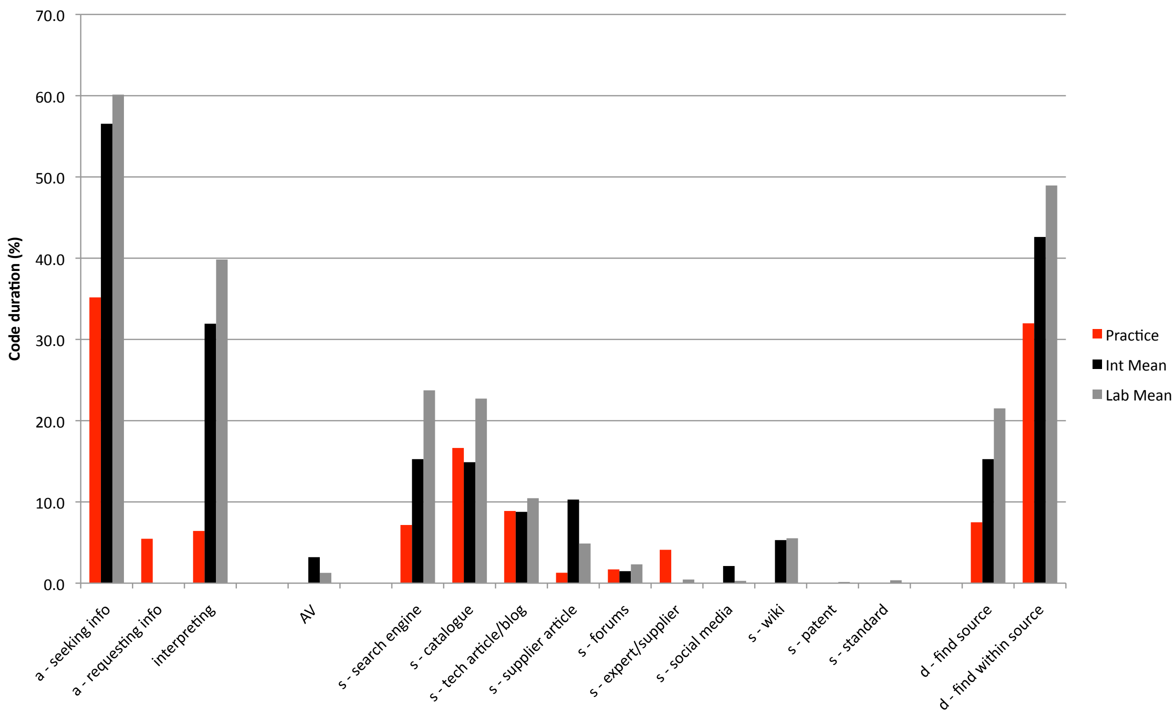

Figure 10.1: Coded activity duration as a percentage of the total situation time

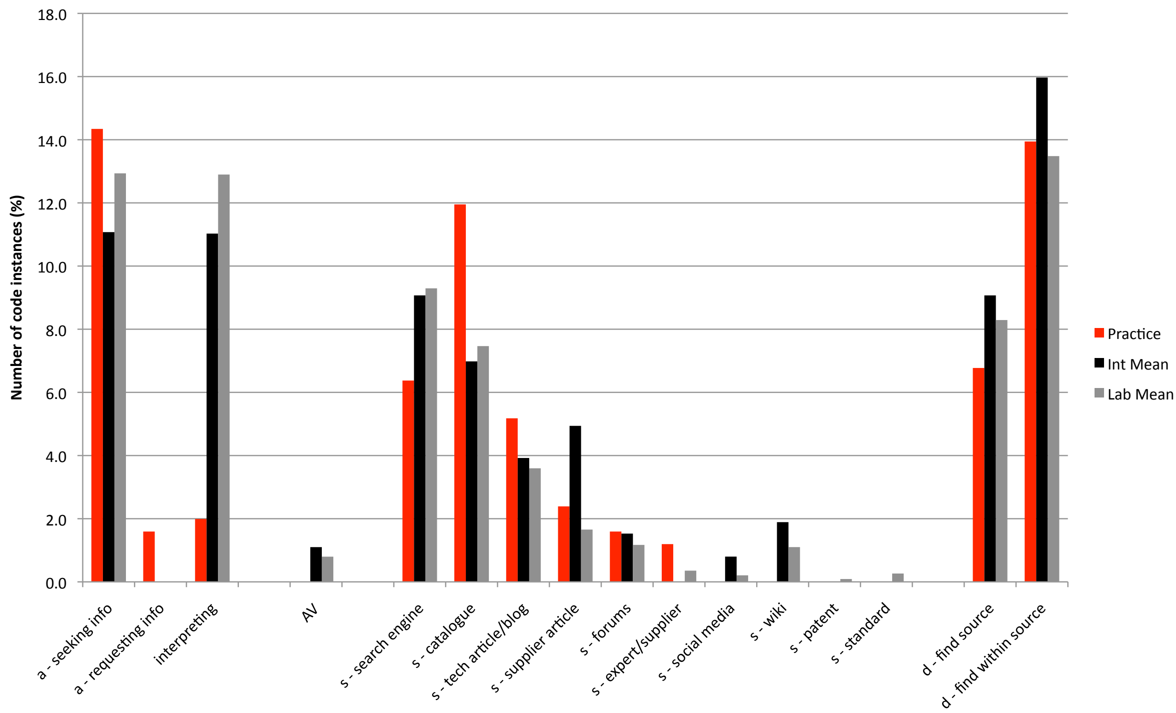

Figure 10.2: № of instances of coded activity as a percentage of the situation total

Figure 10.3 shows the results for the mean time per instance. This gives an indication of how the participants were using each source – either for quick queries or for extended searching or evaluation. From this figure it is evident that, other than in a very small number of cases, the average time spent on a source is short. Specifically, only six of the searching activities ('search engine' – 'finding within source') had an average duration longer than 50 seconds and 79% of the coded search activities average less than 50 seconds. Figure 10.3 also highlights one outlier of note – practice-based participants put more emphasis on 'requesting information' (averaging 90 seconds per instance) compared to the laboratory or intermediary context where this code was not present.

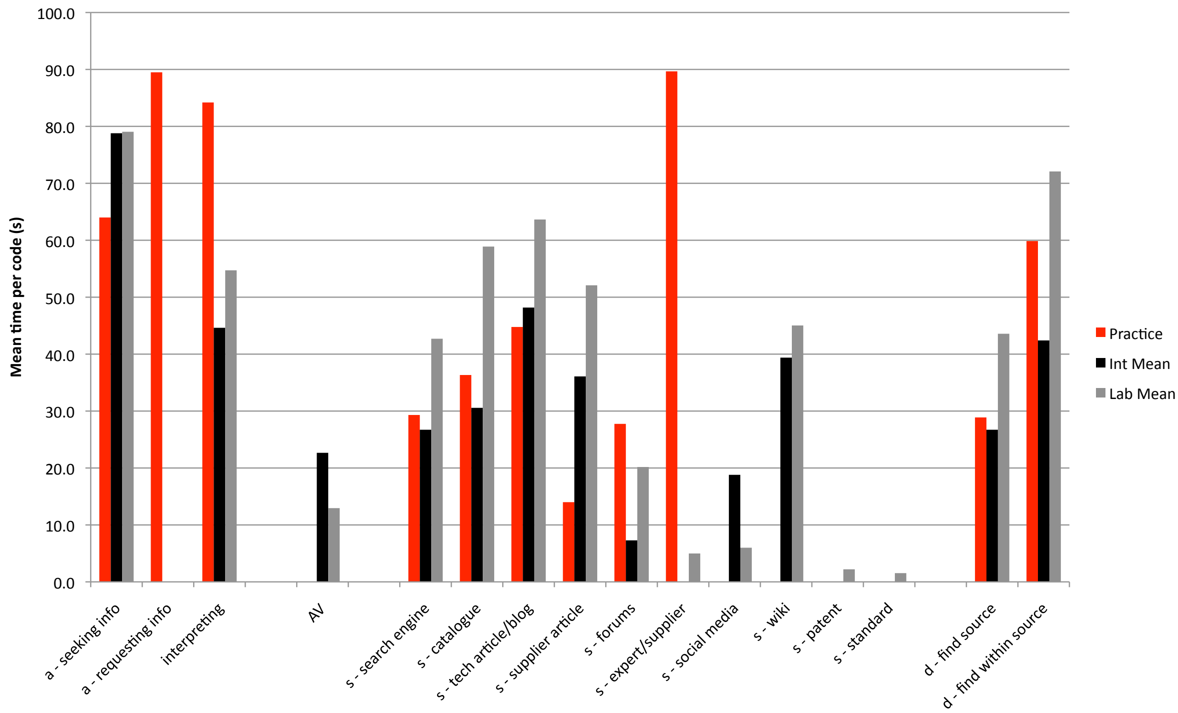

Figure 10.3: Mean time per instance

Figure 10.4 shows the spread of the major codes over time: information seeking, interpreting, finding source and finding within source. Each of these graphs depicts practice, the three intermediary participants and the maximum, minimum and mean laboratory results. These have been calculated from the full set of laboratory participants. As in Chapters 8 and 9, the axes used to depict changes over time are both 'time as a percentage of the total situation time'.

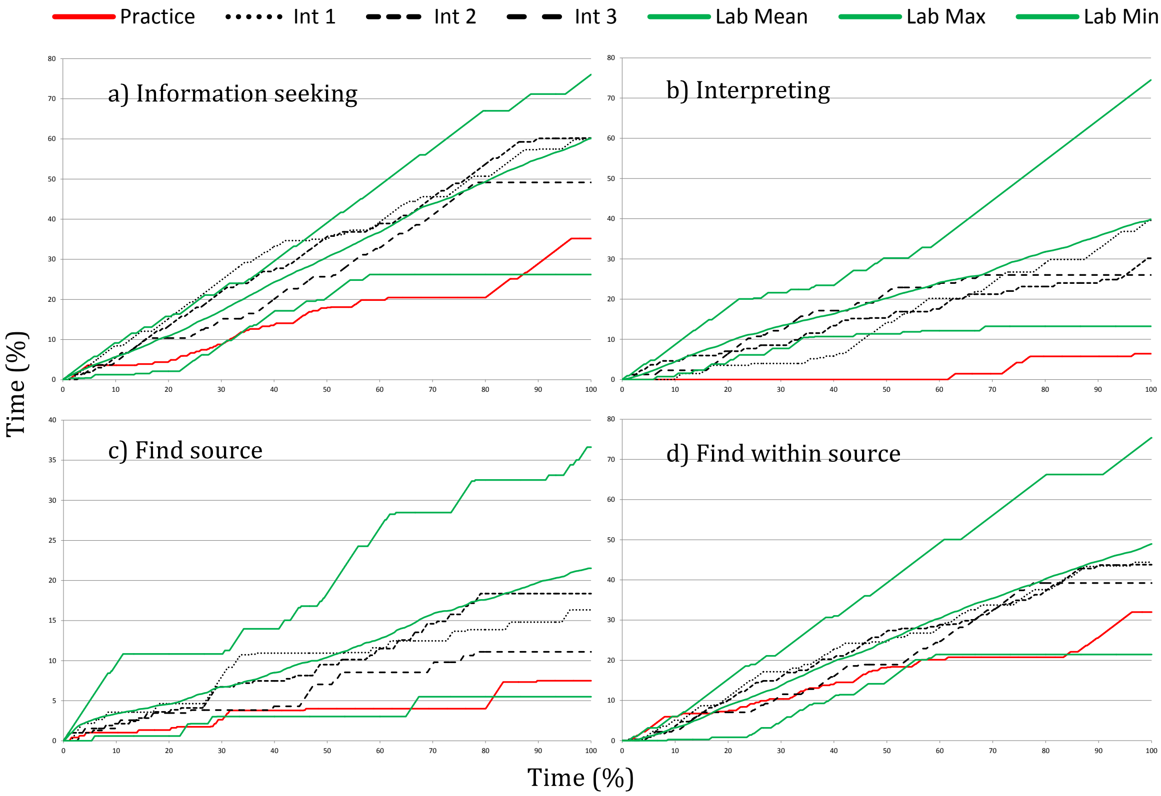

Figure 10.4: Cumulative time as a percentage of the total situation time for the high level activities

Figure 10.4 primarily serves to support the findings drawn from Figure 10.1, i.e. activity is similar across contexts and falls within the maximum/minimum range of the laboratory results. Indeed, for all the coded activities, other than 'interpreting' (where the maximum difference was 33%), the intermediary and practice results were consistently less than 25% from the laboratory mean (information seeking = 25%; finding source = 15%; and finding within source = 17%). However, one major difference is highlighted in this figure – the way in which the practice-based participant split their time between 'information seeking' and 'interpreting'. Unlike in the intermediary or laboratory contexts, where these activities essentially occurred in parallel (i.e. there was a continuous slope for both coded activities), the practice-based participant completely stopped searching for information after 60% of the situation, at which point they exclusively interpreted for a further 20% before returning to searching.

Figure 10.5 shows the participant activity over time for the specific searching activities: search engine, catalogue, technology article/blog, supplier article, forums and wikis. This again emphasises the similarity in activity across the three contexts with the results for the practice and intermediary contexts falling within the range of the laboratory results. As in Figure 10.4, the practice/intermediary results are generally close to the laboratory mean with a maximum difference of 19% for 'catalogues' and a minimum difference of 2% for 'forums' (search engine = 17%; technology article/blog = 3%; supplier article = 13%; and wikis = 6%)

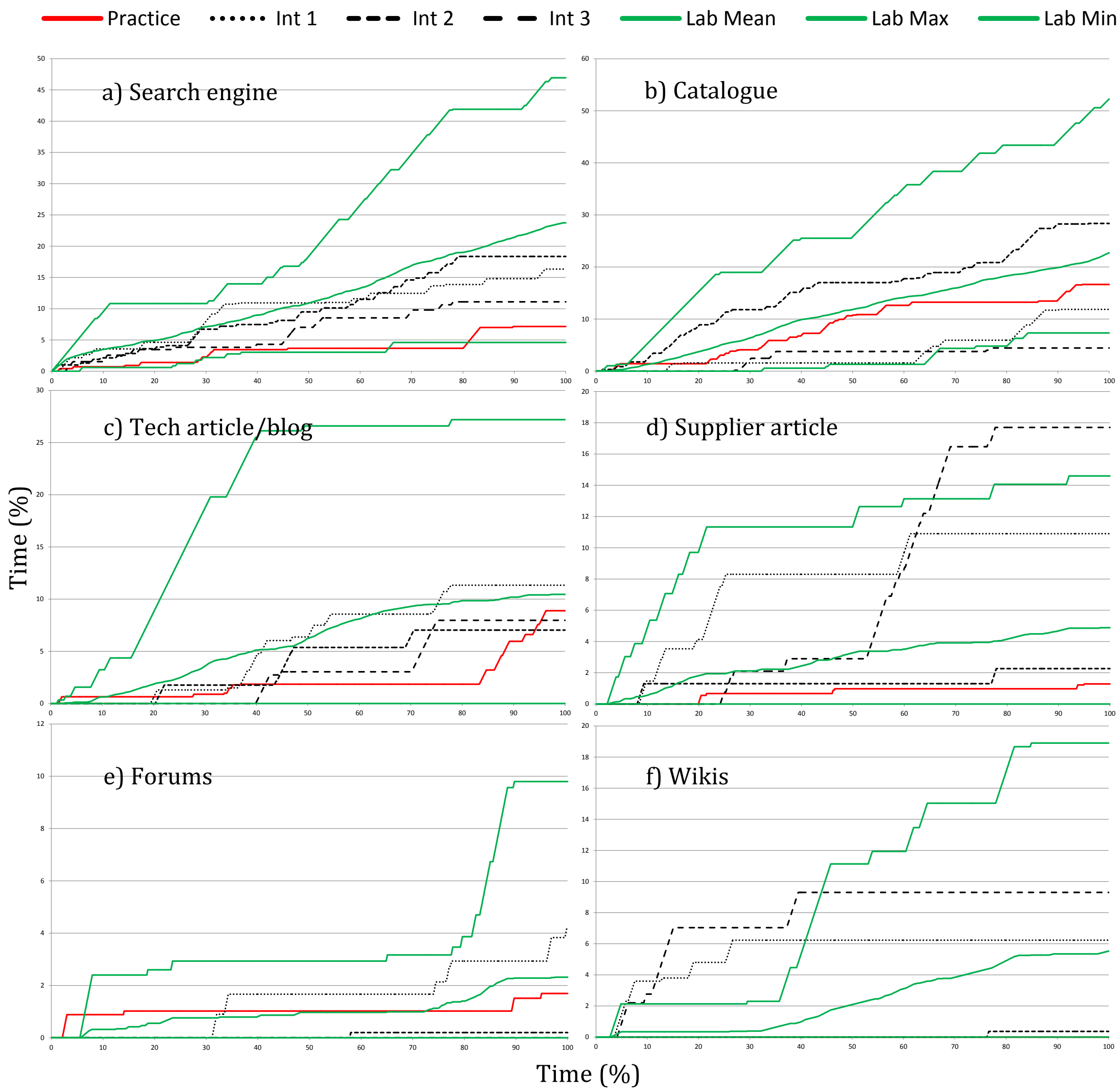

Figure 10.5: Cumulative time as a percentage of the total situation time for specific searching activities

Figure 10.6 highlights the fact that, although there is a spread of results across the contexts, both the total number of searches and the number of sources used fall within the maximum/minimum range of the laboratory results (74/18 and 8/3 respectively) in all but one case (*int 2* has a total number of searches of 80 compared to the laboratory maximum of 74). The similarity between contexts is particularly clear in the number of sources used, with the intermediary/practice participants averaging six sources – the same as the laboratory mean. This similarity was less clear in the total number of searches carried out, with the practice/intermediary mean (62) being larger than the laboratory mean (48).

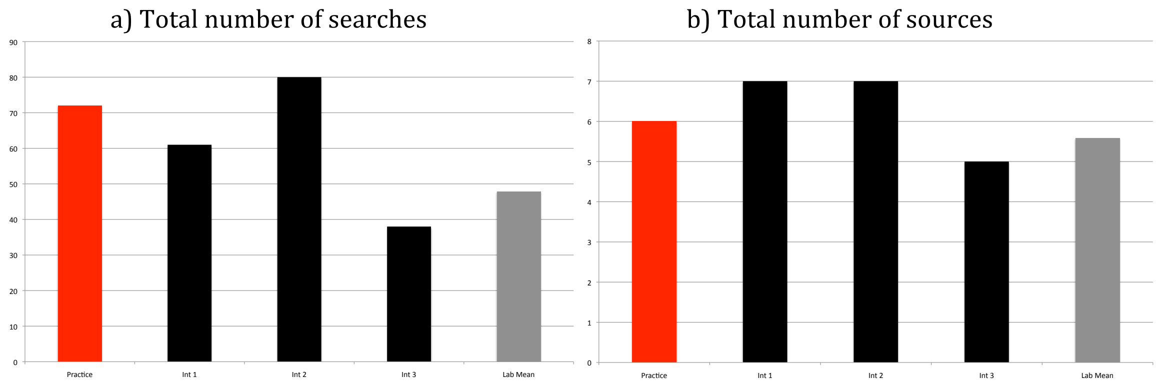

Figure 10.6: The number of searches and sources used by participants during the situation

Finally, Figure 10.7 and Figure 10.8 detail the qualitative assessment of the participants' enthusiasm and contentedness over time. Mean values were used for the laboratory and intermediary contexts in order to compare general trends. In the case of this situation, the practice-based period of comparison was twice as long as the intermediary or laboratory based situations as these were shortened to allow effective experimental design. As such, the practice line in Figure 10.7 and Figure 10.8 is twice as long as the line for the intermediary or laboratory contexts.

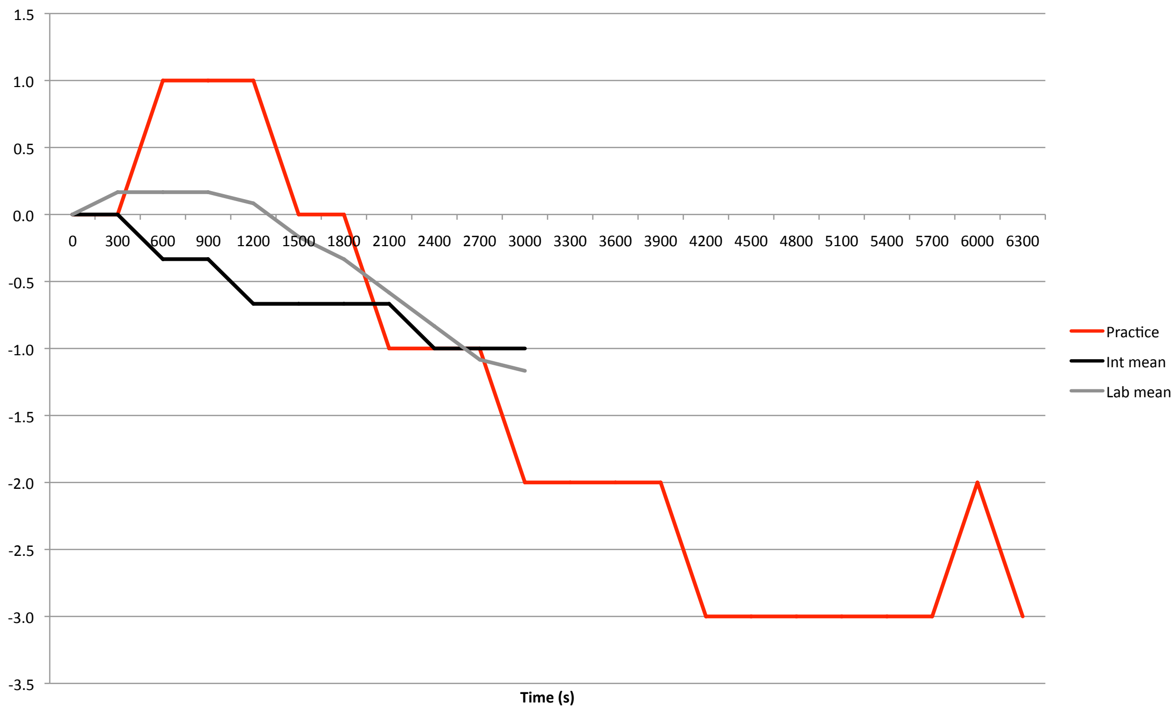

Figure 10.7: Qualitative assessment of participant enthusiasm during the situation

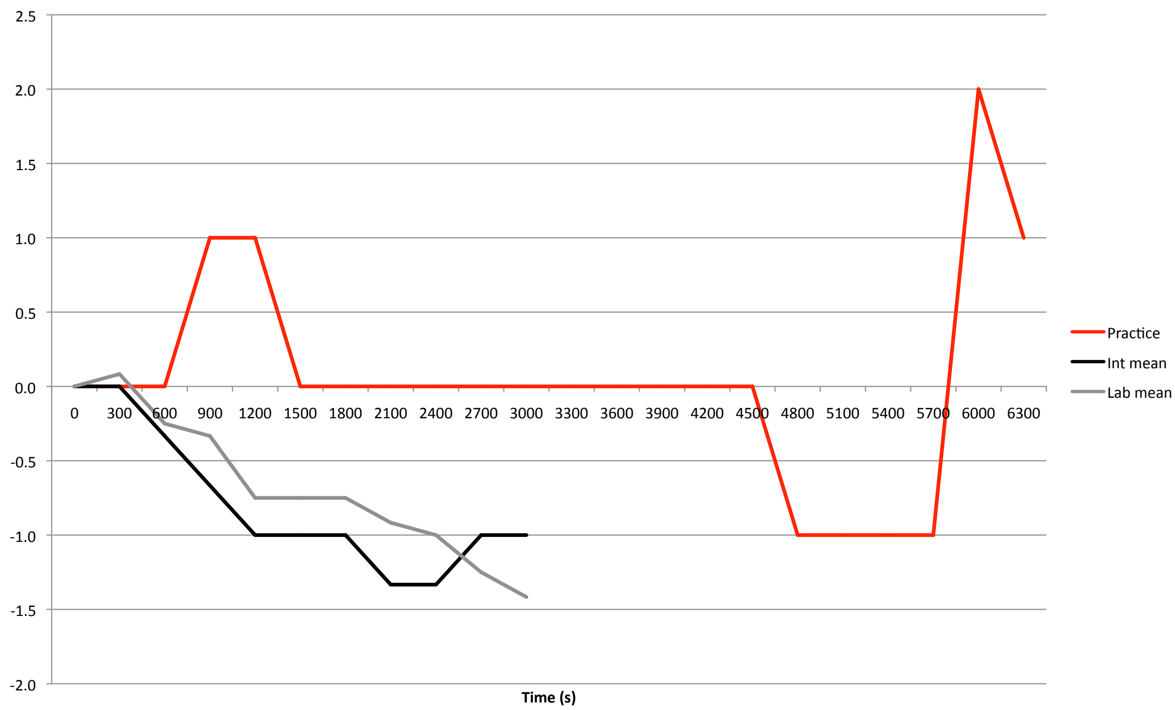

Figure 10.8: Qualitative assessment of participant contentedness during the situation

10.1.2 Characterising the Relationship

Examining each form of analysis in turn (focus of activity, activity over time, situation specific activity and participant enthusiasm and contentedness), it is possible to build up a detailed picture of the relationship between practice and the laboratory for the critical design situation – information seeking.

Firstly, it is possible to assess the focus of the participants' activity using: total duration of coded activity, total number of instances and average time per instance. In terms of total duration of coded activity, as a percentage of the total situation time, practice is consistently less than the laboratory mean (Figure 10.1). Taken as a whole, the practice-based activities average 7.3%, less than the laboratory mean for each activity. This difference can be attributed to the wider scope of activities undertaken in practice and the fact that a much larger proportion of the practitioners' time can be accounted for in breaks, conversations with colleagues and miscellaneous administrative tasks as highlighted in Chapter 7. This is further supported by the fact that the intermediary study showed results closely matching those from the laboratory – averaging just 2.2% less than the laboratory mean. Unlike 'total duration' there do not appear to be any clear trends across contexts associated with 'total number of instances' or 'average time per instance'. In both cases, practice, intermediary and laboratory settings are not consistently ordered (Figure 10.2 and Figure 10.3). In addition, the results for the intermediary and practice settings fall within the range of values found in the laboratory in all but a few exceptional cases. Although these cases may at first appear to pose a threat to establishing a relationship, they actually highlight a key finding. The coded activities 'requesting information' and 'expert/supplier' (5.5% and 4.1% of situation duration respectively) play a more important role in practice in comparison to the laboratory or intermediary settings where they are not present. This can be explained by the fact that as practice operates over longer timescales, a far larger emphasis is placed on interpersonal communication and asynchronous information requests, where instant responses are not required. As such, this forms a critical relationship between, discreet laboratory based studies and practice.

The second form of analysis to be considered is the participants' activity over time. The first group of coded activities to be assessed are 'information seeking', 'interpreting', 'finding source' and 'finding within source' (Figure 10.4). For all of these activities the intermediary results are clustered around the laboratory mean indicating little inherent difference due to the participant. The average difference between the laboratory mean and practice across these four coded activities is 22% with a maximum of 33% ('interpreting') and a minimum of 14% ('finding source'). This suggests that, although there may be differences due to factors other than the participant such as task or setting, they are not likely to be significant, unless specifically investigated using a sufficiently large sample as to allow for individual participant variability. In contrast, there is a much lower level of variation in the results for the specific searching activities (Figure 10.5). For these coded activities, comparison between the three settings shows that the average difference between the laboratory mean and practice is 10% with a maximum of 19% and a minimum of 2%. Based on this, it is unlikely that searching behaviour over time is dependant on setting, instead it appears to be much more dependant on personal factors such as searching strategy or preference in sources.

The third form of analysis was 'the total number of searches' and 'the number of sources used' (Figure 10.6). As with the participants' activity over time, although there is variation across contexts, there is no clear trending or significant separation between the three settings. The presented results show that the individual participants in the practice and intermediary contexts are closely aligned to the average laboratory result and fall within the laboratory range. This again indicates that the number of sources used and the number of searches completed is related to each individual's searching strategy rather than external factors such as setting or task. It is surprising that, although the intermediary and practice based participants were considerably more experienced than the students, their searching activity did not differ significantly. This shows that they do not spread their searching further or have a discernable experience based advantage, i.e. using a smaller number of more directed searches based on past projects.

The final comparative analysis used enthusiasm and contentedness (Figure 10.7 and Figure 10.8). Although these do appear to show some similarities – particularly in the downward trend in enthusiasm – it is clear that swings in contentedness and enthusiasm are more pronounced in practice. This can again be attributed to the much larger scope of activity and the fact that coffee breaks or interruptions by colleagues are common features of practice-based working in contrast to the laboratory or intermediary contexts. It should be noted that, despite this much wider variation in enthusiasm and contentedness, there does not appear to be any correlation between these factors and the other coded activities.

10.1.3 Discussion

Three core findings emerged from the analysis of activities and behaviours in the design situation 'information seeking'. These are:

Finding 1: Participants in practice spend an average of 7% less time on each information seeking activity (seeking, interpreting and sources) due to the wider scope of activities undertaken. Specifically, less time is spent on activities such as 'information seeking' and a number of additional activities are undertaken such as informal meetings, sending e-mail and having breaks.

Finding 2: There are significantly more information requests and other asynchronous, longitudinal activities due to the embedded nature of practice in comparison to the other contexts. The practice based participant spent 5% of their time requesting information via, for example, supplier contact forms. This leads to an embedded scenario where information seeking generates requests, which will be fulfilled at a later time, not necessarily during the same information seeking activity.

Finding 3: Little difference in searching behaviour is observed as a result of setting or task – being more dependant on individual factors e.g. search strategy, source preferences or past experience. Specifically, no significant differences are observed for the activities 'number of searches' or 'number of sources' while 'finding source' and 'finding within source' are within the range of the laboratory results.

Validation

In order to explore the generalizability and, hence the, validity of the relationships outlined in this section, a number of literature sources are examined, each detailing the information seeking behaviour of practitioners in various contexts. Firstly, the overall level of information seeking is considered. To reiterate, the practice-based study found that approximately 45% of participant's time related to the identified information seeking behaviours. This fell within the range identified by King et al. (1994) (40% - 60%) in their review of engineers information needs. This is supported by the more recent findings of Robinson (2010) (55.75%) who examineed the 'information behaviours' of practitioners in a larger industrial context. Further to this, the 45% identified in this study is significantly larger than older studies such as Cave and Noble (1986) (30%) or Puttre (1991) (32%). Thus, although the figure of 45% is lower than that of Robinson, it correlates with the increasing importance of information handling activities. Further to this, all of these studies (King et al., Robinson, Cave and Noble, and Puttre) highlight the variability in searching behaviour and wide scope of activities undertaken by practitioners. These two factors combine to support the first finding in this study, suggesting that practitioners are less focused in their information activities than laboratory-based participants.

Secondly, the work of Robinson (2010) supports the embedded nature of practice and the much higher level of reliance on interpersonal as well as email and other asynchronous information sources. For example, Robinson found that approximately 9% of practitioners' time is spent locating information within source where the source is other people. This, as well as the embedded nature of activities within the design process, supports the second finding that there are significantly more information requests and other asynchronous or longitudinal activities due to the embedded nature of practice in comparison to other contexts (Hales 1991).

Thirdly, in order to validate the variability in information seeking behaviour, it is necessary to consider the information sources and validate the primacy of Internet based searching. Allard et al. (2009) highlight Internet based information as the second most prevalent 'information activity'. However, Allard et al.'s definition of 'information activity' includes input as well as output and thus finds the primary activity to involve software such as word processing or computer aided design. Discarding this factor, Allard et al.'s findings support the results of this study; namely, that the Internet is the primary source for information seeking activities. Further to this, the work of Keller et al. (2007) supports the characterisation of many of the observed Internet activities. In particular they highlighted the importance and complexity (as observed in these studies) of information seeking or 'information gathering' tasks in the context of computer science students. This is also supported by Holscher and Strube (2000) who emphasize the interplay between browsing and search engine activities – linking to the results for 'finding source' and 'finding within source'. Finally, the ratio between these two core codes also relates to the findings of Robinson (2010) (Robinson = 1.6; average of practice, intermediary and laboratory results = 3.1), supporting the robustness of Finding 3 across contexts.

Summary

In summary, although direct validation is not possible, all the identified sources correlate with the findings outlined in this section. Based on this, it is possible to develop the findings into a framework relating the laboratory to practice for each of the main coded activities. This is outlined in Table 10.1, which notes areas of difference between laboratory and practice; with respect to practice, i.e. 'more' represents, for example, a longer duration in practice. The differences highlighted in this table have been determined as significant if they fall outside the interpersonal variation seen in the laboratory. In addition, 'Not Applicable (N.A.)' denotes those coded activities not analysed using the stated focus, e.g. enthusiasm was not analysed using 'total duration'. The various areas are shaded for clarity:

- Greater in practice – example.
- No significant difference – example.
- Less in practice – example.

Although Table 10.1 outlines the major differences between the contexts for each coded activity, it does not relate these to the characteristics of the design situation and, as such, gives little insight into how these characteristics affect designer behaviour and activity. This is critical to developing a robust relationship between the contexts for specific situations. As such, Table 10.2 develops these differences and links them to the underlying characteristics.

Table 10.1: Differences between contexts by activity

Code	Focus of analysis				
	Duration	Instances	Time per instance	Activity over time	Situation specific
Seeking information	no sig. dif.	no sig. dif.	no sig. dif.	less, dif. structure	no sig. dif.
Requesting information	more	more	more	N.A.	N.A.
Interpreting	less	less	no sig. dif.	less, dif. structure	N.A.
Search engine	no sig. dif.	no sig. dif.	no sig. dif.	no sig. dif.	N.A.
Catalogue	no sig. dif.	no sig. dif.	no sig. dif.	no sig. dif.	N.A.
Technology article/blog	no sig. dif.	no sig. dif.	no sig. dif.	no sig. dif.	N.A.
Supplier article	no sig. dif.	no sig. dif.	no sig. dif.	no sig. dif.	N.A.
Forums	no sig. dif.	no sig. dif.	no sig. dif.	no sig. dif.	N.A.
Expert/supplier	more	more	more	N.A.	N.A.
Social media	no sig. dif.	no sig. dif.	no sig. dif.	N.A.	N.A.
Wiki	no sig. dif.	no sig. dif.	no sig. dif.	no sig. dif.	N.A.
Patent	no sig. dif.	no sig. dif.	no sig. dif.	N.A.	N.A.
Standard	no sig. dif.	no sig. dif.	no sig. dif.	N.A.	N.A.
Finding source	no sig. dif.	no sig. dif.	no sig. dif.	N.A.	N.A.
Finding within source	no sig. dif.	no sig. dif.	no sig. dif.	N.A.	N.A.
Enthusiasm	N.A.	N.A.	N.A.	larger range	N.A.
Contentedness	N.A.	N.A.	N.A.	larger range	N.A.

Table 10.2 is based on characteristics of the design situations, which were mentioned previously in this chapter and others (Chapters 1, 2 and 5). The table shows how each characteristic changes across contexts and what effect this change has, based on the comparison of the three studies outlined in this section. The table highlights where the similarities are between contexts (shaded gray) in order to show how each characteristic was isolated using the three studies. Characteristics are also colour coded to denote the nature of the identified relationship:

- Green – there are no significant differences between laboratory and practice for this characteristic.
- Orange – There are significant differences between laboratory and practice. The nature of these differences is detailed in the final column.
- Black – This characteristic was not applicable for comparison, as it did not change between contexts, e.g. team size in the first critical design situation.

In addition Table 10.2 highlights where each characteristic is described more fully.

Table 10.2: The relationship between practice and the laboratory for information seeking

Characteristic of design situation	Comparison			Relationship: Practice to Laboratory
	Practice	Intermediary	Laboratory	
Team size	1			Not applicable for comparison purposes because there only one participant was used in each situation
Setting (inc. environment, social, cultural and historical)	Practice (Figure 6.2)		Laboratory (Figure 8.2)	Results from practice were within the range of variation see in the laboratory, therefore no significant differences were identified
Task (Table 8.2)	Electronic component	Flexible camera mount		Results from practice were within the range of variation see in the laboratory, therefore no significant differences were identified
Level of constraint	Much greater flexibility in activity and source	Limited to experimental constraints		Practice showed shorter overall code duration as a percentage of total time as well as an increased level of emotional variation
Stage of the design process	Early feasibility			Not applicable for comparison purposes because all the situations were set in the early feasibility stage of the design process
Embeddedness in the design process	Fully embedded within the wider design process	Activity only feeds into stages 2, 3 and 4 with no prior work		Significantly more use of asynchronous information sources and less focused activity – see 'Level of constraint'
Participant (inc. experience, age, education and sociometic)	Representative of practitioners (Section 7.1)		Representative of students (Section 8.1)	Results from practice were within the range of variation see in the laboratory, therefore no significant differences were identified

10.2 Design Situation 2: Ideation

This section explores the critical design situation 'ideation' and follows the same format as Section 10.1. As such, the section starts with results before identifying relationships and discussing the validity of the findings.

10.2.1 Results

Figure 10.9 highlights two main areas where there are differences between the contexts. Firstly, both the intermediary (38%) and practice (38%) results show significantly less 'exploring' activity than the laboratory mean (56%), falling bellow the minimum laboratory value of 44%. This suggests that practitioners spend less time exploring, possibly because they are more focused in this activity. Secondly, the coded activities 'recognising need', 'informing' and confirming' all account for significantly less time in practice compared to the laboratory or intermediary results (Table 10.3).

Table 10.3: Differences in duration between contexts for selected activities

Context	**Duration of coded activity (%)**		
	Recognising need	Informing	Confirming
Laboratory mean (Minimum)	8 (6)	42 (39)	13 (10)
Intermediary	9	36	13
Practice	0	3	0

Figure 10.10 also highlights the lack of 'recognising need', 'requesting information', 'informing' and 'confirming' in practice. In addition, Figure 10.10 emphasises the lack of 'goal setting', which, despite its duration only accounted for 0.7% of instances. This implies that all 'goal setting' activity occurred in a small number of instances, different to the laboratory or intermediary contexts, where it accounted for 4% and 5% of instances respectively. The other coded activity, where practice exceeded the range of laboratory results is that of 'solidarity' possibly implying that the practice-based team were more supportive than the artificially formed teams.

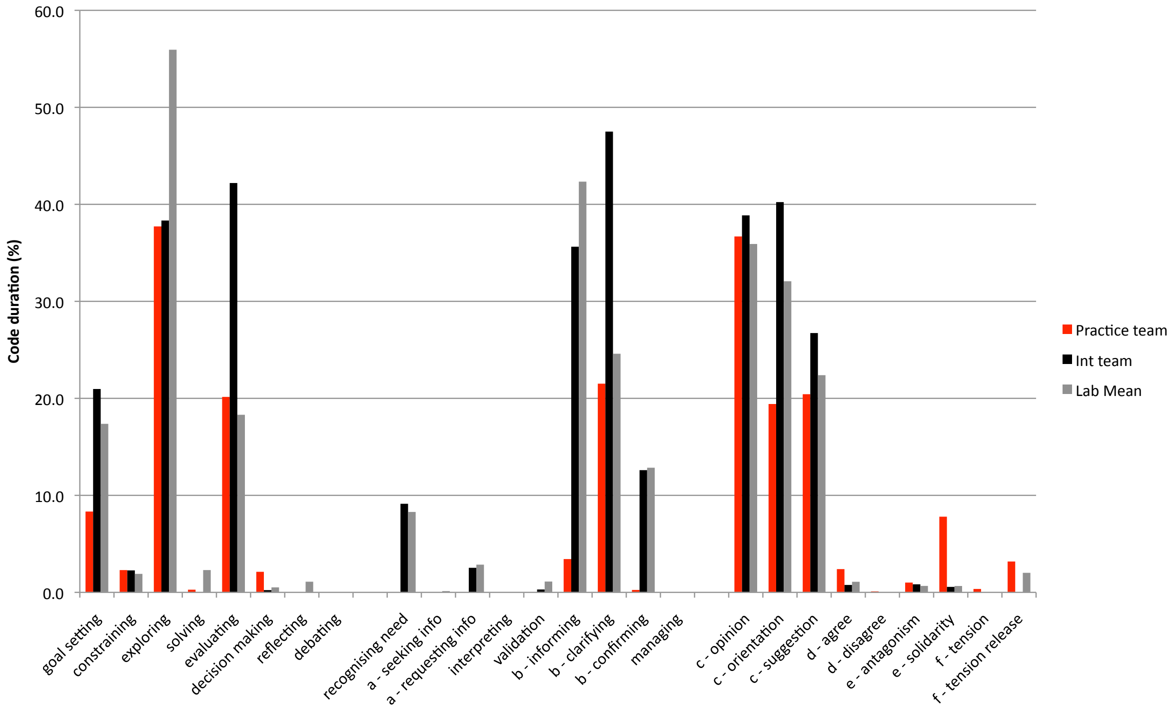

Figure 10.9: Coded activity duration as a percentage of the total situation time

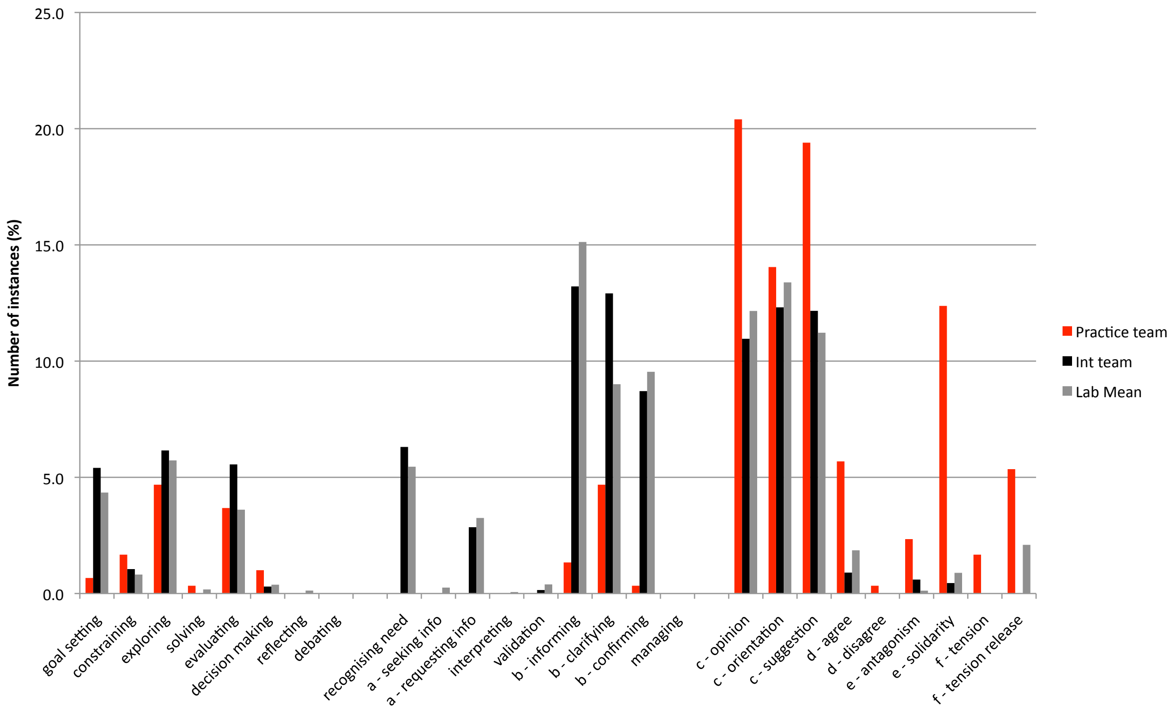

Figure 10.10: № of instances of coded activity as a percentage of the situation total

Figure 10.11 highlights the conversational nature of the task, with only 23% of the coded activities lasting longer on average than 20 seconds. Of particular note are the significantly longer 'goal setting' activities in practice (165 seconds versus a laboratory maximum of 28 seconds). This supports the findings outlined in Figure 10.9 and Figure 10.10 that goal setting took place in a small number of long instances rather than the large number of shorter activities encountered in the laboratory and intermediary contexts. In addition, both 'evaluating' and 'clarifying' lasted longer on average than the laboratory maximum (73 v. 32 seconds and 61 v. 19 seconds respectively). These features imply that the practice-based participants were more focused – spending more time per idea on evaluation and possibly with clearer leadership leading to longer more directed clarification activities.

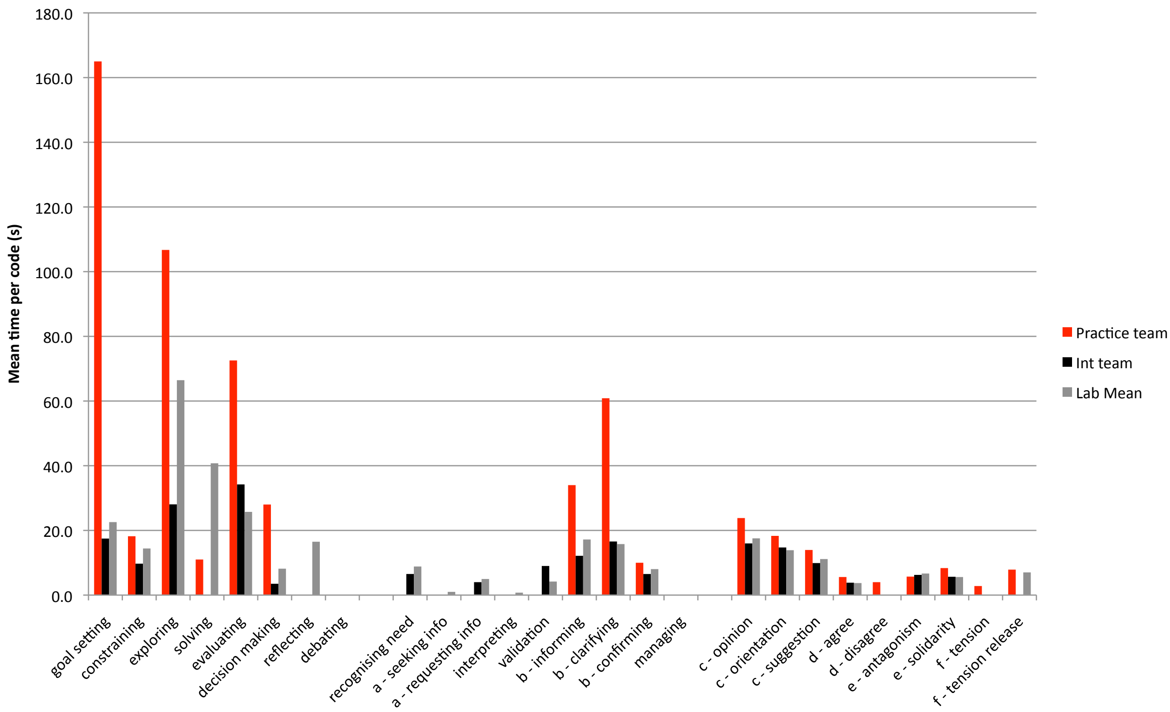

Figure 10.11: Mean time per instance

Examining the coded activities in more detail, Figure 10.12 shows the various teams' activity over time for: goal setting, constraining, exploring and evaluating. Of particular note is the difference in the structure of 'goal setting' in practice. This activity shows a single distinct event at the start of the situation where all the goal setting takes place in comparison to the other settings which showed a linear relationship, increasing throughout the situation (trend line for the laboratory mean: slope = 0.20, R^2 = 0.97; trend line for the intermediary team: slope = 0.23, R^2 = 0.91). This elaborates and partially explains the findings outlined in Figure 10.9, Figure 10.10 and Figure 10.11. The structure suggests that a single briefing was given based on prior 'goal setting' and 'recognising need' activities in comparison to the laboratory studies, where these activities, by necessity, took place during the situation. No significant differences are apparent for the other coded activities with the practice values consistently falling within the range of the laboratory results over time.

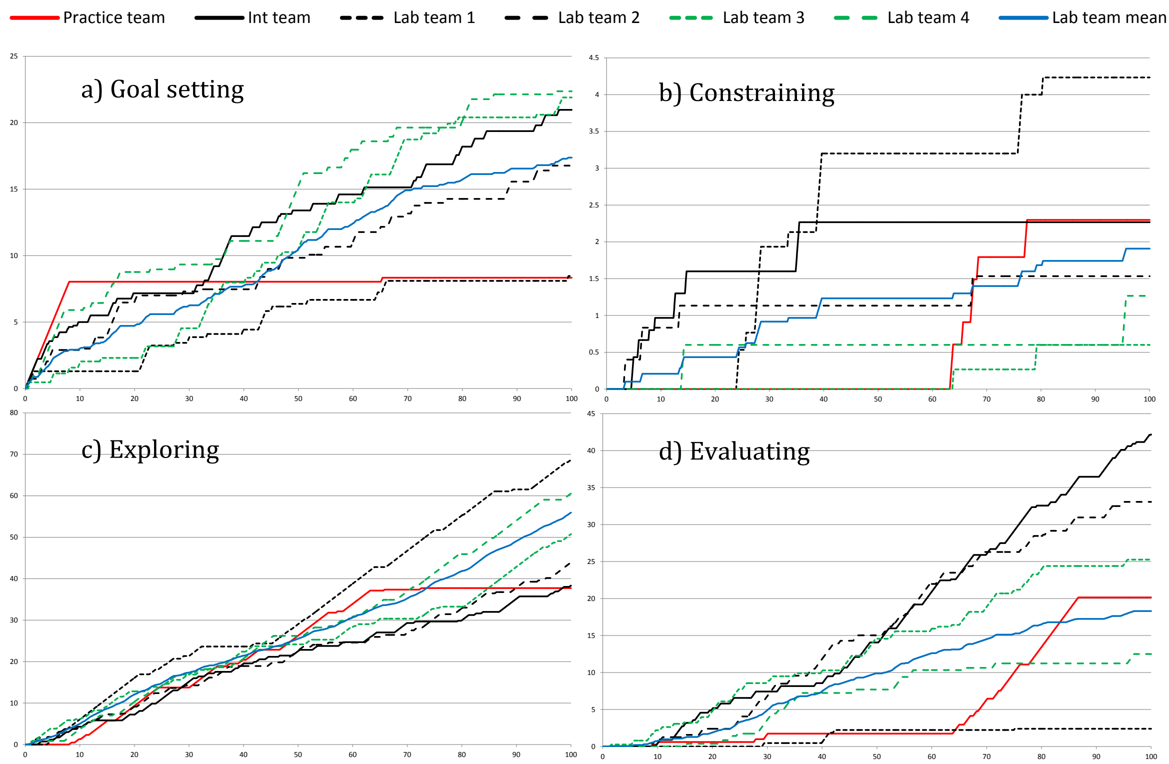

Figure 10.12: Cumulative time as a percentage of the total situation time for high level activities

Further to Figure 10.12, Figure 10.13 shows the activity over time for the coded activities dealing with team interaction: recognising need, informing, clarifying, confirming, opinion, orientation and suggestion. The results for 'recognising need', 'informing' and 'clarifying' support the scenario implied by Figure 10.12 with no 'recognising need' activity taking place during the situation and a short 'informing' period followed by a 'clarification' carried out at the start with no further discussion of goal. However, despite this clear difference, the three contexts show a high degree of similarity in their conversational structure with 'opinion', 'orientation' and 'suggestion' showing similar trends across contexts.

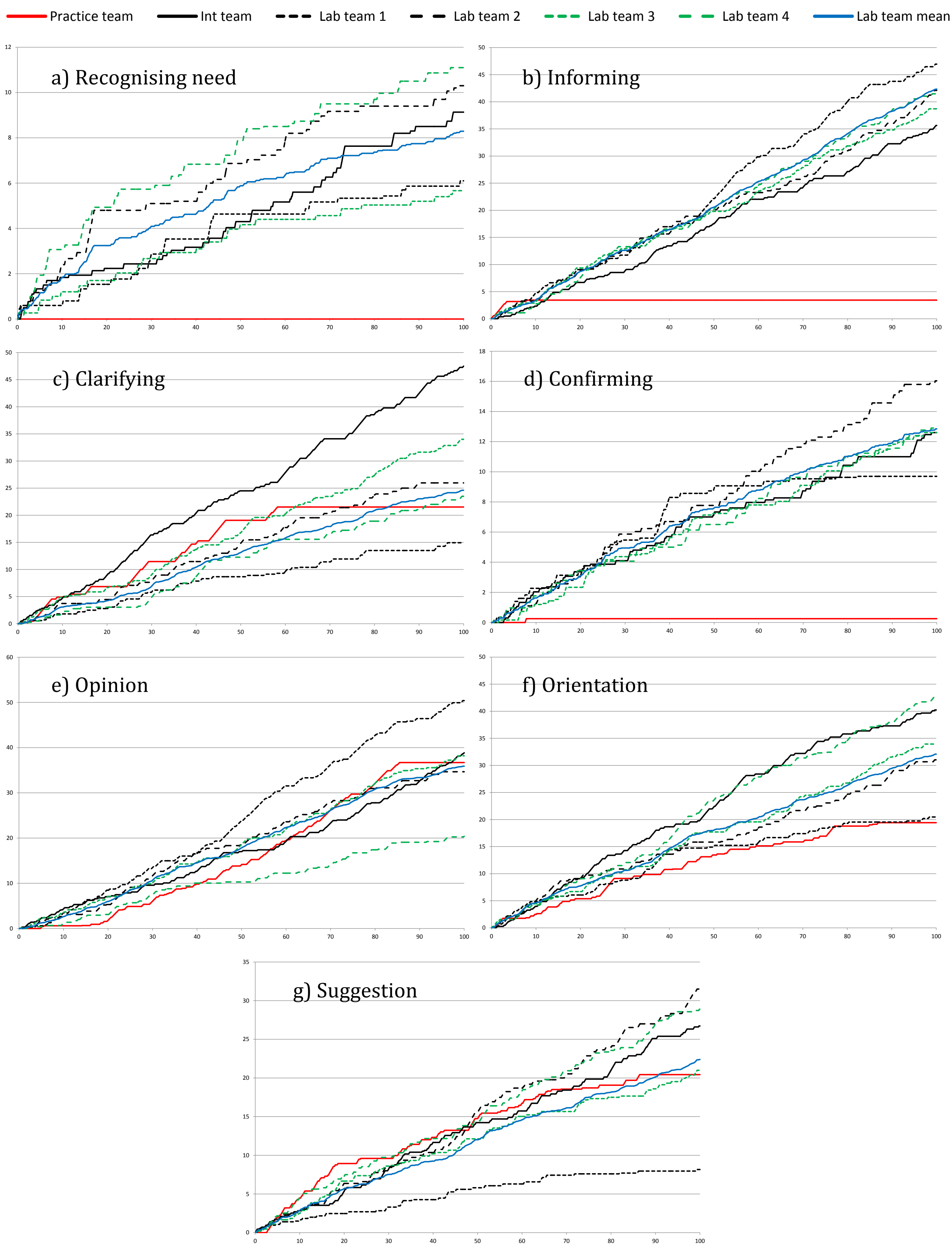

Figure 10.13: Cumulative time as a percentage of the total situation time for specific activities

Table 10.4 gives the data for linear trend lines used to approximate the results from the three contexts in order to support this comparison. The fact that all R^2 values exceed 0.8 suggests that all three contexts can be approximated effectively using a linear trend, while the similarity in slope indicates that the contexts are comparable.

Table 10.4: Trend line data for conversation activities over time

Context	**Duration of coded activity (slope/R^2)**		
	Opinion	Orientation	Suggestion
Laboratory mean	0.37/0.99	0.34/0.99	0.23/0.99
Intermediary	0.35/0.98	0.44/0.98	0.27/0.99
Practice	0.36/0.92	0.23/0.94	0.25/0.85

Exploring ideation specifically, Figure 10.14 shows the count of cumulative ideas generated over the course of the situation for each of the teams.

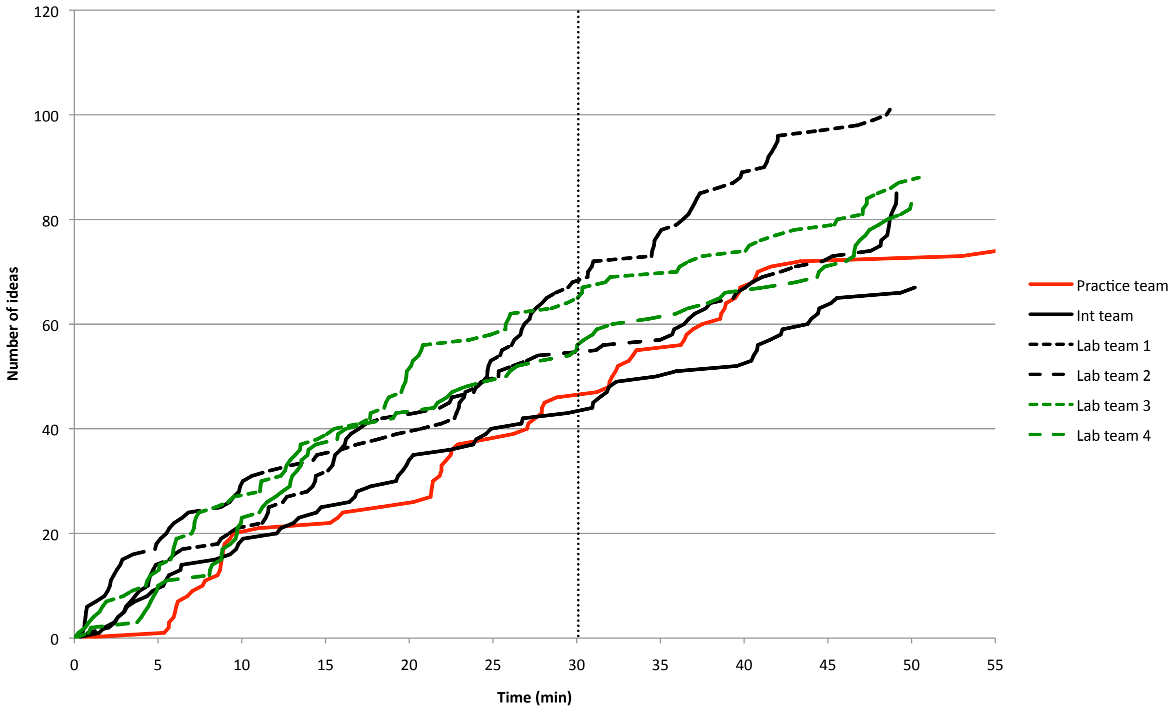

Figure 10.14: Ideas generated during the situation

Further to the trends shown in Figure 10.14, Table 10.5 decomposes the ideation results in order to explore the rate of idea generation. The data here has been split into two periods (0 – 30 minutes and 30 – 50 minutes). This split is based on Howard et al.'s (2010) assertion that ideation rate drops significantly after 30 minutes of a brainstorming session. As such, splitting the results in this way allows for a comparative validation against Howard et al.'s work. In contrast to the difference in the ideation rate/number of ideas, the R^2 values for linear trend line approximations are closely related with an average of 0.96 and a spread of only 0.04. This indicates that a linear approximation is an equally good representation for all contexts, suggesting that they all have the same underlying structure and trends.

Table 10.5: Details of ideation for the three contexts and the laboratory teams

	Total number of ideas		**Ideation rate (ideas per minute)**		**R^2 value for linear trend line**	
Time (minutes)	0 – 30	30 – 50	0 – 30	30 – 50	0 – 30	30 – 50
Lab 1	68	33	2.27	1.65	0.98	0.95
Lab 2	54	31	1.80	1.55	0.87	0.95
Lab 3	64	24	2.13	1.20	0.98	0.97
Lab 4	55	28	1.83	1.40	0.95	0.94
Practice	46	26	1.84	1.04	0.95	0.97
Int	43	24	1.43	0.8	0.99	0.95
Lab Mean	60	29	2.01	1.45	0.95	0.95

Of the results outlined in Table 10.5 of particular interest is the change in ideation rate over time. As such Table 10.6 gives further detail, outlining the drop in ideation rate in raw terms (ideas per minute) and also as a percentage of the initial rate. This allows for a more nuanced analysis and provides a basis for contextual comparison.

Table 10.6: Change in ideation rate for the three contexts

	Drop in ideation rate (ideas per minute)	**Drop in ideation rate (% of initial rate)**
Practice	0.80	43
Intermediary	0.63	44
Laboratory Mean	0.56	28

Finally, Figure 10.15 and Figure 10.16 show the qualitative assessment of the participants' enthusiasm and contentedness over time. Mean values were used for the laboratory context in order to compare general trends. Neither enthusiasm or contentedness show a clear pattern across contexts with the only major result being that there is a larger range in contentedness in practice (3) compared to the other contexts (1 for intermediary and 0.25 for the laboratory).

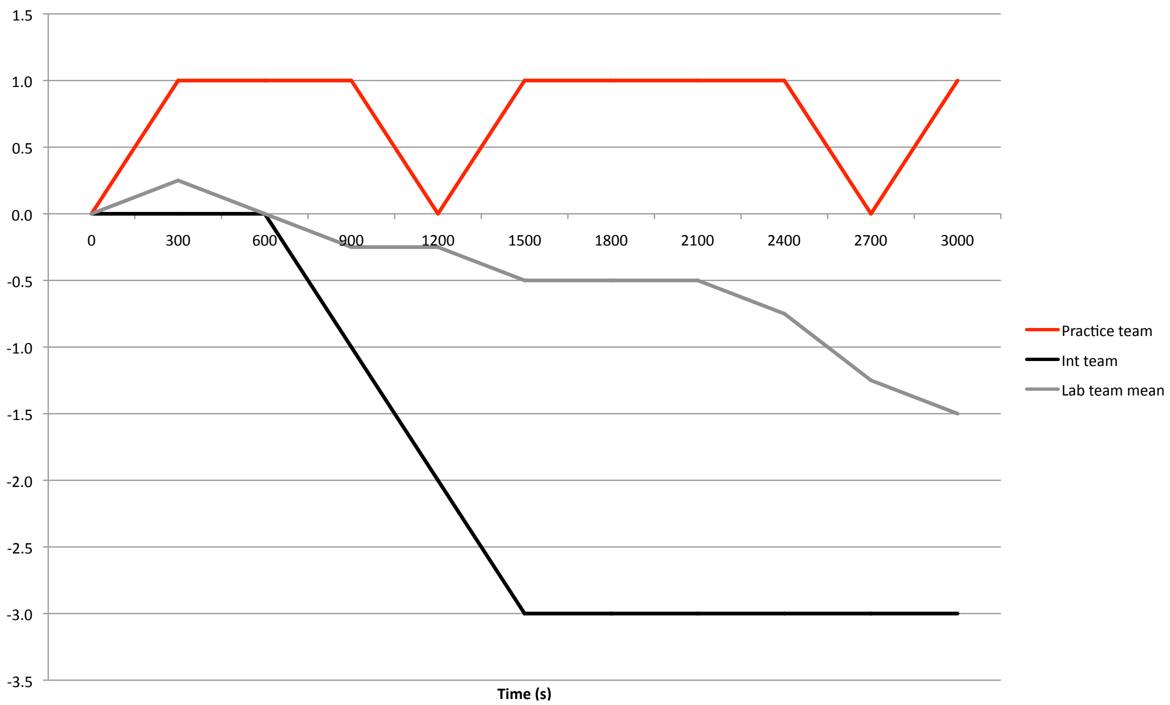

Figure 10.15: Qualitative assessment of participant enthusiasm during the situation

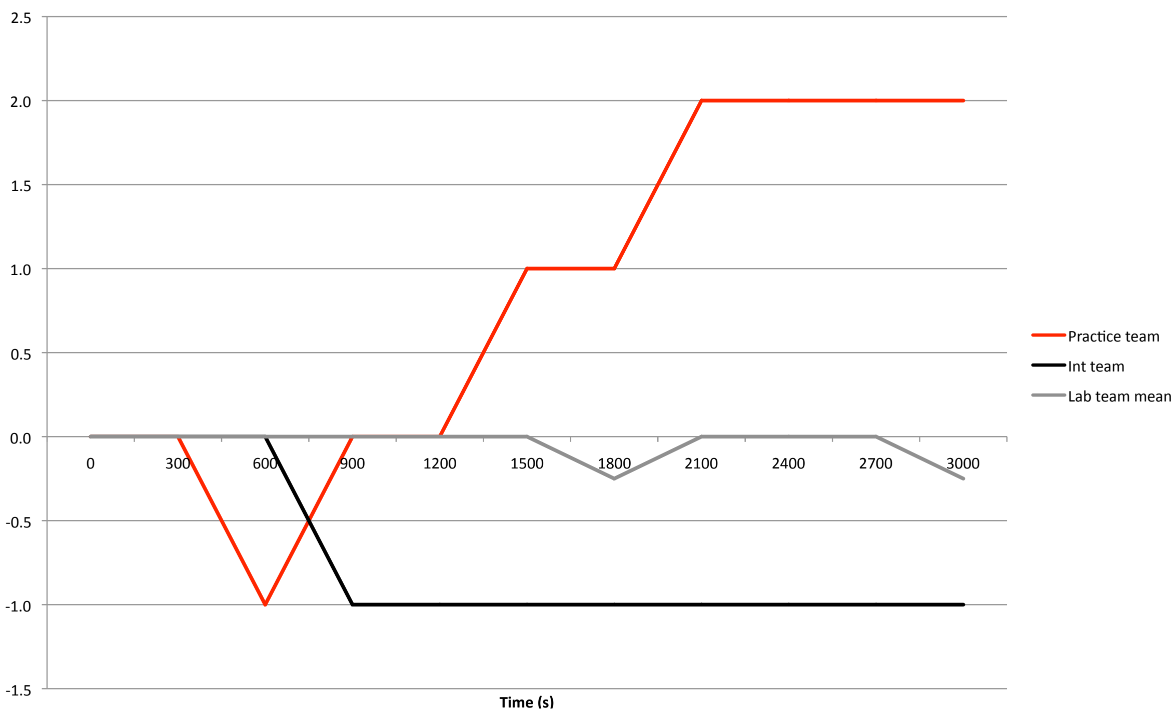

Figure 10.16: Qualitative assessment of participant contentedness during the situation

10.2.2 Characterising the Relationship

As with Section 10.1.2, there are four forms of analysis to discuss with regard to the second critical design situation. These are the same as those used for the first situation except that the analysis focused on the single situation specific coded activity: ideas generated over time.

The first area to be examined is the focus of the participants' activity using 'total duration of coded activity', 'total number of instances' and 'average time per instance'. In contrast to the first critical design situation, there were no clear trends apparent in terms of the duration of the coded activities (Figure 10.9). This was also true for 'total number of instances' and 'average time per instance', except in a small number of cases where there were significant differences across contexts. In the case of 'total number of instances', the coded behaviours 'agree', 'antagonism', 'solidarity', 'tension' and 'tension release' were significantly more prominent in practice compared to the other two contexts. As the intermediary results closely aligned with those from the laboratory, it is unlikely that this difference was due to factors such as the team having previously worked together or the experience of the participants. Based on the elimination of these factors, it is possible that this difference can be attributed to the more relaxed nature of the situation encountered in practice. This is supported by the results for the participants' enthusiasm and contentedness which both show significantly more positive results for practice in comparison to the laboratory based situations (Figure 10.15 and Figure 10.16).

In the second case, the practice based participants spent significantly longer per instance on the coded activity 'goal setting'. In order to understand this case, it is necessary to examine how these activities were distributed over time in the different contexts (Figure 10.12a). Taking these results into account, it is apparent that in the practice context 'goal setting' was carried out in a single instance at the start of the situation where the team leader briefed the team members. A possible explanation for this is the fact that in practice the task goal was fixed and well established prior to the start of the activity and as such little refinement or further discussion was necessary. This is in contrast to the laboratory and intermediary contexts where participants continued exploring possibilities throughout the task and as such addressed goal setting on an issue by issue basis (as seen in the staggered curve given in Figure 10.12a) rather than in single briefing.

The second form of analysis to be considered is the participants' activity over time. The first group of coded activities were 'goal setting', 'constraining', 'exploring' and 'evaluating' (Figure 10.12). As noted above, the number of instances of 'goal setting' varies significantly between practice and the other two contexts – accounting for only 1% of the time in practice compared to 5% in the intermediary context and an average of 3% in the laboratory. However, the results for the primary coded activity in terms of ideation – 'exploring' – show a closer correlation (practice = 5%; intermediary = 6%; laboratory mean = 6%), suggesting that the actual problem solving activity is similar across contexts despite the differences in leadership/goal setting. The other two coded activities (constraining and evaluating) show variation between contexts but not of a significant or consistent nature. Figure 10.13 further supports the finding that 'goal setting' activity differs significantly in practice. Firstly, the codes 'recognising need', 'informing' and 'confirming' are not present in practice compared to the relatively tightly clustered results for the laboratory and intermediary contexts (range at end of situation = 5, 11 and 6% respectively). This again serves to support the explanation developed in regard to 'goal setting'. In the case of practice, a clear team leader coupled with a pre-established task goal means that there is little clarification needed and 'informing' and 'recognising need' take place in a briefing at the start of the session or prior to the session respectively. However, the other codes (clarifying, opinion, orientation and suggestion) are closely correlated across contexts suggesting that the underlying mechanisms and the structure of the ideation discussions are fundamentally similar.

The third form of analysis is a comparison of the number of ideas generated over time (Figure 10.14 and Table 10.5). This, coupled with an assessment of the ideation rate, show that, although there is correlation across contexts, practitioners have a consistently lower total number of ideas and ideation rate (difference between the laboratory mean and practice = 17 ideas and 0.3 ideas per minute respectively). This again suggests that the underlying mechanisms driving idea generation are similar but that there are fundamental differences between practitioners and students. These results show that students generated more ideas initially and continued to do so over the entire test period. The similarity between the intermediary and practice contexts also supports the identification of the primary differentiating factor as the participant rather than the task or the setting. This is further supported by the similarity in number of ideas, ideation rate and drop in ideation rate as detailed in Table 10.5 and Table 10.6.

Finally, as discussed previously, there are clear differences between the levels of enthusiasm (Figure 10.15) and contentedness (Figure 10.16) observed across contexts. Although these do not show any clear relationships, they do support the finding that the more relaxed nature of the situation encountered in practice gives rise to a wider range of emotional activity e.g. tension/tension release which account for 2 and 5% of instances in practice compared to just 0 and 2% in the laboratory.

10.2.3 Discussion

Three core findings emerge from the analysis of the results discussed in this section. These are:

Finding 4: Goal setting activities (recognising need, informing and confirming) take the form of a discreet briefing and account for significantly less of the situation in practice compared to the laboratory, due to differences in embeddedness. It is possible that this is caused by the need having been defined during pervious activities with little additional time necessary for discussing the problem. In this case these activities are only present during the first 10% of the situation, suggesting that much of this activity had already taken place during prior work.

Finding 5: There is little difference across contexts in terms of the fundamental solving (constraining, exploring and evaluating) and interaction activities (opinion, orientation and suggestion). All of these activities show no significant differences over time when compared to the laboratory or intermediary contexts.

Finding 6: Fundamental ideation activity is similar across contexts with the difference in the number and rate of ideas generated being due to the level of experience of the participant rather than the task or the setting. Linearity of the curve and R^2 values show no significant differences across contexts while there are differences in magnitude with practitioners producing fewer ideas irrespective of context.

Validation

In order to assess the generalizability and validity of the findings, it is possible to draw on the results of Howard et al. (2010). From the work of Howard et al. (2010), two teams can be identified that provide possible sources of validation. Both of these teams completed 50 minutes of uninterrupted brainstorming and as such can be compared to the teams assessed in this study. Further to this, the teams were both larger than those examined in this work (9 and 6 members) and were recorded in practice. Figure 10.17 details the results for these two teams as well as the findings for this study.

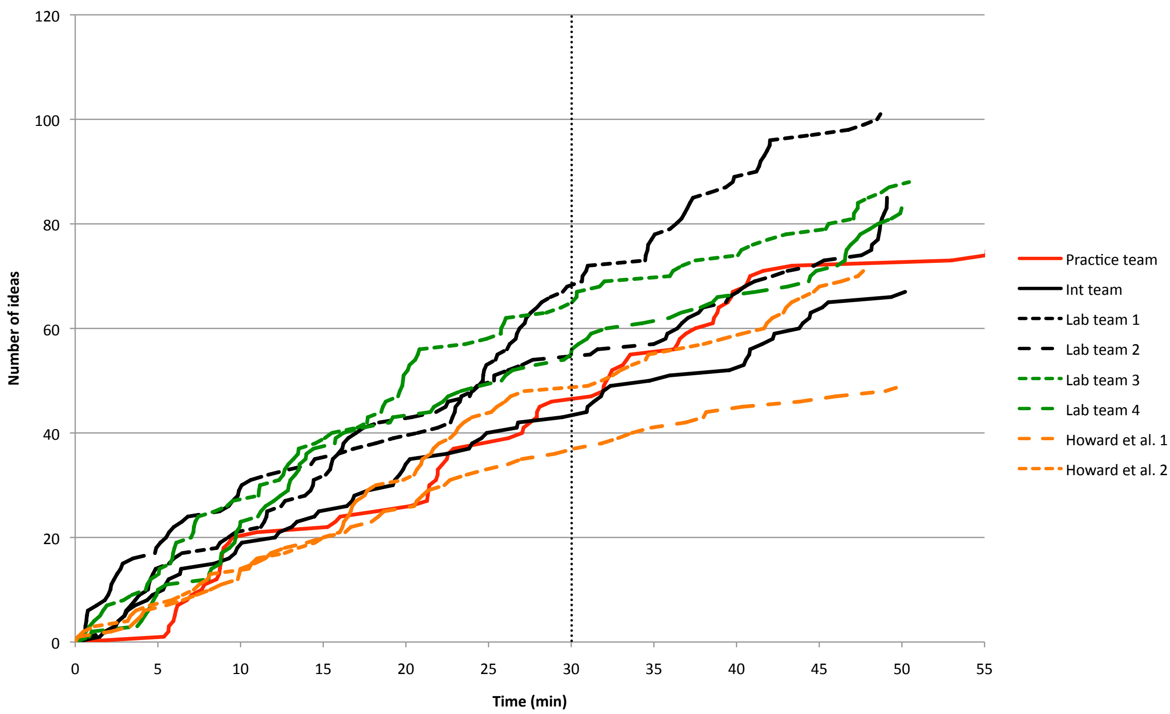

Figure 10.17: Validating ideation against Howard et al. (2010)

Figure 10.17 shows that, although there is some variation amongst the results, Howard et al.'s (2010) teams fall in line with the expected result, supporting the initial findings outlined in Section 10.2.2. Further to this, the laboratory studies using student participants are tightly clustered and consistently higher than the equally tightly clustered results for the practitioner participants as highlighted by Table 10.7.

Table 10.7: Range in number of ideas generated over time

	Range in number of ideas	
Time (minutes)	0 – 30	30 – 50
Laboratory	13	9
Practice (incl. intermediary and Howard et al.'s teams)	12	13

This confirms both of the points identified in Section 10.2.2 – practitioners consistently produce fewer ideas irrespective of other factors (including group size) and the findings from practice are representative of other independent studies of practitioners. The fact that the teams all perform in a consistent manner also supports the finding that underlying ideation activity is similar across contexts and is not significantly affected by differences in goal setting behaviour.

Exploring these points further, the data in Table 10.8 reinforces the results outlined in Figure 10.17. Table 10.8 again shows the laboratory studies to be consistently higher in terms of ideation rate (for both 0 – 30 minutes and 30 – 50 minutes) and lower in terms of drop in rate as a percentage. It should be noted that the drop in rate is less significant in the findings of Howard et al. (2010) suggesting that there are other possible factors affecting this activity. However, for the purposes of this thesis, the data supports the findings summarised in this section.

Table 10.8: Validating changes in ideation rate against Howard et al. (2010)

	Ideation rate (ideas per minute)		**Drop in ideation rate**	
Time (minutes)	0 - 30	30 - 50	Ideas per minute	% of initial rate
Practice	1.84	1.04	0.80	43
Intermediary	1.43	0.8	0.63	44
Laboratory Mean	2.01	1.45	0.56	28
Howard et al. team 1	1.60	1.15	0.45	28
Howard et al. team 2	1.20	0.8	0.40	33

The conclusions are further supported by the extant literature (Cross 2004; Judith and Herbert 2007). Indeed, Atman et al. (1999) suggest that the fact that experienced practitioners produce fewer ideas has it roots in the more efficient nature of the experienced design process. In the case of ideation, it is argued that experienced designers are more capable of parallel thinking (Seitamaa-Hakkarainen and

Hakkarainen 2001) and have more structured cognitive processes (Kavakli and Gero 2002). Due to these enhanced skills, less iteration is needed to achieve an acceptable result, in contrast to the novices typical 'trial and error' approach – not seen in experts (Ahmed et al. 2003). Based on this, it is possible to conclude that direct validation via Howard et al. (2010) as well as indirect validation from literature confirms the key findings for this study.

Summary

In summary, all the identified sources correlate with the findings outlined in this section with no major contradictions. Based on this, it is possible to develop these findings into a framework relating the laboratory to practice for each of the main coded activities as in Section 10.1. This is outlined in Table 10.9, which notes areas of difference between laboratory and practice, with respect to practice. Again, differences are defined as significant if they fall outside the interpersonal variation seen in the laboratory. The same colour key is used as for Table 10.1 for clarity.

Although Table 10.9 outlines the major differences between the contexts for each coded activity, it does not relate these to the characteristics of the design situation and, as such, gives little insight into how these characteristics affect designer behaviour and activity. However, Table 10.10 develops these differences and links them to the underlying characteristics.

Table 10.9: Differences between contexts by activity

Code	**Focus of analysis**				
	Duration	Instances	Time per instance	Activity over time	Situation specific
Goal setting	no sig. dif.	less	more	less, dif. structure	N.A.
Constraining	no sig. dif.	no sig. dif.	no sig. dif.	no sig. dif.	N.A.
Exploring	less	no sig. dif.	no sig. dif.	no sig. dif.	N.A.
Solving	no sig. dif.	no sig. dif.	no sig. dif.	N.A.	N.A.
Evaluating	no sig. dif.	no sig. dif.	more	no sig. dif.	N.A.
Decision making	more	more	more	N.A.	N.A.
Reflecting	no sig. dif.	no sig. dif.	no sig. dif.	N.A.	N.A.
Debating	no sig. dif.	no sig. dif.	no sig. dif.	N.A.	N.A.
Recognising need	less	less	less	less, dif. structure	N.A.

Seeking information	no sig. dif.	no sig. dif.	no sig. dif.	N.A.	N.A.
Requesting information	less	less	less	N.A.	N.A.
Interpreting	no sig. dif.	no sig. dif.	no sig. dif.	N.A.	N.A.
Validation	no sig. dif.	no sig. dif.	no sig. dif.	N.A.	N.A.
Informing	less	less	more	less, dif. structure	N.A.
Clarifying	no sig. dif.	less	more	no sig. dif.	N.A.
Confirming	less	less	no sig. dif.	less, dif. structure	N.A.
Opinion	no sig. dif.	more	more	no sig. dif.	N.A.
Orientation	no sig. dif.	no sig. dif.	more	no sig. dif.	N.A.
Suggesting	no sig. dif.	more	no sig. dif.	no sig. dif.	N.A.
Agree	no sig. dif.	more	more	N.A.	N.A.
Disagree	no sig. dif.	no sig. dif.	more	N.A.	N.A.
Antagonism	no sig. dif.	more	no sig. dif.	N.A.	N.A.
Solidarity	more	more	more	N.A.	N.A.
Tension	no sig. dif.	more	more	N.A.	N.A.
Tension release	no sig. dif.	more	no sig. dif.	N.A.	N.A.
Ideas	N.A.	less	N.A.	less	higher drop in rate
Enthusiasm	N.A.	N.A.	N.A.	no sig. dif.	N.A.
Contentedness	N.A.	N.A.	N.A.	larger range	N.A.

Table 10.10 is based on the various characteristics identified during the analysis of the results. The table shows how each characteristic changes across contexts and what effect this change has, based on the comparison of the three studies outlined in this section. The same shading and colour conventions are used as in Table 10.2.

Table 10.10: The relationship between practice and the laboratory ideation

Factor	Comparison			Relationship: Practice to Laboratory
	Practice	Intermediary	Laboratory	
Team size	4	3		Results from practice were within the range of variation see in the laboratory, therefore no significant differences were identified
Setting (inc. environment, social, cultural and historical)	Practice – normal meeting room	Instrumented meeting room (Figure 9.1)	Laboratory (Figure 8.3)	Results from practice were within the range of variation see in the laboratory, therefore no significant differences were identified
Task (Table 8.2)	Easily mounted water flow measurement	Flexible camera mount for aerial vehicle		Results from practice were within the range of variation see in the laboratory, therefore no significant differences were identified
Level of constraint	Relatively unconstrained			Not applicable for comparison purposes because all the situations were constrained to a similar degree
Stage of the design process	Early feasibility			Not applicable for comparison purposes because all the situations were set in the early feasibility stage of the design process
Embeddedness in the design process	Highly embedded within wider work	Minimal embeddedness – activity builds on stage 1 and feeds into stages 3 and 4		Problem identification and goal setting activity account for significantly less time and differ in structure taking the form of a discreet 'briefing' in practice. However, problem solving and discursive activity showed no significant differences
Participant (inc. experience, age, education and sociometic)	Representative of practitioners (Section 7.1)	Representative of students (Section 8.1)		Practice-based participants consistently produced fewer ideas at a lower rate and showed a large drop in ideation rate over time

10.3 Design Situation 3: Review Meeting

This section explores the critical design situation 'review meeting'. This follows the same format as Sections 10.1 and 10.2, starting by outlining the key results before identifying relationships and discussing validation.

10.3.1 Results

Figure 10.18 highlights the general similarity between the contexts with only four coded activities showing significant differences between practice and laboratory. Firstly, 'evaluating' in practice (11%) is lower than the laboratory minimum (13%) and substantially lower than the laboratory mean (30%). Secondly, there is significantly more 'debate' activity in practice (20%) even compared to the laboratory maximum (4%). Thirdly, 'clarifying' appears more prominent in practice – accounting for 60% of the time – compared to the laboratory (mean = 30% and maximum = 46%) and the intermediary (27%) contexts. Finally, 'sketching' activity is significantly greater in the laboratory (70%) and intermediary (46%) contexts compared to practice (6%). Although, they do not show a clear pattern of activity, these differences collectively suggest that activity in practice is more diverse and as such clarifying and debate are more prominent in comparison to more task specific activities such as sketching or evaluating.

Figure 10.19 highlights the similarity between the contexts and again shows the disparity in terms of 'debating' (2.9% in practice and 1% in the laboratory). Further, Figure 10.19 emphasises the more diverse use of artefacts in practice with both 'drawing' (3%) and 'communications' (10%) playing an important role – highlighting the embedded nature of the practice-based situation. The only other coded activity to show a significant difference is that of 'goal setting' where practice (2%) is smaller than the laboratory (mean = 5% and minimum = 3%) and intermediary (5%) contexts. This could indicate that 'goal setting' activity has a different structure or that there is a difference in level of leadership.

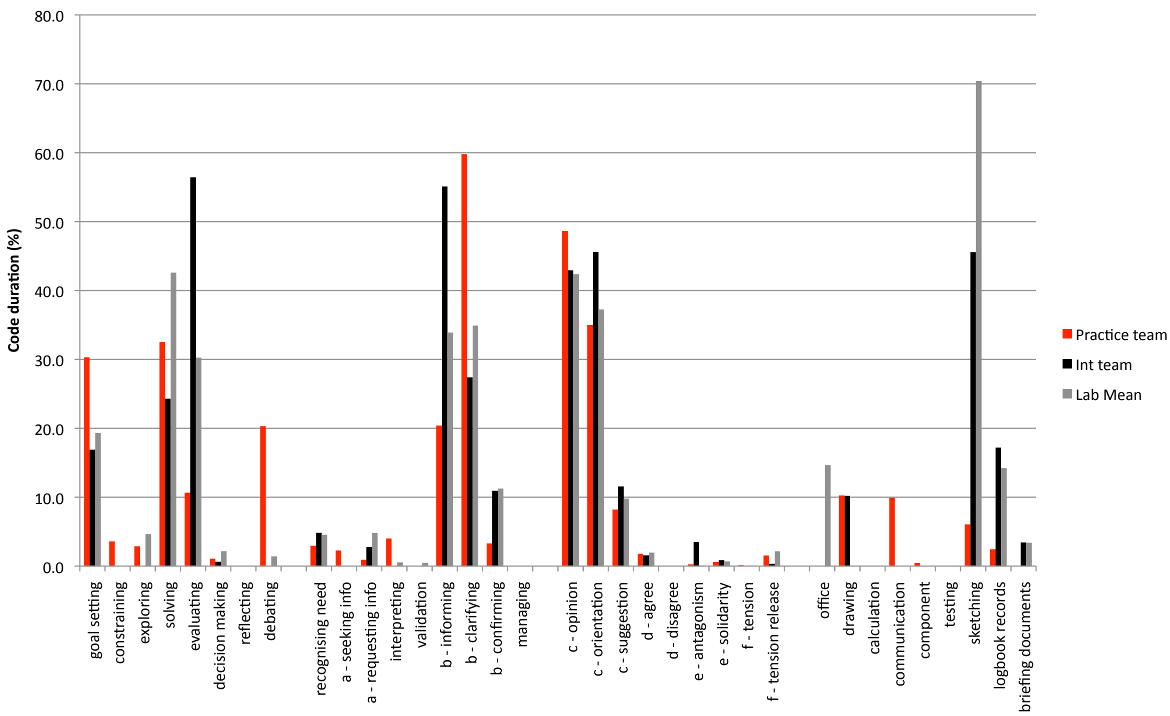

Figure 10.18: Coded activity duration as a percentage of the total situation time

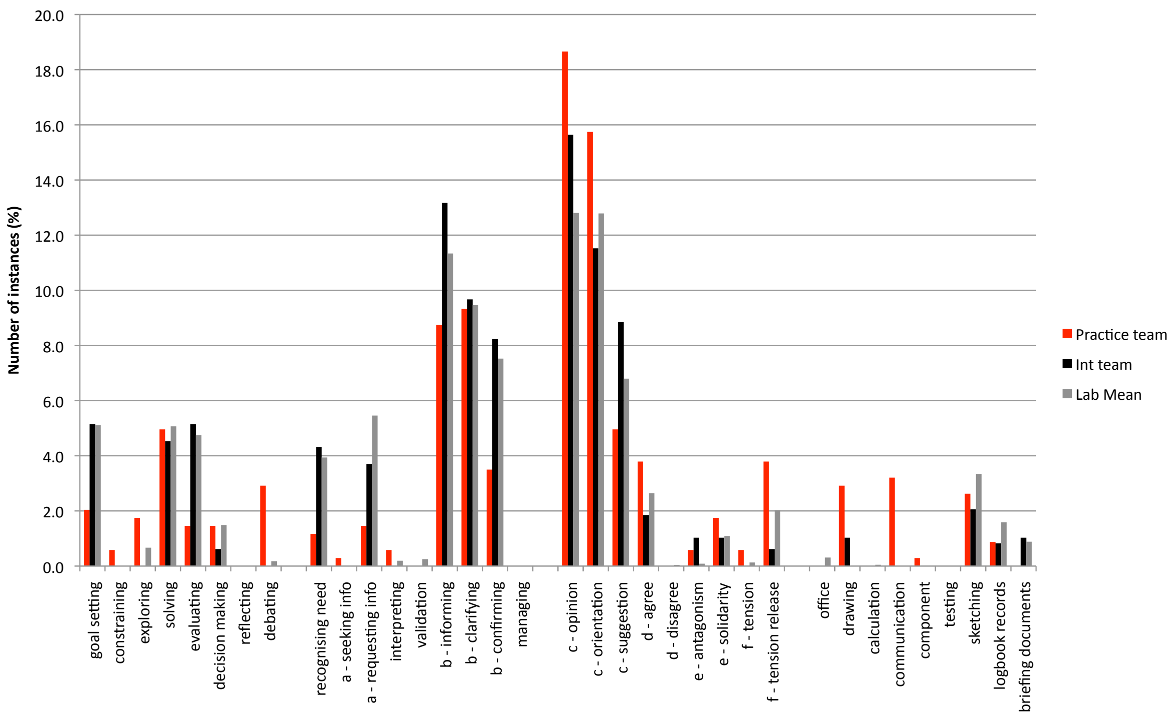

Figure 10.19: № of instances of coded activity as a percentage of the situation total

Figure 10.20 shows a distinct trend between the laboratory and practice in terms of the length of the coded activities. Taken as an average over the coded activities, 'goal setting' to 'managing' activities last 56 seconds longer in practice than those in the laboratory. This pattern does not extend to the intermediary context, which is within the range of results seen in the laboratory. As the practice-based situation only included two participants, it is possible that this lengthening in average activity time could be a product of team size. However, no such pattern is present in the conversational activities ('opinion' to 'tension release') where there are no significant differences across the contexts. The only other area of difference highlighted by Figure 10.20 is that in the laboratory and intermediary contexts, sketching activities last on average 136 seconds in comparison to practice, which lasts only 39 seconds.

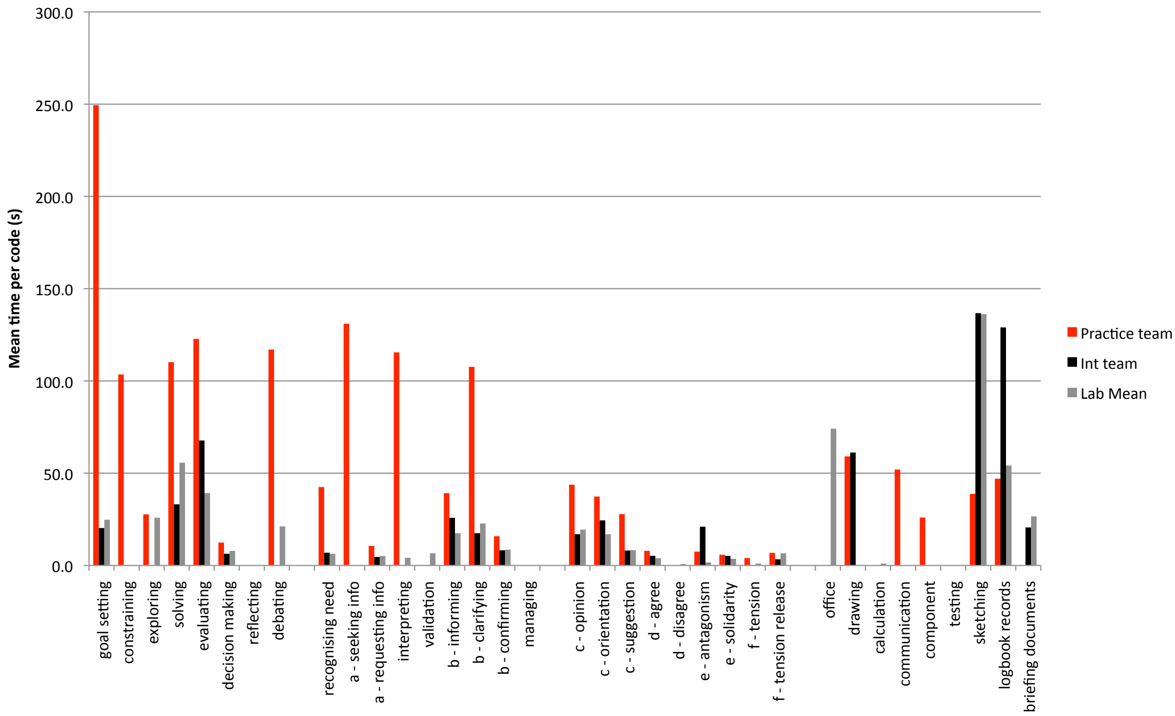

Figure 10.20: Mean time per instance

Examining the coded activities in more detail, Figure 10.21 shows the teams' activity over time for: goal setting, solving and evaluating. Of particular note from this analysis is the difference in the structure of 'goal setting' in practice. This activity shows a single distinct event near the start of the situation where all the goal setting takes place in comparison to the other settings which show a linear relationship, increasing throughout the situation (trend line for the laboratory mean: slope = 0.21, $R^2 = 0.91$; trend line for the intermediary team: slope = 0.16, $R^2 = 0.90$). This structure suggests that one instance in particular accounted for the 'goal setting' activities in practice compared to the laboratory studies where these activities took place throughout the situation. Further to this, 'evaluating' also showed a slightly different structure in practice compared to the laboratory with a single event accounting for all the 'evaluating' activity in comparison to the linear relationship in the other contexts (trend line for the laboratory mean: slope = 0.36, R^2 = 0.97; trend line for the intermediary team: slope = 0.65, R^2 = 0.95). The differences in these two coded activities can be attributed to meeting structure and focus. In practice, multiple tasks were undertaken as part of an overarching review meeting whereas the laboratory and intermediary participants were more focused on 'evaluating' and 'solving' in order to complete the final design.

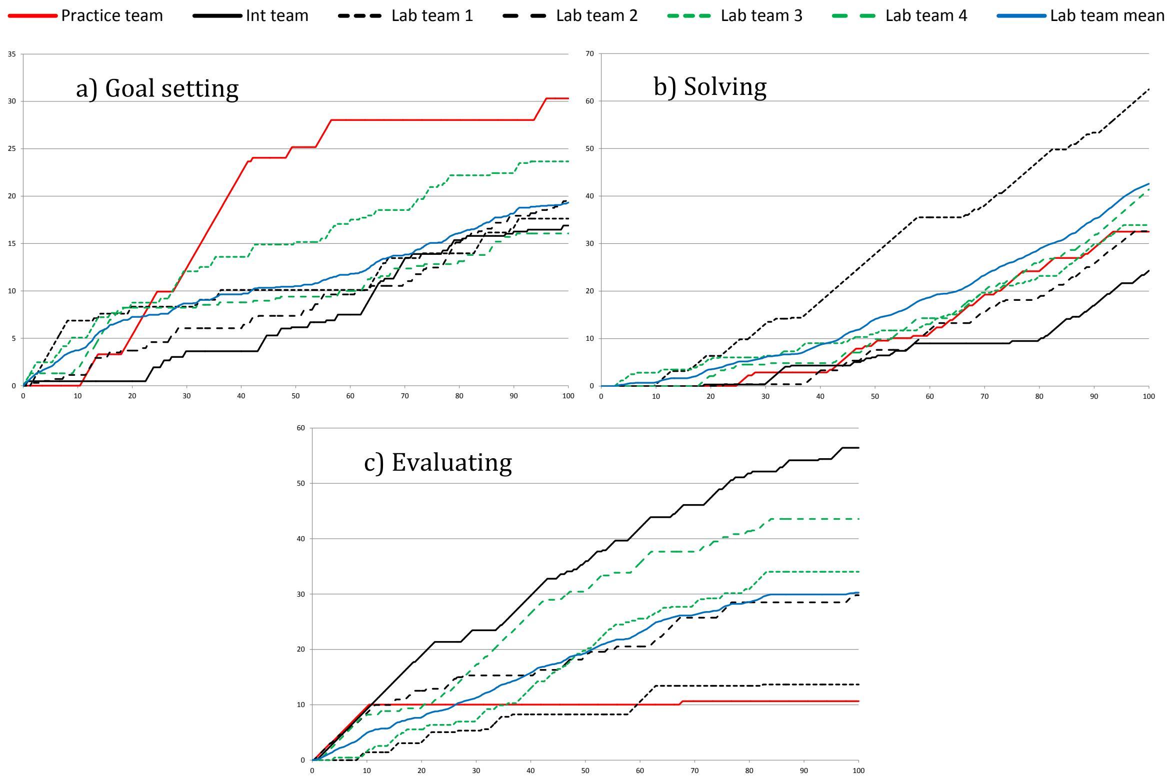

Figure 10.21: Cumulative time as a percentage of the total situation time for high level activities

Further, Figure 10.22 shows the activity over time for the coded activities: recognising need, informing, clarifying, confirming, opinion, orientation and suggestion.

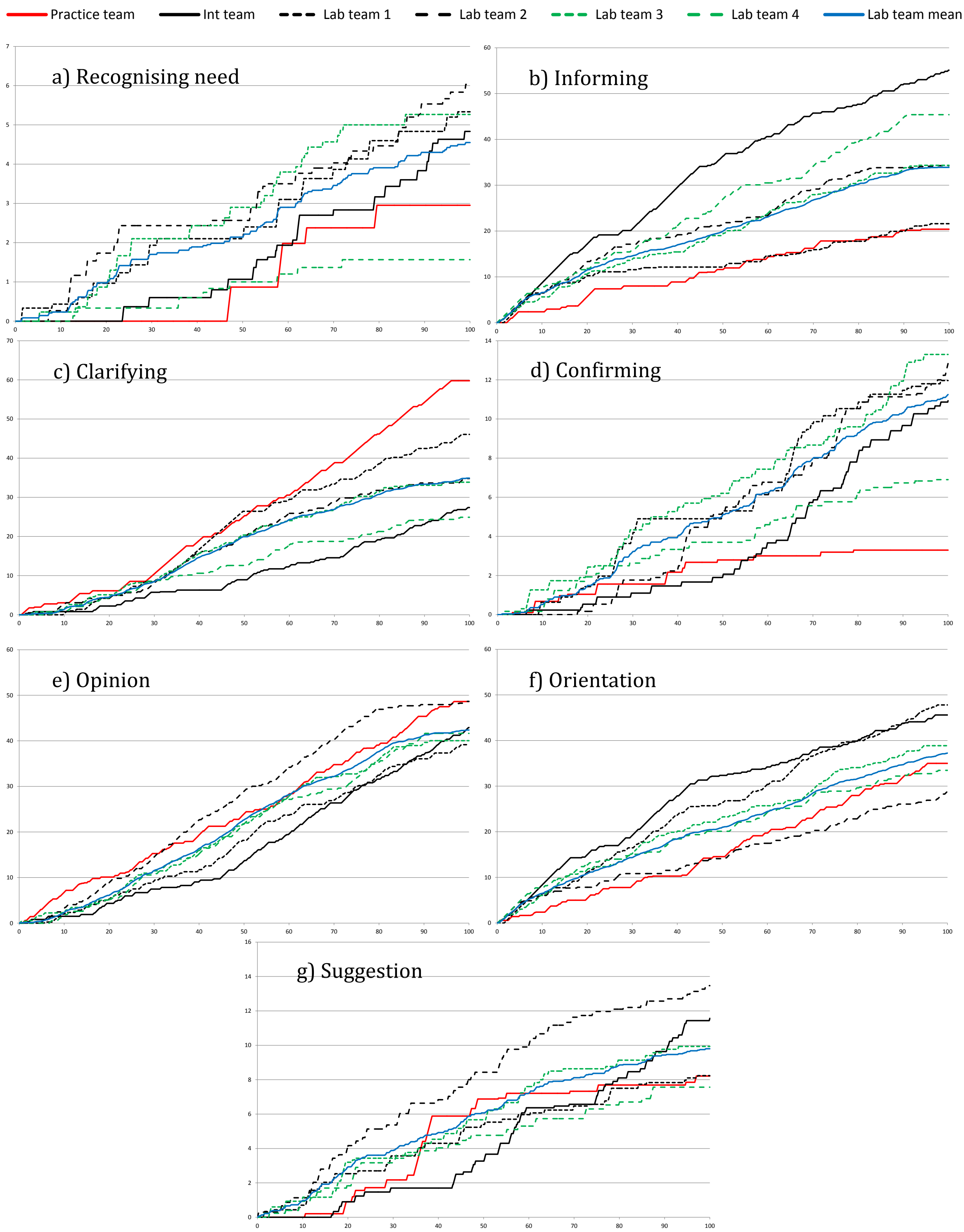

Figure 10.22: Cumulative time as a percentage of the total situation time for specific activities

No significant differences were apparent for these coded activities except in the case of confirming. In this case, although practice initially conforms to the laboratory results, activity ceases at approximately half way through the situation. As the other coded activities do not show this attenuation, this suggests that the practice-based participants changed task at this point to one, where confirmation was less important. However, this does not appear to affect the conversational aspects of practice, as supported by the activities 'opinion' to 'suggestion', which are closely related across the contexts as highlighted in Table 10.11.

Table 10.11: Trend line data for conversation activities over time

Context	Duration of coded activity (slope/R^2)		
	Opinion	Orientation	Suggestion
Laboratory mean	0.45/0.99	0.40/0.96	0.11/0.97
Intermediary	0.37/0.92	0.53/0.89	0.10/0.89
Practice	0.49/0.99	0.34/0.98	0.10/0.86

Finally, Figure 10.23 and Figure 10.24 show the qualitative assessment of the participants' enthusiasm and contentedness over time. Mean values were used for the laboratory and intermediary contexts in order to compare general trends. In the case of this situation, the practice-based period was twice as long as the other situations as these were shortened to allow effective experimental design. Again, there was a larger range in enthusiasm and contentedness in practice (8 and 4 respectively) compared to the laboratory (2 and 0.25) or intermediary (4 and 0) contexts.

Figure 10.23: Qualitative assessment of participant enthusiasm during the situation

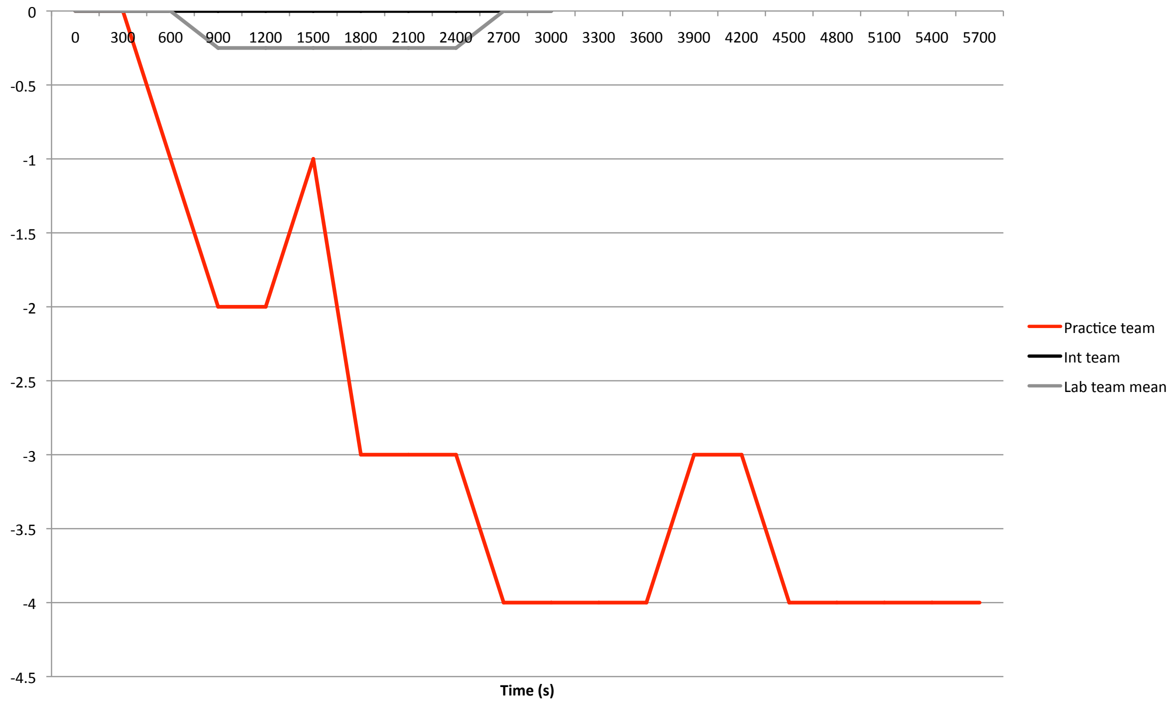

Figure 10.24: Qualitative assessment of participant contentedness during the situation

10.3.2 Characterising the Relationship

This section uses the three forms of analysis to discuss the third critical design situation. These are the same as those used for the first two situations except that the specific searching activities was analysed as part of the first form of analysis.

The first form of analysis is the focus of the participants' activity using: total duration, total number of instances and average time per instance. For the first two measures ('total duration' Figure 10.18 and 'number of instances' Figure 10.19), no consistent trends were found, with few significant differences apparent between the practice, intermediary and laboratory results. The major exceptions to this are the coded activities 'sketching' (less in practice) and 'debating (more in practice). Further to this, a wider range of artefacts is used in practice (5) compared to the laboratory (3 excluding 'briefing documents' as these were a contrivance specific to the experimental approach) or intermediary (3 excluding 'briefing documents') contexts, with more time given to the use of 'communications' and 'components'. This can be attributed to the fact that in the practice context, the situation was embedded within the design process and, as such, distributed communication and prototyping play a larger role in comparison to the laboratory context where there is often insufficient time to develop these aspects (see Chapter 7).

Other than these exceptions, both figures show a close relationship between the laboratory and practice. However, examining the average time per instance (Figure 10.20), practice consistently spends significantly more time per instance (an average of 59 seconds for the activities 'goal setting' to 'managing'). It is difficult to suggest an obvious reason for this trend but it must nonetheless be acknowledged when comparing laboratory and practice.

In terms of the situation specific activities (Figure 10.22) – 'office' to 'briefing documents' – again no clear patterns across contexts were found. The exception to this is that the intermediary and laboratory based studies used significantly more sketching (Figure 10.18) than the practice based situation (46%, 70% and 6% respectively). However, it is not clear if this is a function of the differing task or whether it is due to other factors such as familiarity with the subject or some more fundamental aspect of practice.

The second form of analysis to be considered is the participants' activity over time. The first group of coded activities were 'goal setting', 'solving' and 'evaluating' (Figure 10.21). A number of findings can be examined using Figure 10.21. Firstly, 'goal setting' (in contrast to Section 10.2) plays a more significant role in practice in comparison to the other two contexts. Secondly, the solving activity is tightly clustered across contexts with a range of 18% excluding an outlier at 63% (20% greater than the next highest result). Finally, 'evaluating' shows significantly more spread compared to the other coded activities with a final range of 45%. In this case, practice also shows a different structure to that observed in the laboratory or intermediary contexts. These findings suggest that although the fundamental problem solving/evaluation process is similar across contexts, 'goal setting' plays a larger role in practice. This can again be attributed to the fact that the practice-based situation is embedded within the wider design process and therefore plays an important shaping role not present in the laboratory or intermediary context. The conclusion that the problem solving activity/interactions are fundamentally similar across contexts is further supported by the results outlined in Figure 10.22. This shows that although there is a spread of results there are no significant differences between conversational activities across the three contexts as highlighted in Table 10.11. Indeed, in most cases the three groups of results are tightly clustered around the laboratory mean – 'opinion', 'orientation' and 'suggestion' having final ranges of 10%, 19% and 5% respectively.

The final form of analysis is a comparison of enthusiasm and contentedness (Figure 10.23 and Figure 10.24). In terms of enthusiasm there appears to be a common downward trend, however, there is no clear pattern associated with contentedness. As such it is again arguable that large swings in contentedness and enthusiasm are more pronounced in practice. This can be attributed to the much larger scope of activity and the fact that coffee breaks and interruptions by colleagues are common features of practice-based working in contrast to the laboratory or intermediary settings (as in Section 10.1).

10.3.3 Discussion

Three core findings emerged from the analysis of the results discussed in Section 10.3.2. These are:

Finding 7: Sketching plays a larger role in the intermediary and laboratory contexts in comparison to practice. Specifically, sketching activity accounts for 64% more time in the laboratory and each instance of sketching lasts on average 97 seconds longer. This is due to the fact that a wider range of activities are undertaken in practice with more time focused on activities such as goal setting, which are not associated with sketching.

Finding 8: Goal setting activity is significantly greater in magnitude and has a less linear structure in practice in comparison to the other contexts. In this case both goal setting and clarifying account for significantly more time in practice (11% and 30% more than the laboratory mean respectively). In addition goal setting effectively ceases after 60% of the situation in contrast to the other contexts.

Finding 9: Fundamental solving (solving and recognising need) and conversational activity (opinion, orientation and suggestion) show no significant differences across contexts. This is despite differences in evaluating activity (accounts for 19% less time than the laboratory mean and effectively ceases after 10% of the situation).

Validation

In order to explore the generalizability of these findings, a number of sources are considered. Although there are no extant studies dealing with participant activity in the level of detail and with the same focus as this study, there are several indicators that support the reported findings.

Firstly, there is a significant difference in the way the teams utilised sketching. The role of sketching in each of the three contexts was primarily in design development – being used to expand on various concepts and ideas. However, a key driver in the laboratory and intermediary studies was the production of a final concept leading to a dominance of sketching activity – particularly during the period when the team synthesised a final design. This is supported by the intermediary results. In this case, despite the use of practitioners, sketching activity is markedly similar to that of the student participants – suggesting that sketching is task rather than participant dependent. This is supported by several sources. Firstly, Perry and Sanderson (1998) highlighted the fact that sketching is but one part of a more complex design activity. This finding was developed through the work of Huet et al. (2009), who examined the various roles sketching plays in the design process. Finally, and crucially for this study, Song and Agogino (2004) fully explored the various roles of sketching and emphasised its task dependency. As such, it is possible to conclude that sketching activity is primarily task-dependent and accounts for significantly less time in practice due to the more varied nature of the undertaken tasks. However, the similarity of the other codes related to sketching activity – particularly 'clarifying' and 'informing' – suggest that the fundamental use of sketching for specific tasks is similar across contexts.

Secondly, there are significant differences in the structure and magnitude of 'goal setting' activity. In this case, 'goal setting' in practice accounted for an average of 11% more of the situation and took the form of a series of discreet events lasting an average of 225 seconds long per instance than the in the laboratory and intermediary contexts where 'goal setting' activity could effectively be modelled as linearly distributed throughout the situation (R^2 = 0.91 and 0.90 respectively). As in Section 10.2.3 the differences between contexts can be attributed to the level, to which the situation is embedded within a larger process. Practice, being fully embedded within a design process, shows a high degree of goal setting throughout the review due to the need to set tasks and identify goals for further work. This is in contrast to the laboratory/intermediary task, where participants only had to select and detail a final concept.

Thirdly, the work of Huet et al. (2007) supports the finding that there is little fundamental difference in the activity of students and practitioners during a comparable design review situation. Specifically, Huet et al. state that a design review involving graduate students was 'considered comparable to industry practices' as assessed by a group of industrial experts. This is further supported by the correlation between the intermediary and laboratory contexts – implying that variation in activity is not primarily due to participant.

Summary

In summary, although direct validation is not possible, all the identified sources correlate with the findings outlined in this section. Based on this, it is possible to develop these findings into a framework relating the laboratory to practice for each of the main coded activities as in Section 10.1. This is outlined in Table 10.12, which notes areas of difference between laboratory and practice, with respect to practice. Again, the highlighted differences are defined as significant if they fall outside the interpersonal variation seen in the laboratory. The same colour key is used as in Table 10.1 for clarity.

Although Table 10.12 outlines the major differences between the contexts for each coded activity, it does not relate these to the characteristics of the design situation and as such gives little insight into how these characteristics affect designer behaviour and activity. As such, Table 10.13 develops these differences and links them to the underlying characteristics. Table 10.13 shows how each characteristic changes across contexts and what effect this change has, based on the comparison of the three studies outlined in this section. The same shading and colour conventions are the same as in Table 10.2.

Table 10.12: Differences between contexts by activity

Code	**Focus of analysis**			
	Duration	Instances	Time per instance	Activity over time
Goal setting	more	less	more	more, dif. structure
Constraining	more	more	more	N.A.
Exploring	no sig. dif.	no sig. dif.	no sig. dif.	N.A.
Solving	no sig. dif.	no sig. dif.	more	no sig. dif.
Evaluating	less	no sig. dif.	more	less, dif. structure
Decision making	no sig. dif.	no sig. dif.	more	N.A.
Reflecting	no sig. dif.	no sig. dif.	no sig. dif.	N.A.
Debating	more	more	more	N.A.
Recognising need	no sig. dif.	less	more	no sig. dif.
Seeking information	more	no sig. dif.	more	N.A.
Requesting information	less	less	more	N.A.
Interpreting	more	no sig. dif.	more	N.A.
Validation	no sig. dif.	no sig. dif.	less	N.A.
Informing	less	no sig. dif.	more	no sig. dif.
Clarifying	more	no sig. dif.	more	more
Confirming	less	less	more	less, dif. structure
Opinion	no sig. dif.	more	more	no sig. dif.
Orientation	no sig. dif.	no sig. dif.	more	no sig. dif.
Suggesting	no sig. dif.	no sig. dif.	more	no sig. dif.
Agree	no sig. dif.	no sig. dif.	more	N.A.
Disagree	no sig. dif.	no sig. dif.	no sig. dif.	N.A.
Antagonism	no sig. dif.	more	more	N.A.
Solidarity	no sig. dif.	no sig. dif.	more	N.A.
Tension	no sig. dif.	no sig. dif.	no sig. dif.	N.A.
Tension release	no sig. dif.	no sig. dif.	more	N.A.
Office	no sig. dif.	no sig. dif.	no sig. dif.	N.A.
Drawing	more	more	more	N.A.
Calculation	no sig. dif.	no sig. dif.	no sig. dif.	N.A.
Communication	more	more	more	N.A.
Component	more	no sig. dif.	more	N.A.
Testing	no sig. dif.	no sig. dif.	no sig. dif.	N.A.

Sketching	less	no sig. dif.	less	N.A.
Logbook record	less	no sig. dif.	no sig. dif.	N.A.
Briefing documents	less	less	less	N.A.
Enthusiasm	N.A.	N.A.	N.A.	larger range
Contentedness	N.A.	N.A.	N.A.	larger range

Table 10.13: The relationship between practice and the laboratory for review meetings

Factor	Comparison			Relationship: Practice to Laboratory
	Practice	Intermediary	Laboratory	
Team size	2	3		Results from practice were within the range of variation see in the laboratory, therefore no significant differences were identified
Setting (inc. environment, social, cultural and historical)	Practice – normal meeting room	Instrumented meeting room (Figure 9.1)	Laboratory (Figure 8.3)	Results from practice were within the range of variation see in the laboratory, therefore no significant differences were identified
Task (Table 8.2)	Small household mechatronic device	Flexible camera mount for aerial vehicle		Sketching plays a less significantly role due to the less focused nature of the meeting in practice i.e. other activities are undertaken in addition to those carried out in the laboratory context
Level of constraint	Limited flexibility due to existing projects	Limited to experimental constraints		There is a larger range in emotional variation and there is also differences in coded activity over time due to the fact a wider variety of activities and foci are covered as part of the review task in practice
Stage of the design process	Early feasibility			Not applicable for comparison purposes because all the situations were set in the early feasibility stage of the design process
Embeddedness in the design process	Highly embedded within wider work	Minimal embeddedness – activity builds on stages 1, 2 and 3 but does not feed into further work		Goal setting activity is significantly greater and has a less linear structure due to the more embedded context i.e. goal setting in practice is more significant as there is a important future planning element not present in the laboratory
Participant (inc. experience, age, education and sociometic)	Representative of practitioners (Section 7.1)	Representative of students (Section 8.1)		Results from practice were within the range of variation see in the laboratory, therefore no significant differences were identified

10.4 Using the Characterisations

The aim of this work has been to characterise the relationship between practice and the laboratory, which has been described throughout this chapter. In order support the future use of these characterisations they have been summarised in tables such as Table 10.12. However, it is important to understand how these might be used in a research context. As such, there are three main ways in which these results can be used to support future design research:

- They can be used to form the basis for assessing the likely impact of a laboratory study e.g. if the study focused on 'exploring' behaviour in design reviews it is possible to see from Table 10.12 that there is likely to be little difference in how engineers or students might perform. However, if the study was focused on 'constraining' behaviour the researcher could conclude that the laboratory context is likely to under represent this behaviour in practice. As such, the researcher can assess whether effects observed in the laboratory are likely to be diminished, remain the same or increase in the practice context.
- They can be used to guide validation approaches e.g. if a study was focusing on general design review behaviour it is possible to see from Table 10.12 that any validation in practice should focus on the behaviours 'constraining', 'goal setting' and 'debating' where significant differences are highlighted.
- They can be used as a substitute for full validation e.g. if a study is focused on an area were no differences are identified then validation could take the form of a small confirmatory case study. However, where significant differences are highlighted the required validation activity must be more significant. It is to be noted that caution should be exercised if this route is adopted as careful consideration should be given to the applicability of these results in reference to the given contextual information.

10.5 Concluding Remarks

This chapter described the results of the three studies with respect to the core comparison between laboratory and practice defined in the methodology (Chapter 4).

This has been achieved using the three identified critical design situations as a basis for comparison.

Each situation was discussed and the individual relationships identified, providing a foundation for future research and the adaption of laboratory based results for application in practice. In particular, as the core empirical method provides a basis for further comparison future work can build on and further validate the findings discussed here. For each critical design situation, the various characteristics of the design situation were shown to have different relationships across contexts. However, there were also common relationships that occurred in all of the critical design situations.

Bringing the findings for the three critical design situations together allows a high-level characterisation of the common relationships. This shows that, although there are significant differences between the contexts, there is also much commonality. Further to this, even where there are differences, these can be associated with one of several key characteristics, allowing the researcher to control their impact and account for their influence when applying laboratory-based findings in practice. Table 10.14 highlights these common characteristics and relationships – detailing the critical link between practice and the laboratory as defined in the methodology (Figure 4.4).

The next chapter discusses the overall implications and limitations of these findings and relates them to the lager body of research reported in this thesis.

Table 10.14: Summary of the identified relationships between practice and the laboratory

Factor	Relationships by Critical Situation			General Relationships: Practice to Laboratory
	1	2	3	
Team size	N.A.	No significant differences apparent	No significant differences apparent	Results show no significant differences within the range of 3 – 5 team members. All results were within the range of variation see in the laboratory
Setting	No significant differences apparent	No significant differences apparent	No significant differences apparent	Results show no significant differences due to the differences between the office and laboratory environments. All results were within the range of variation see in the laboratory
Task	No significant differences apparent	No significant differences apparent	Less sketching activity	Sketching activity is task dependant with significant differences in the design review where there was the largest variation in task between contexts
Level of constraint	Greater emotional variation Shorter overall code duration	N.A.	Greater emotional variation Greater variation in activity over time	There is consistently greater variation in the scope of activities undertaken and in the range of enthusiasm and contentedness
Stage of the design process	N.A.	N.A.	N.A.	Not applicable for comparison purposes because this characteristic could not be isolated in any of the three situations
Embeddedness in the design process	Greater use of asynchronous information sources Less focused on specific searching activity	Less, less linear problem identification and goal setting related activities	More, less linear goal setting related activity More artefacts used	This characteristic has the most significant affect on activity and behaviour. In particular it affects what prior work/information is brought to a situation and as well as the outputs in the form of future planning not directly linked to the current situation
Participant	No significant differences apparent	Less ideas produced at a lower rate Greater drop in ideation rate over time	No significant differences apparent	Although this factor is important, as there is significant interpersonal variation it has little discernable affect across contexts except in the case of ideation. This suggests it plays an important role where cognitive aspects are being considered

"The prize and the cause of our labour"

Ovid

11

Overall Discussion

This chapter presents the concluding discussion for this thesis. This is primarily focused on an overall discussion of the core empirical method and the characterisation of the relationship between practice and the laboratory as apposed to the specific discussion of results outlined in Chapter 10. Firstly, the state of the art is summarised in order to allow reflection on how the identified research questions were addressed (Sections 11.1). Secondly, the main research contributions are discussed, including their implications and limitations (Sections 11.2 and 11.3). Finally, the scope and limitations of the research are summarised (Section 11.4).

11.1 State of the Art

A literature review of design research (Chapter 2) and associated fields (Chapter 3) revealed that there was six core issues: theory deficit, insufficient contextualisation, system clarity, method variability, experimental control and closing the loop (Table 3.2). Coupled with a practitioner-centric view of design research, this drove the identification to two key research questions:

- How can practitioner behaviour and activity be characterised to enable comparison between design situations?

- What is the relationship between practitioner behaviour in practice and laboratory-based critical design situations?

Based on an analysis of possible research methods a three-stage approach, supported by a core empirical method was identified as the most effective means of addressing the research questions. Using this approach, critical design situations were identified and compared for laboratory and practice. The following sections offer a discussion of the core empirical method and the final characterisation of the relationship between laboratory and practice.

11.2 The Three-stage Approach and Core Empirical Method

A cohesive approach to support comparison between design situations was a critical research objective due to the lack of existing literature providing comparative methods and specifically the identified lack of standardisation and linking theory in design research methods (Table 3.2). In order to fulfil this objective, two discreet parts emerged. A three-stage multi-perspective approach was described in Chapter 4, which was supported by a core empirical method (Chapter 6). This section discusses the implications of applying this approach and core empirical method (Section 11.2.1) as well as the major perceived limitations (Section 11.2.2) and the practical aspects of implementing the method (Section 11.2.3).

11.2.1 Implications

The three-stage approach outlined in Figure 4.4 was specifically created to address the research questions identified in Chapter 4 and summarised in Section 11.1. The approach formalises the comparison of different situations by giving a framework, in which various contexts can be examined whilst maintaining standardisation of methods. This allows not only comparison between the situations of interest, but also drives validation by introducing an intermediary situation. Without a common basis for comparison, none of these implications are realisable. As such, a core empirical method was developed to support this approach.

The core empirical method (Chapter 6) built on existing approaches to tackle the methodological issues identified in Chapter 3 and the specific methodological problems described in Table 6.3: linking to theory, describing context, sampling design, research design, data collection, reflexivity, analysis and value of findings. The method developed in this thesis combines multilevel capture, coding and analysis strategies into a cohesive approach in order to address these problems. This approach allows researchers to examine design practitioners within the wider context of their working practice. Each aspect of the approach was tailored to address the limitations of existing approaches as outlined in Table 6.3.

The capture step firstly outlines the formalisation of context capture in four main areas – activity, social, cultural and historical. Secondly, a multi-perspective capture approach is outlined – detailing participant activity using numerous complementary sources: Panopto, webcams, mobile cameras and logbooks via LiveScribe. Finally, an acclimatization period is formalised as part of the data collection process – reducing the experimental effects on the participant. This enables the development of a robust dataset, which can be analysed at multiple levels of detail and with various research foci – essential for the comparison of multiple situations.

The coding step outlines the creation and implementation of the five-level coding strategy – context (1), activities (2), interactions (3), designer observances (4) and detailed descriptions (5). This novel multi-level strategy allows the researcher to contextualise the wider situation in which the participant is working whilst also allowing a flexible yet detailed coding of the data set by progressive filtering at each level of the process. This enables a rapid interrogation of the dataset at multiple levels of detail whilst maintain context and methodological robustness, and reducing overall workload (see Chapter 7).

The analysis step outlines an approach in which the researcher aligns, analyses and reflects upon the dataset. Further to this, the multilevel coding and analysis strategy allows the researcher to interrogate the data at increasing levels of detail at little additional effort by allowing subsequent levels to be selectively applied, i.e. to situations of interest rather than the entire dataset. This is achieved using three levels: the analysis of individual codes (high-level); the analysis of groups and subsequently subgroups of codes (mid-level); the analysis of specific individual codes or subgroups dependent on research focus as defined in Level 5 of the coding strategy. This enables an analysis of the coded data, which supports both high-level contextualisation and rapid, detailed analysis of large bodies of data while also allowing flexibility of research focus without sacrificing rigour.

Collectively, the three steps support improved reporting of contextual information, standardisation of approach and development of theory. Further to this, they allow the researcher to more effectively structure and navigate through the large amounts of data often generated in observational studies. Finally, the multiple sources and levels of coding and analysis make the method extremely flexible in terms of research focus without sacrificing the benefits of standardisation or rigour.

The proposed method addresses many of the identified problems developed in Chapters 2 and 3 and summarised with respect to empirical methods in Table 11.1. In particular, it supports linking to theory, contextualisation, standardisation and clarity of research design, mitigation of bias, clarity and scope of data analysis, and improved value of findings. Table 11.1 also highlights how the identified problems are addressed by the core empirical method (See Figure 6.5 for further detail on where each point is addressed).

Table 11.1: Problems and their mitigation by the core empirical method

Problem	Description of mitigation	Where addressed
Linking to theory	Contextualisation and multi-level analysis allow situations to be linked to existing work and wider theory by linking them together	Capture strategy: context Multilevel analysis strategy
Describing context	Defining a set of contextual variables and the use of Level 1 codes to describe the high-level structure of the study	Capture strategy: context
Sampling design	Contextualisation of the population company as well as the participant population allows greater specificity in selection design	Capture strategy: context
Clarity of research design	Description of the coding schema and the ability to define more detailed levels of analysis from combinations of codes supports standardisation and clarity	Multilevel capture and coding strategies
Mitigation of bias in data collection	Acclimatization period and multimodal capture allow for reduced experimental effects and triangulation of multiple sources of data to help reduce bias	Capture strategy: data collection
Reflexivity	The semi-automated nature of the capture strategy eliminated the need for researcher/participant interaction during the study period	Capture strategy: technical setup and data collection
Data analysis	Multiple levels of coding and analysis coupled with multimodal capture allow characterisation of the system at multiple levels of detail helping to reduce bias	Multilevel coding and analysis strategies
Value of findings	The ability to give detailed analysis for selected situations while retaining high-level contextual information supports validation, replication and critique	Multilevel coding and analysis strategies

11.2.2 Limitations

The main limitation of the three-stage approach is the pragmatic demands of carrying out three comparable studies. This is particularly important, where statistically significant sample sizes are necessary or where large portions of the studies require the involvement of practitioners. However, the three-stage comparison is nevertheless a powerful approach. Although not adopted in this research, the approach allows for the combination of multiple studies carried out in varied contexts into a cohesive comparative framework where variables can be identified and isolated. As such, although pragmatic considerations are a major limitation, the potential for expansion of this approach to include multiple intermediary situations offers significant scope for future research – particularly if this is supported by widespread adoption of methodological standards such as those proposed in the core empirical method.

There are several limitations affecting the core empirical method. The primary weakness is the size of the sample able to be used at various levels of detail. However, the multi-level approach allows the researcher to define the sample size required (from statistically significant to single case) and then apply the appropriate level of coding and analysis without losing the advantages of standardisation, contextualisation and additional detailing.

A second issue requiring further validation is the period of acclimatization provided to the participants. This was based on a conservative estimate obtained from a review of relevant literature. A possible improvement would be to carry out a series of studies to explicitly determine the extent of the disruption caused by experimental setup and the length of time required for participants to return to normal practice. In this case the acclimatization period was considered sufficient as evidenced by participant's checking private emails, using online banking and other personal activities. However, for each specific context, the acclimatization period should be designed accordingly.

11.2.3 Practical Aspects

As discussed in Chapters 7, 8 and 9 there were a number of practical issues highlighted by the studies, which can be summarised as: the difficulty in capturing activity away from the office, particularly at home; the complexity of group design activities, even in the laboratory context; and the need to further refine codes to allow for automation or further streamlining of the coding process. Other than these issues, however, the core empirical method was validated in all of its practical aims. In particular, it was able to be adapted to multiple contexts and research foci without losing the benefits of standardisation. Further, it significantly reduced the coding workload whilst allowing multiple sources to be triangulated – improving the capture of difficult situations such as informal meetings or working away from the office. Finally, as the core method allows the adaption of standardised elements and also reduces the coding workload it can be seen that this method will not only impact research but could also have an impact on industry. In this context it offers the possibility for companies to build on a rigorously validated method in order to understand their own design activity with significantly less intellectual and practical effort than is currently the case.

11.3 Characterising the Relationship Between Laboratory and Practice

Characterising the relationship between laboratory and practice was the research aim of this thesis. The relationships described in Chapter 10 were based on three studies – practice (Chapter 7), laboratory (Chapter 8) and intermediary (Chapter 9). Characterising the relationship produced two distinct contributions: the relationships for each activity (Section 11.3.1) and the relationships with regards to contextual characteristics (Section 11.3.2). This section discusses the implications of developing these relationships (Section 11.3.3), the specific implications for design practitioners (Section 11.3.4) as well as the perceived limitations (Section 11.3.5).

11.3.1 The Relationships for Each Activity

This was based on an activity-by-activity analysis of the difference between the laboratory and practice contexts. This characterised each relationship with respect to the different analysis foci for each coded activity – producing a matrix of comparative relationships. The analysis foci included: duration, instances, time per instance, activity over time and stage specific analysis. These relationships were then characterised as 'more', 'not significantly different' or 'less' in practice, when compared to the laboratory.

The relationships were described for each of the identified critical situations in Tables 10.1, 10.9 and 10.12. Comparing between the two contexts, these tables highlighted the number of observed differences for each critical situation. Table 10.1 showed 12 differences from 56 areas of comparison. Tables 10.9 and 10.12 showed 42 of 91 and 59 of 114 respectively. These figures can be summarised as 21, 46 and

52% difference between contexts, where 100% would be an observed difference for every activity in each analysis focus.

11.3.2 The Relationships with regards to Contextual Characteristics

This was a synthesis of the characterisation of the individual activities and was based on the three-point comparison, supporting the isolation and development of relationships for a number of key characteristics: team size, setting, task, level of constraint, embeddedness and the participant. These relationships were described for each of the identified critical situations in Tables 10.2 (2 of 7 characteristics show significant differences), 10.10 (2 of 7 characteristics show significant differences) and 10.13 (3 of 7 characteristics show significant differences), before being drawn together to describe common relationships summarised in Table 10.14 (4 of the 7 characteristics show significant general differences).

11.3.3 Design Research Implications

Together, these two complementary characterisations address a critical gap in the design research literature regarding the relationship between laboratory and practice. Further to the associated method, there are four key implications of identifying the relationships detailed in this research:

1. Direct relationships between designer behaviour in the laboratory and practice for the three critical design situations allow linking and comparison of research findings.
2. Relationships can be combined to provide general relations enabling comparison between laboratory and practice for other situations.
3. The studies validate the core empirical method, which addresses the empirical aspects of the core issues.
4. The method and study together provide a foundation for standardisation and combination of studies in different contexts or of situations.

The primary contribution and implication of the identified relationships is in linking and supporting comparison of research findings across laboratory and practice contexts. These links have been established for each of the three critical situations and provide the foundation for expansion across other design situations such as those highlighted in the observational study (Table 7.10) including embodiment design, design development or reporting. Critically, the nine major findings discussed in Chapter 10 reveal fundamental similarities, in terms of participant behaviour and activity, between laboratory and practice. Further, they highlight the specific characteristics where variation in behaviour is likely, such as 'participant experience' in the ideation situation or 'embeddedness within the design' process in the information seeking situation. These findings validate the use of laboratory-based studies and also support the application of results generated in the laboratory context to situations in practice.

Further, by developing the relationship between laboratory and practice for three different critical design situations, it is possible to identify key characteristics affecting designer behaviour and activity across situations. As such, although these results do not provide definitive relationships for other situations, they form a basis for comparison across contexts, which can be generalised across the design process – highlighting areas likely to cause differentiation.

As part of the studies reported in this research, the core empirical method and underlying multi-perspective approach have been validated. This has the direct implication of validating the core empirical method (Chapter 6) in design research, which, as discussed in Section 11.2.1, addresses many of the empirical aspects of the core issues. Further, as the associated fields heavily influence the method, its validation provides a foundation for further adoption and development of appropriate methods from these fields in design research. Finally,

Combining the method and studies described in this research has an important indirect implication. The results (and subsequent validation of the core method) demonstrate the efficacy of using standardised methods and intermediary settings to isolate and examine variables. As such, they provide a foundation for and promote the adoption of standardised methods, improved contextualisation for comparative purposes and the use/aggregation of multiple studies across contexts and situations in order to develop a deeper understanding of practitioner behaviour and activity. This supports further understanding of the link between the influencing variables and practitioner behaviour and activity as well as the identification and examination of critical variables across contexts.

Table 11.2 sums up the discussion outlined in this section, summarising how the results help to mitigate each of the core issues identified in Table 3.2.

Table 11.2: Issues and their mitigation by the characterisation of the relationship between laboratory and practice

Core issue	**Description of mitigation**
Theory deficit	Helps to develop links between contexts and improve the wider understanding of the affect of various characteristics on practitioners
Insufficient contextualisation	Helps to identify and detail the key contextual characteristics affecting practitioner behaviour and activity across contexts
System clarity	The results provide a detailed multi-perspective picture of practitioner behaviour and activity across contexts and situations The results validate the use of laboratory based studies and support further integration of laboratory and practice based research
Method variability	The findings promote the use of standardised comparable methods and the use of triangulation and the utilisation of methods from the associated fields
Experimental control	The findings promote the use of intermediary settings, the capture of additional contextual information, baseline data
Closing the loop	Not applicable

11.3.4 Design Practitioner Implications

In addition to the research focused implications there are two key implications for design practitioners.

Firstly, the description of the relationships outlined in Chapter 10 allows the practitioner to understand and more effectively apply findings from experimental design research studies. Further, the qualitative discussion allows the practitioner to decompose the application of research findings while also giving insight into the various factors affecting their own work.

Secondly, the creation of a standardised method allows design practitioners to apply a validated research approach without having to carryout significant development work. Also, it is envisaged, that by being able to add to/draw on a standardised body of studies practitioners will be able to more rapidly identify relevant data that can be used to explore their specific issues without the requirement for further studies.

11.3.5 Limitations

The main limitation of the study described in this thesis (Chapter 10) is the size of the sample used. Specifically, in order to fully validate the findings, it would be necessary to examine a larger sample of situations in practice and carry out sufficient laboratory and intermediary studies to allow statistically significant averages/trends to be identified. This would allow quantitative relationships to be established between contexts where possible and would allow a more refined analysis of the contextual characteristics affecting designer behaviour and activity. Further, by assessing a much larger sample of practice-based situations, a more nuanced picture could be developed of how situations in practice vary and what variables are most important or common across situations.

There are two main ways this limitation could be addressed based on the research described in this thesis. Firstly, the core method allows future researchers to build on the standardised elements to contribute to a central body of data, which could subsequently be used to develop a large statistically significant dataset. Secondly, the findings outlined in Chapter 10 could be used to guide specific exploration of behaviours where significant differences were observed – detailing and validating each relationship individually to build up a mosaic of complementary studies.

A second limitation is that, although this study sought to compare a situation as closely as possible in different contexts, some variation in the makeup of the situation was unavoidable, i.e. changing the three situations such that they formed a single coherent set of tasks for the laboratory study. Although, this is a limitation of the comparison element, it is a strength of the methodology as the type of manipulation used to create the laboratory situations is typical of design research studies and as such provides a more suitable basis for validation of laboratory-based studies.

A final pragmatic limitation is that due to the exploratory nature of this work, coding and analysis were time consuming labour intensive activities. Automating these processes would not only facilitate the development of larger datasets, but also allow for significant reuse of existing studies.

11.4 Concluding Remarks

The scope and limitations of the presented research can be summarised as follows. Firstly, the core empirical method and multi-perspective approach are based on a broad review of literature in design research and the associated fields and, as such, are potentially widely applicable across a range of different design situations and study types. In this context, the method was validated for three different research foci (the critical situations) and for high-level through to detailed analysis. Secondly, the presented research focused on practitioner centric study. In this context, the research findings and method were validated against a number of extant studies and establish a number of core relationships between laboratory and practice in design research. Thirdly, the validation of the method and presented research findings provide a foundation for standardisation and combination of design research studies in different contexts and situations for improved significance and validation of field-wide research (Sections 10.1.3, 10.2.3 and 10.3.3). Finally, the identified relationships depict the variation in participant behaviour and activity between the laboratory and practice within the context of a small sample of UK based students and practitioners. In this context, the relationships can tentatively be applied to research throughout the UK. Further research is required to validate the identified relationships across cultural/national boundaries.

Based on the results detailed in Chapter 10 and discussed in this chapter, a number of conclusions can be drawn. Further, based on the identified limitations, future research areas can be identified. These conclusions and research opportunities are detailed in the next chapter.

"Per scientia ad astra"

12

Conclusions

This research had the aim of understanding the relationship between empirical design studies in the laboratory and in practice. To this end a novel core empirical method was created and used to undertake three primary studies, which were subsequently used to develop the link between the two contexts.

This chapter outlines the major conclusions can be been drawn from the research presented in this thesis. Firstly, a summary of the research is presented, breaking down how the research questions and objectives have been answered. Secondly, the implications of the research are outlined. Thirdly, the contribution to knowledge is presented. Finally, areas for further research are outlined, based on the limitations discussed in the previous chapter.

12.1 Summary

This research tackled each of the research objectives in order to address the overarching research aim via two research questions. This section outlines how the objectives, research questions and aim were addressed.

12.1.1 Research Objectives

There were five research objectives forming the foundation of the research. This section outlines each objective, how it was addressed, the main findings and where this can be found within the thesis.

Objective 1: To create a methodology for investigating the relationship between practice and laboratory-based studies.

This objective was addressed by the creation of a three-stage methodology (Chapter 4) using studies in practice, laboratory and intermediary contexts to develop a three-point comparison of designer behaviour and activity for a number of critical design situations. The methodology is depicted in Figure 12.1, which is a repetition of Figure 4.4 and is included as an aid memoire. This was supported by a review of literature in design and its associated fields.

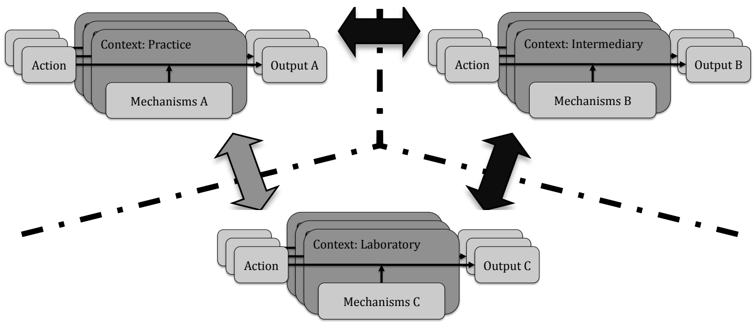

Figure 12.1: The three-stage methodology

Objective 2: To review and devise a technology strategy for capturing designer behaviour and activity.

This objective was addressed by the identification of capture technologies (Chapter 5) and the creation of a multi-perspective capture approach able to flexibly capture participant behaviour and activity in multiple contexts (Table 5.11). This was supported by a review of existing capture technologies and approaches as well as a scoping study using student participants to assess the performance of the capture technologies in a range of possible design situations (Section 5.4).

Objective 3: To create an empirical method to capture, code and analyse designer behaviour and activity.

This objective was addressed by the creation of the core empirical method, which including multi-level capture, coding and analysis strategies (Chapter 6). This was created to address the core issues using the mitigating approaches identified in Objective 1 and was specifically designed to mitigate eight problems affecting contemporary methods. The main contributions of the core empirical method are summarised in Figure 12.2, which also acts as an aid memoir for Figure 6.5 where these are described in more detail. This was supported by the scoping study described in Chapter 5.

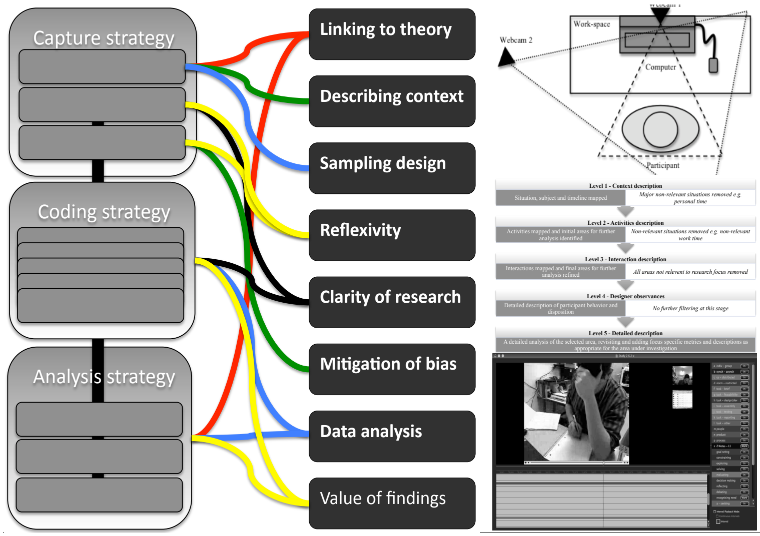

Figure 12.2: Summary of the major contributions of the core empirical method

Objective 4: To identify and characterise designer behaviour and activity for critical design situations.

This objective was addressed by the identification of the three critical situations (Chapter 7) and the characterisation of designer behaviour in practice (Section 7.5.2). This was supported by an extensive observational study of practice including three weeks of observation using three practitioner participants. It is to be noted that it was also necessary to establish what constituted critical situations in the context of this work. This was done using the observational study, which identified: information seeking, ideation and design review. These were subsequently validated by comparison to extant literature

Objective 5: To characterise the relationship between practice and laboratory-based studies for critical design situations.

This objective was addressed by the characterisation of two sets of relationships linking laboratory and practice (Chapter 10). This link was characterised on an activity-by-activity basis in Tables 10.1, 10.9 and 10.12 and with respect to the underlying characteristics of the design situation in Tables 10.2, 10.10 and 10.13. This defined a set of multifaceted relationships for each of the three critical design situations based on the three studies – one in practice, one in the laboratory and one in an intermediary setting. This was then aggregated to identify general relationships with respect to the characteristics of the design situation (Table10.14).

12.1.2 Research Questions

Based on the completed research objectives, it is possible to answer the two research questions. This section outlines each of the research questions, how they have been answered and which objectives contributed to them.

Research Question 1: How can designer behaviour and activity be characterised to enable comparison between design situations?

This research question was addressed using Objectives 1 and 2. It was answered using the three-stage methodology. This allowed isolation of specific variables, which supported by the core empirical method – utilising multi-level capture, coding and analysis – drives standardisation, contextualisation and multi-level comparison (Figure 6.5). This was supported by a literature review of methods and technologies as well as a scoping study using student participants.

Further to the methodological aspect of developing the comparison this research also established 4 key areas for characterising specific differences in behaviour: focus of activity, activity over time, situation specific activity and participant enthusiasm and contentedness.

Research Question 2: What is the relationship between designer behaviour in practice and laboratory-based critical design situations?

This research question was addressed using Objectives 3, 4 and 5. It was answered by the creation of the two sets of relationships (activity-by-activity and with respect to situational characteristics). These were then combined to derive general relationships between laboratory and practice with respect to the fundamental characteristics of the design situation as outlined in Table 10.14. These can be summarised as follows:

Significant Differences

- **Task**: Sketching activity is task dependant with significant differences in the design review where there was the largest variation in task between contexts.
- **Level of constraint**: There is consistently greater variation in the scope of activities undertaken and in the range of enthusiasm and contentedness.
- **Embeddedness**: This characteristic has the most significant affect on activity and behaviour. In particular it affects what prior work/information is brought to a situation and as well as the outputs in the form of future planning not directly linked to the current situation.
- **Participant**: Although this characteristic is important, as there is significant interpersonal variation it has little discernable affect across contexts except in the case of ideation. This suggests it plays an important role where cognitive aspects are being considered.

No Significant Differences

- **Team size**: Results show no significant differences within the range of 3 – 5 team members. All results were within the range of variation see in the laboratory.
- **Setting**: Results show no significant differences due to the differences between the office and laboratory environments. All results were within the range of variation see in the laboratory.

Not Applicable

- **Stage of the design process**: Not applicable for comparison purposes because this characteristic could not be isolated in any of the three situations.

12.2 Research Aim

The research aim was:

"To improve empirical design research by characterising the relationship between practice and laboratory-based studies for design situations."

This has been fulfilled by the identification and description of relationships linking laboratory and practice for three critical design situations using the core empirical method.

12.3 Implications

Addressing the research aim via the research questions has two main implications for design research, summarised as follows:

- The creation and validation of the core empirical method supports the further adoption of standardisation, contextualisation and, uniquely, multi-level coding and analysis as key methodological practices for improving design research methods. Further, the method and studies together form a foundation for the comparison of multiple studies with various research foci, context and situation; supporting the generation of larger datasets and the identification of fundamental trends and relationships within design.

- The development of the relationship between laboratory and practice supports the application and impact of design research findings in practice. Further, it promotes the validation and application of extant studies within the field, which do not currently have independent practice-based validation. Finally, it allows practitioners to more meaningfully draw on laboratory-based research by providing a deeper understanding of the likely underlying variables and how these affect research findings.
- The combination of the described relationships and the standardised method allow design practitioners to more effectively apply research findings whilst also providing them with a method that can be use to explore specific design issues without having to do significant development work. Further, by providing a standardised method it is anticipated that practitioners will be able to more effectively build on and identify areas of relevant research data/knowledge without having to carry out the major research themselves.

Based on these conclusions a number of contributions to knowledge can be identified and are summarised in the next section.

12.4 Contributions to Knowledge

There are two primary contributions to knowledge based on the work described in this thesis.

Firstly, the core empirical method contributes to the existing body of empirical methods in design research. This contribution includes the multi-perspective methodological approach, the multi-source capture strategy, the five-level coding strategy and the multi-level analysis strategy. Although, combining capture, coding and analysis into a single method is not in itself new, each element constitutes a novel contribution creating a more effective overarching method. This integrated method can deal with multiple research foci for characterising designers behaviours and activities whilst maintaining context, standardisation and also addressing the identified methodological problems.

Secondly, the presented research relates laboratory-based studies to practice for three critical design situations. Establishing a relationship for a number of variables in different contexts. This comparison exceeds existing work carried out in design research and provides a novel insight into how changing the context affects activity and behaviour – linking laboratory to practice. This link not only supports the adaption, application and comparison of laboratory-based research to practice but also provides, the foundation for bringing together human-centric research within design research.

In addition to these primary contributions, two secondary contributions can be identified. Firstly, the review of research methods drove the synthesis and description of six core issues and mitigating techniques. This brings together design and the associated fields in a novel way, providing a foundation for further inter-disciplinary comparison and development, particularly with regard to improved methods. Secondly, the validation of using an intermediary study as an effective tool for discriminating and identifying key relationships contributes an important technique to the range methods available to the design researcher.

12.5 Further Research

Finally, the discussion outlined in Chapter 11 and the conclusions identified in this chapter highlight several potential areas for further research. These fall into two main areas: methodological (Section 12.5.1) and empirical (12.5.2).

12.5.1 Further Research in Methods

There are numerous areas for further research in the development of methods for design research, summarised as follows:

- Describing, defining and grouping a comprehensive set of contextual variables that can be used to effectively baseline participants and studies to allow aggregation and comparison.
- Developing automated or semi-automated measures for some or all of the defined coded activities in order to effectively allow increased sample size and reduced workload.
- Developing rigorously defined links between the elicited contextual information and sample design in order to more effectively target of studies.
- Specifically examining the change in behaviour and activity caused by experimental processes and setup in order to identify optimum acclimatization periods and to examine the effect of introducing such technologies.
- Developing links between the various levels of the coding strategy in order to identify relationships between individual and groups of codes and to further streamline the coding and analysis process.

12.5.2 Further Research in Designer Activity and Behaviour

There are four areas for further research in the examination of designer behaviour and activity, summarised as follows:

- Determining the specific effect various contextual characteristics have on designer behaviour.
- Expanding the sample size of the outlined studies in order to identify the presence of statistically significant trends and assess the magnitude of their effect.
- Broaden the scope of the outlined studies in order to assess the effect of cultural or national variables.
- Expand the use of contextual characteristics to drive standardisation and comparison between studies by developing a framework in which extant studies can be aggregated in order to identify significant trends and patterns across multiple contexts and situations.
- Specifically vary the identified characteristics (e.g. task or embeddedness) to further explore the nature of the relationship between contexts and identify

fundamental trends/relationships which are unaffected by changing characteristics.

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Appendix A

Code Groups

This appendix shows an example of how the groups of codes were identified and further grouped into categories such as conceptual design or design review. The full set of codes and code combinations is provided digitally in the file: Code data.xlsx. Figure A provides an example for the groups conceptual design and design review showing how the individual codes were presented and then sorted.

Conceptual design

Design review

Track Name																							
indiv - group	1					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
synch - asynch		1	1																				
co - distributed		1	1			1	1	1															1
task - brief				1					1														
task - feasability										1	1												
task - design/dev	1	1			1	1						1	1	1	1								1
task - assembly																							
task - testing																							
task - reporting																							
task - other			1													1	1	1	1	1			
focus - people																							
focus - product	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1		1
focus - process																			1	1		1	
goal seting							1	1	1			1				1			1	1			
constraining			1																				
exploring	1																						
solving						1							1				1	1					1
evaluating					1					1	1			1									
decision making		1																					
reflecting				1																			
debating										1											1	1	
recognising need																							
a - seeking info															1								
a - requesting info											1												
interpreting					1																		
validation																							
b - informing		1		1			1												1				
b - clarifying			1					1	1		1			1	1			1					1
b - confirming																	1						
managing			1													1		1		1			

Figure 0.1: Code groups for conceptual design and design review

Appendix B

Observation Study Background Questionnaires

Company Background

Please fill out this questionnaire in order to give some contextual information on the company's background and composition.

If you do not wish to answer any question for any reason please mark as such and move on.

All answers will remain strictly confidential and will be used for characterisation and generalization purposes only. All answers will be anonymised. Please fill in your answers for all questions. If a particular point is not accounted for please use the other option at the end of the question to fill this in. Space is provided at the end of the sheet for any comments you may have.

Q1. Company Size?

What is the annual turn over of the company?

How many full time employees work for the company?

Approximately what percentage of the company's employees are engineers as opposed to dedicated management or support staff?

Q2. Company focus?

What is/would be the company's mission statement?

What does the company specialise in and how is this covered?

Medical engineering	

Q3. Company background?

Does the company have any significant partners such as sister, parent or subsidiary companies or institutions?

No	
No	

If yes, how closely is the company tied to its partners?

How old is the company in its present form?

Comments/feedback

Personal Background

Please fill out this questionnaire in order to give some contextual information on your background, training and experience.

If you do not wish to answer any question for any reason please mark as such and move on. This questionnaire will in no way be used to reflect on you personally.

All answers will remain strictly confidential and will be used for characterisation and generalization purposes only. All answers will be anonymised. Each question has had example answers filled in (italics). Please replace these with your answers. If a particular point is not accounted for please use the other option at the end of the question to fill this in. Space is provided at the end of the sheet for any comments you may have.

Q1. Socioeconomic background?

What is your age?

26

What is your postcode?

BA2 3DF

What is your current occupation?

Mechanical engineer (job description)

What is your highest level of education (Include any equivalent vocational or other education at the relevant level)?

Select one :

Doctoral degree
Masters degree
Bachelors degree
Associate degree
Some university 1 2 3 4 years (please circle as appropriate)
School A levels
School GCSE's

What is your gross individual income per year (range to nearest 10K)?

Select one:

0-10K
10-20K
20-30K
30-40K
50-60K
60-70K

70-80K
80-90K
90-100K
100K+ please specify unless over 200K

What is your current level of property ownership?

Select one:

Rent
Own 1 house – with mortgage
Own 1 house – no mortgage
Do you own any other properties: How many – What type –
Other (please explain)

Q2. What is your educational background (Detail)?

A levels/equivalent:

Subject	Grade
Maths	*A*

Degree(s)/equivalent:

Level	Institution	Description
MEng	*University of Bath*	*Automotive engineering with placement – specialising in biological design in the final year*

Other education or professional qualifications of note:

Type	Description
CEng	*Engineering chartership*

Q3. What is your professional background (Detail)? – Please state any experience over 6 months.

Placement(s) during degree (if applicable):

Company	Duration	Job role	Comments on your experience there
Castrol, BP – Approx size of site ~ 400 personnel	*14 months*	*Test engineer*	*Running and designing engine test cycles for lubricant oil testing. Primarily using a engine test cell.*

Previous employment:

Company	Duration	Job role	Comments on your experience there
Castrol, BP – Approx size of site ~ 400 personnel	*14 months*	*Test engineer*	*Running and designing engine test cycles for lubricant oil testing. Primarily using a engine test cell.*

Comments/feedback

Appendix C

Observation Study Participant Information

Checklists

Start of Day:

1. Turn on Panopto (log in if necessary)
2. Remove 'power point' tab
3. Add additional camera
4. Ensure cameras have not been moved and are:
    a. First camera pointed at participants body
    b. Second camera pointed along desk area
5. The three recording streams should now be:
    a. Computer screen
    b. Front on camera
    c. Side camera (small feed)
6. Start recording
7. Ensure mobile camera is charged and ready for any meetings
8. Ensure pen is charged and ready for note taking

End of Day:

9. Stop Panopto recorder
10. Dock and synchronise pen
11. Copy Panopto recording file for that day onto hard drive (specific folder for participant and date)
12. Fill in end of day questionnaire if appropriate
13. Ensure mobile camera is docked and charging
14. Ensure pen is docked and charging

Appendix C

Equipment Briefing Document

LiveScribe pen

1 x dock

1 x pen

1 x notepad

Keep the dock plugged into the computer for charging the pen whenever the pen is at its base station. This can be removed and reattached as necessary to charge the pen. The pen and its associated note pads should be used for all written work using a pad, effectively replacing your logbook.

Ensure the pen is ON when using it. The pen can be used on other paper, post-its etc, however, this will not be recorded. Data will be collected from these at the end of each day.

Webcam

2 x webcams

1 x tripod mounted – looking at desk activity

1x screen mounted – looking at participant activity

These should always be attached and active when the computer is at its base station.

In the event of needing to move the computer (for a meeting etc.) –

Pause panopto

Unplug cameras

After meeting

Plug in cameras

Un-pause panopto

Data will be collected from these at the end of each day through the Panopto software.

Mobile camera

1 x mobile camera

1 x charger (at base station)

1 x camera case

When leaving the desk, put camera around neck and start recording ('rec' button on back). Ensure camera is stopped after the meeting. When the camera is not in use, use charger to keep it topped up. Always ensure meeting participants know and are fine with being recorded – This will be discussed and agreed during the training week. Data will be collected from these at the end of each day and the memory cards cleared for the next.

Computer

You are free to use the computer in any way you see fit or require for work.

- When at work ensure Panopto is on and running at all times unless there are extenuating circumstances as agreed during the training week
- Ensure ManicTime is installed, please do not delete
- Install any software updates for the webcams

Panopto

Runs actively when started. The program can be paused if personal matters need to be dealt with, this will be agreed during the training week. This will require some free space on your computer to record the video data.

Manic-Time

Runs in background when computer is on, do not delete.

Daily Record Form

Q1. Were there any significant events that you feel were not captured during the day?

A. yes no

Q2. If yes for Q1, please briefly describe the nature of the event(s) and its impact on your day/work. – Use additional space if necessary.

Appendix C

A. Description and impact

Q3. Were there any significant work related events that you feel were not captured during out of work hours?

A. yes no

Q4. If yes for Q3, please briefly describe the nature of the event(s) and its impact on your day/work. – Use additional space if necessary.

A. Description and impact:

Appendix D

Product Design and Development Course

Course outline document:

ME30294: Product Design and Development 2011 - 12

Elies Dekoninck and Chris McMahon

Introduction

This unit aims to:

- Introduce strategic, cultural, organizational and technological aspects of product development in a global context.
- Introduce the product design discipline and typical activities undertaken such as: concept generation, ergonomics and styling.

The course will benefit students interested in New Product Development (NPD). The course will enhance theoretical knowledge of NPD processes and introduce design activities that can supplement existing technical engineering skills.

Each lecture topic covers either: a sub-discipline/specialisation of product development; or a strategic issue of importance to product development. By covering a broad range of topics we hope to spark your interest in these topics, and improve your own product development processes and practice. The assignments will allow you to research and expand on the topics of particular interest to you.

Relation to other Units

Although this is a theoretical course, not a practical one, it is designed to complement the practical course: ME 40213 Specialist Design I.

Course Structure and Activities

The programme is made up of a triple lecture / tutorial slot on Monday afternoon will be used for a mixture of lectures and tutorials. Each tutorial will be different in its approach: guidance on individual assignments, exam preparation, group work for assignment.

The course will be assessed through: an individual assignment; a group assignment; and a written examination. The breakdown and dates are as follows.

Assessment:	**Proportion of marks:**	**Key Dates:**
Individual Assignment	25 %	Submit Monday 14/11/11 before 23:59
Group project	25 %	Concept presentations 05/12/11 Poster submission 12/12/11 before 12:00
Exam	50 %	Week 13/14/15

We will be making extensive use of the University's virtual learning environment (VLE), 'Moodle' during the course. We may also use other parts of the University's virtual learning environment system during the course and will up-load: lecture notes, exercises, and samples of previous course work.

Appendix E

Laboratory Study Briefing Documents

Welcome to the Bath Engineering Design experiment

Understanding how engineers' work is vital to effectively communicating engineering research to industry. One means to achieve this is through the study of teams of young designers. Areas of particular and sustained interest include information seeking, creativity, design development and design review.

By taking part in this exciting study *you* will be helping to push back the boundaries of understanding in these areas. In addition to supporting much of the research carried out in this department this study gives you a chance to gain an insight into your own design practice.

All results will be anonymised during analysis and publication – All data will be stored securely and destroyed in accordance with the data protection act.

The study is in 5 parts:

1. Two short questionnaires
2. Task 1: An information seeking activity
3. Task 2: A brainstorming activity
4. Task 3: A design development activity
5. Task 4: A design review activity

Q: Why do we care about these tasks?

A: Collectively these tasks account for nearly 30% of an engineer's time and are worth millions of pounds to the UK economy. Better understanding these activities allows researchers to more effectively make changes, develop tools or simply solve engineering design problems.

Appendix E

Q: What do you get out of this study?

A: In addition to the financial incentive there are several other motivating factors you may be interested in. Based on the tasks in this study you will have the opportunity to gain a better understanding of your own design activity and potentially identify areas that you can develop in the future. We will also be generating a measure of your creative style and level - things often assessed during job interviews – these will be fed back to you individually.

Appendix E

Experimental Brief - TASK 1
This is an individual task using the computer provided and will last for fifty minutes. Please do not talk to the other participants at this stage.

You are free to use the notepad and computer provided, as well as any books or catalogues you choose in the DAC. Please search for information in order to fulfil the following brief:

"You are to design a universal camera mount for use on an aerial vehicle. The aerial vehicle is to be used by an amateur photographer, primarily to take still photos. Using any means available to you search for and note down information that may help."

You will be told when to begin by the researcher who will also let you know when there is 5 minutes left.

If you have any further questions please ask now.

Appendix E

Experimental Brief - TASK 2

This is a group task using the meeting area provided and will last for fifty minutes. Please feel free to discuss and make notes etc. as you wish. You are free to use the notepad, whiteboard and notepaper provided.

During this task we would like you to brainstorm ideas to fulfil the following brief. The aim of this task is to generate as many viable ideas as possible within the time available. Please record these ideas on the whiteboard as they occur but feel free to make additional notes as necessary.

"Using the specification provided, develop a variety of concepts capable of mounting any camera, while slung under a helium balloon. The mount must be capable of orientating the camera to any point in a hemi-spherical plane underneath the balloon, and must be operated remotely."

Please see the attached sheets for more information.

You will be told when to begin by the researcher who will also let you know when there is 5 minutes left.

If you have any further questions please ask now.

Appendix E

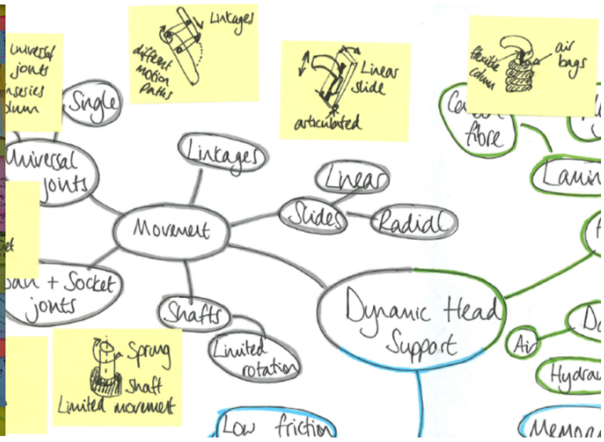
Brainstorming

Produce as many ideas as possible.

Consider all information that you have gathered in stage 1.

Consider as many technologies, products, theories and systems as possible.

Be supportive of all ideas proposed. Instead of finding faults, suggest ways that they could be improved.



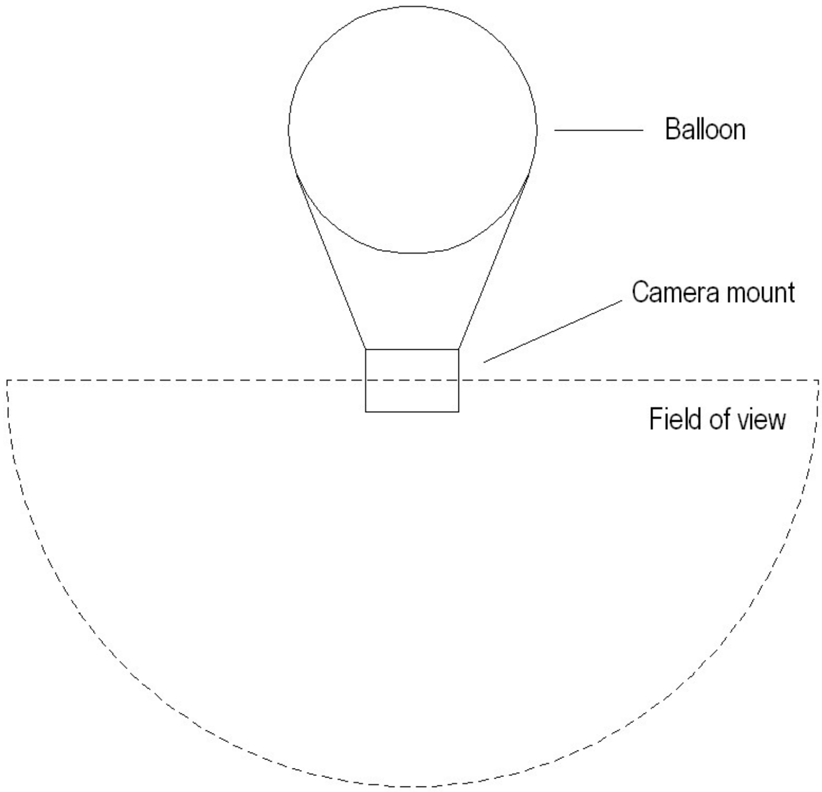
Specification

Total mass of camera and mount	*6kg*
Must take a range of cameras within weight limits	
Cost (cost price) of the mount	*£75*
Operational life (per charge)	*1.5 hours*
Speed of operation – 360º pan	*max 30s min 10s*
Type of control	*via laptop*
Range of controller	*100m*
Range of rotation	*360º by 180º*
Volumetric size	*200x200x150mm*
Balloon connection	*flexible*
Balloon size	*Spherical -*

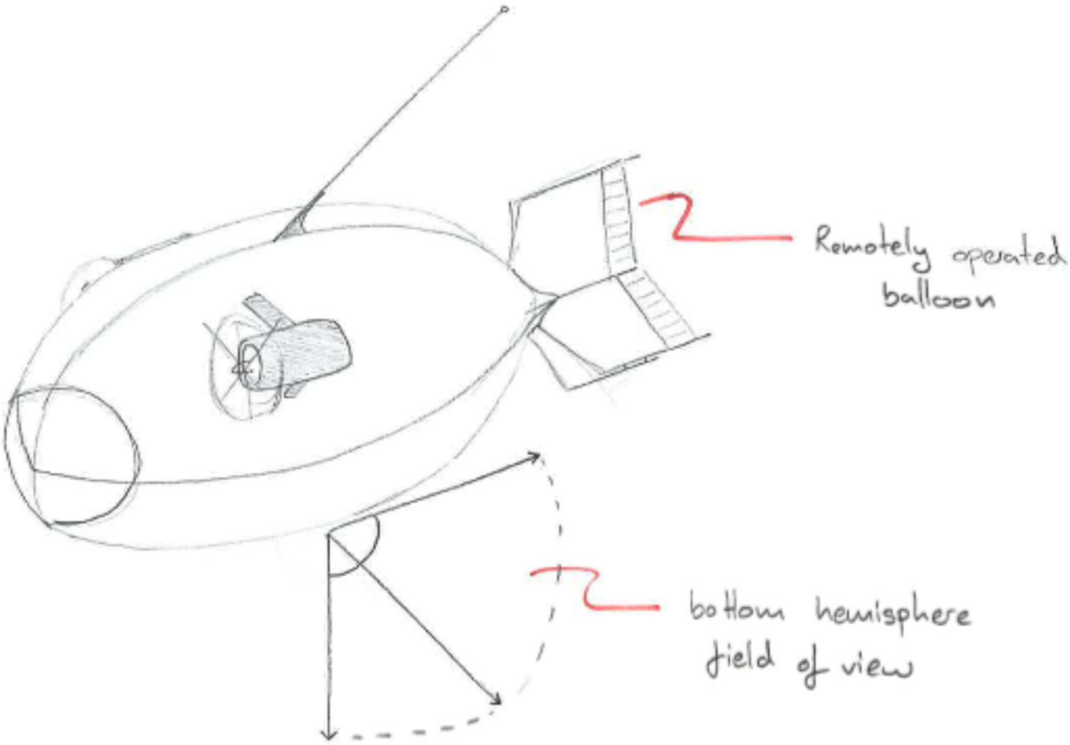
The design for the balloon has already been finalised, and is tolerant of any connection or interface with the camera mount.

Although you should try to minimise motion in the mount where possible, you do not need to consider vibration.

Appendix E



Balloon
Camera mount
Field of view



Remotely operated balloon
bottom hemisphere field of view

Appendix E

Experimental Brief - TASK 3
This is an individual task using the computer provided and will last for one and half hours. Please do not talk to the other participants at this stage.

During this task we would like you to develop one (1) of the concepts discussed during your brainstorming session based on the following brief. You are free to use the computer and notepad provided as well as any books you wish from the DAC. Develop your concept to as high a level of detail as possible. Please record each action in your logbook as you proceed.

"Develop an appropriate, feasible, dimensioned, detailed solution."

Further details

Available machines for manufacture: lathe, end mill, injection moulding, and laser cutter
Assembly: By hand

Your work from this stage will be given to a skilled technician, who will build a fully operational prototype. It must therefore include:

- *General dimensions*
- *All critical dimensions*
- *Materials to be used*
- *A description of the mode of operation of all systems*
- *A description of the method of assembly*
- *A description of how the design completes its function*
- *Preferred methods of manufacture*

Although unfamiliar with the project, the technician will attempt to fill in any information that they need, should you not provide it.
Complete as much work as you can, within the time allotted.

You will be told when to begin by the researcher who will also let you know when there is 5 minutes left.

If you have any further questions please ask now.

Appendix E

Experimental Brief - TASK 4

This is a group task using the meeting area provided and will last for fifty minutes. Please feel free to discuss and make notes etc. as you wish. You are free to use the notepad and notepaper provided (please do not use the whiteboard for this task). During this stage one member will be asked to take a team leader role and should pay particular attention to delivering the final concept as outlined below.

During this task we would like you to review your designs (as developed in the previous task). The aim of this task is to select and develop one (or a combination of ideas) into a final concept to be taken forward to production. Please see the following brief:

"With your colleagues, and using your detailed developed concepts, select and further develop a single, final concept that best fulfils the brief and specification. Please record this final concept on a single sheet of the provided A3 paper."

You will be told when to begin by the researcher who will also let you know when there is 5 minutes left.

If you have any further questions please ask now.

Appendix E

Experimental Debrief

The aim of this study has been to develop a detailed picture of trainee engineers design behaviours and activities when confronted with a number of different commonly encountered design situations. This data will be used to compare with data from industrial engineers who have also completed this study. Based on this comparison a qualitative and quantitative measure of similarity will be developed for the information seeking, creativity and reviewing tasks. This will then be used to support the validation of experiments conducted using trainee engineers such as you – a critical issue in engineering design research today.

If you are interested in discussing the implications of this work further please approach either of the researchers conducting the study, who will be more than happy to provide you with further information.

Thank you for your time – without you this research would not be possible

Thanks from Phil and Chris!

Appendix E

Questionnaire 1 – Creative Style (KAI Test)

This questionnaire has been designed to determine your creative style; the way in which your behaviour will lead to a creative outcome. Please think about each question and answer honestly.

Please include your name on the answer sheet. All results will be anonymised during analysis and publication.

You will have up to 10 minutes, after which the researcher will collect your answers.

Brief:

We all find it necessary to present a certain image of ourselves ***consistently*** over a long period. In some cases this proves easy ***as we are like this***; sometimes it is very difficult as we are not like this at all.

For instance, some of us are early risers. It is easy for such people to present the image of being good timekeepers at work. So, if you are an early riser and were asked how easy or hard it is for you to present an image at work of a good timekeeper you would put a clear cross on the scale below on or near 'very easy'.

V.Hard	Hard		Easy	V.Easy

. . . .

If you are the extreme other sort, you would find being on time ***every*** morning for a ***long period*** difficult, and you may well put a cross on the scale at the 'Very hard' end.

Please indicate the degree of difficulty (or ease) that would be required for you to maintain the image, ***consistently*** for a ***long time***, for each item that is asked of you on the next page.

Appendix E

How easy or difficult do you find it to present yourself consistently, over a long, period as:

	V.Hard	Hard		Easy	V. Easy
A person who is patient	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who conforms	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who when stuck will always think of something	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who enjoys the detail work	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who would sooner create something than improve it	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who is prudent when dealing with authority or general opinion	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who never acts without proper authority	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who never seeks to bend (much less Break) the rules	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who likes bosses and work patterns which are consistent	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who holds back ideas until they are obviously needed	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who has fresh perspectives on old problems	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who likes to vary set routines at a moment's notice	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who prefers changes to occur gradually	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who is thorough	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who is a steady plodder	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who copes with several new ideas and problems at the same time	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who is consistent	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who able to stand out in disagreement alone against a group of equals and seniors	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who is stimulating	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who readily agrees with the team at work	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who has original ideas	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who masters all details painstakingly	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who proliferates ideas	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
A person who prefers to work on one problem at a time	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .

Appendix E

A person who is methodical and systematic	. . . .
A person who often risks doing things differently	. . . .
A person who works without deviation in a prescribed way	. . . .
A person who likes to impose strict order on matters within own control	. . . .
A person who likes the protection of precise instructions	. . . .
A person who fits readily into 'the system'	. . . .
A person who needs the stimulation of frequent change	. . . .
A person who prefers colleagues who never 'rock the boat'	. . . .
A person who is predictable	. . . .