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Understanding and Supporting Creativity in Design

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"The thing that makes a creative person is to be creative and that is all there is to it."

Edward Albee

Andy Warhol's "Pop Art" style applied to Auguste Rodin's "The Thinker" sculpture.

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List of Abbreviations

ANOVA - ANalysis Of VAriance
CoI - Communities of Interest
CoP - Communities of Practice
CSCW - Computer Supported Cooperative Work
CST - Creativity Support Tools
EDC - Envisionment and Discovery Collaboratory
EMS - Electronic Meeting Systems
GDSS - Group Decision Support Systems
GUI - Graphical User Interface
HCI - Human-Computer Interaction
H-Creativity - Historical Creativity
H-Novel - Historical Novelty
PC - Personal Computer
PD - Participatory Design
PDA - Personal Digital Assistant
P-Creativity - Psychological Creativity
P-Novel - Psychological Novelty
PSPD - Public Social Private Design
RFID - Radio-Frequency IDentification
RO - Research Objective
RQ - Research Question
SD - Standard Deviation
UCD - User-Centred Design
UI - User Interface

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Thank you!

Abstract

The topic of this thesis is to understand and support creativity in design. While the interdisciplinary field of Human-Computer Interaction has been described as a 'design-oriented field of research', it has been argued that our understanding of design is relatively poor. The process of design has been described as involving a certain 'mystical element'. The 'mystical element' of the process of design has been described using terms such as 'creativity'. With a poor understanding, it is hard to know how best to support creativity. This could impact the processes and outcomes of design. This thesis attempts to increase our understanding of creativity in design, thereby increasing our knowledge of how best to support the creative design process.

The thesis develops an understanding of creativity in the forms of a definition of creativity, metrics and measures of creativity and an understanding of the creative process as it is expressed in the activity of design. These contributions are developed throughout the thesis building upon theoretical work and are refined reflecting upon our practical studies.

Furthermore, we develop an understanding of how to support creativity in design by eliciting requirements for creativity support tools, based upon our theoretical work and practical studies. The application of these requirements are reflected upon and illustrated through the evaluation of an existing support tool and the design, development and evaluation of our own creativity support tool: Public Social Private Design (PSPD).

Chapter 1

Introduction

The field of Human-Computer Interaction (HCI) by its very nature is concerned with the design, development and evaluation of interactive systems for human use and the study of phenomena surrounding them [Dix *et al*, 1993; Hewett *et al*, 1996; Preece, 1994]. Within the field of HCI, design has been a primary focus [Atwood & Wania, 2006; Fallman, 2003]. Fallman [2003] goes as far as to say, 'HCI has emerged as a design-oriented field of research, directed at large towards innovation, design, and construction of new kinds of information and interaction technology'. However, many researchers [e.g. Fallman, 2003; Rosson *et al*, 1987] argue that our understanding of design is relatively poor. Design has been described as involving some 'mystical element' [Fallman, 2003], which has been described by many researchers and practitioners using terms such as 'creativity' [e.g. Alborzi *et al*, 2002; Buur & Bødker, 2002; Fallman, 2003; Guindon, 1990; Rosson *et al*, 1987]. This thesis is a study of creativity in design.

This thesis builds upon a wealth of research from various fields of research developing a theoretical understanding of creativity. It presents a practical perspective, refining our theoretical understanding of creativity, eliciting requirements for creativity support tools (CST). These requirements further act as a set of heuristics for evaluating tools for supporting creativity. An in-depth evaluation of an existing CST - the Envisionment and Discovery Collaboratory (EDC) - allowed us to identify strengths and weakness of the EDC, suggesting improvements to the EDC and other CST, as well as allowing us to reflect upon and refine our requirements for CST. This led to the design, development and evaluation of our own CST: Public Social Private Design (PSPD).

This chapter presents the background to this research, identifying the research problem, questions and objectives to be addressed throughout the thesis. We report the research approach taken to address our research questions (RQ) and research objectives (RO), and briefly note the contributions of the thesis. We then set the scene for the thesis, outlining the remaining chapters.

1.1 Background

HCI involves the design, development and evaluation of interactive systems and the study of their use [Dix *et al*, 1993; Hewett *et al*, 1996; Preece, 1994]. The field of HCI has been described as a 'design-oriented field of research' [Fallman, 2003]. Design in HCI often involves the design of interfaces, interactions and experiences [Grudin, 1990; Preece *et al*, 2002; Wright & McCarthy, 2004].

Design has been described as a *process* that produces a *new or refined product* [Alexander, 1964; Coyne, 1995; Ehn, 1989; Fallman, 2003; Jones, 1970; Mayall, 1979; Rasmussen *et al*, 1994; Rittel, 1984; Schön, 1983; Simon, 1996; Vicente, 1999]. In terms of design in HCI, the product is the interface, interaction or experience. However, what is the process that produces such products?

The process of design has been described as involving a certain 'mystical element' [Fallman, 2003]. Both researchers and practitioners have found it difficult to articulate where their design ideas come from, or even differentiate between the process of generating new ideas and refining them [Rosson *et al*, 1987]. The 'mystical element' of the process of design has been described using terms such as 'creativity' [e.g. Alborzi *et al*, 2002; Buur & Bødker, 2002; Fallman, 2003; Guindon, 1990; Rosson *et al*, 1987].

If we don't understand creativity in design, it is hard to know how best to support the creative process of design [Johnson & Currthers, 2006; Rosson *et al*, 1987]. Furthermore, it is argued that the support provided for the creative process of design impacts the quality of the design process itself and its resultant products [Rosson *et al*, 1987]. Hence, two research problems emerge: our poor understanding of the creative process of design; and the lack of support for the creative process of design.

1.2 Research questions

Despite the fact that HCI is a 'design-oriented' field of research, we do not have a clear understanding of the creative process of design. This prompted our first RQ:

RQ1: What is creativity in design?

While this question may be relatively novel to the field of HCI [e.g. Candy & Edmonds, 1999; Candy & Hori, 2003; Johnson & Currthers, 2006], it has existed for many years in other fields of research [e.g. Sternberg, 1999; Sternberg & Lubart, 1995]. Some researchers in the field of psychology have long been interested in understanding creativity (e.g. definitions, metrics and processes), although after nearly 100 years of research on the topic no unified understanding has been reached [e.g. Amabile, 1983; Boden 1994; Guilford, 1950; Osborn, 1957; Wallas, 1926]. In recent years, some researchers in the field of HCI have reframed and tackled this problem from a different perspective (see chapters 2 and 3).

Reflecting upon the occurrence of creativity in practical situations, such as design, our theoretical understanding may be verified and refined (see chapter 4). This is also true for tools intended to support the creative process of design (see chapters 5 and 6).

With an understanding of the creative process of design we can hope to effectively support this process. This prompted our second RQ:

RQ2: How can we support creativity in design?

Researchers and practitioners trying to support creativity have generally taken either a theoretical approach to understanding how to support creativity [e.g. Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973] or a practical approach [e.g. Arias *et al*, 2000; Fischer, 1999a; Streitz *et al*, 1999; Sugimoto *et al*, 2004]. These two approaches have remained largely disjoint from each other. However, rather than remaining disjoint, it would be advantageous to juxtapose these different perspectives, allowing lessons to be learned from the various fields of research (see chapter 2).

As when addressing our first RQ, an understanding of how to support creativity may be developed by studying the occurrence of creativity during practical design situations (see chapter 4). These theoretical and practical perspectives on creativity may then be used to evaluate existing support tools (see chapters 3 and 5) and design a new CST (see chapter 6), which would in turn inform the design and development of future tools aimed at supporting creativity.

As we can see from above, it was not the aim of this thesis to address our RQ sequentially. Nor was it the case that they were mutually exclusive. Rather, our research aimed to accumulate, refine and reflect upon the knowledge gathered throughout this thesis - much like the process of design itself [e.g. Schön, 1983]. Emerging from the theoretical foundation set up in chapter 2, four research objectives were identified to be addressed throughout the thesis:

RO1: Understand the effect of group composition on creativity in design when social influences are controlled (see chapter 3)

RO2: Elicit requirements for CST (see chapter 4)

RO3: Reflect upon and refine our requirements for CST (see chapter 5)

RO4: Design, develop and evaluate a new tool to support creativity in design (see chapter 6)

The accumulation of knowledge from addressing these RO can then be used to address both our RQ (see chapter 7).

Some of the contributions of this thesis, resulting from addressing our RQ and objectives have been reported in a number of peer-reviewed publications (see appendix A).

1.3 Research methodology

In order to address our two RQ, we studied creativity from both a theoretical and a practical perspective. This is an advance from the majority of previous research that has considered theoretical [e.g. Amabile, 1983; Boden 1994; Diehl & Stroebe, 1987; Guilford, 1950; Lamm & Trommsdorff, 1973; Osborn, 1957; Wallas, 1926] and practical [e.g. Arias *et al*, 2000; Fischer, 1999a; Streitz *et al*, 1999; Sugimoto *et al*, 2004] perspectives on creativity in relative isolation. Combining the perspectives allowed us to compare similarities and differences, accumulating knowledge to answer our RQ.

The combination of theoretical and practical perspectives on creativity required us to adopt a number of quantitative and qualitative research methods. It has been argued that research studying creativity needs to draw upon multiple research methodologies [e.g. Mayer, 1999; Shneiderman *et al*, 2006]. Our research addressing the theoretical perspective of creativity primarily drew upon social and cognitive research traditions. Whereas, our research considering creativity from the practical perspective drew upon more ethnographic techniques.

Experiments were used to answer specific questions that emerged from our research. Building upon the literature reviewed in chapter 2, we replicated and refined a study observing the effects of group composition on creativity. Data captured from the experiment using data logs and retrospective techniques allowed us to perform statistical testing, thus providing empirical evidence informing our understanding of creativity in design (see chapter 3). Furthermore, building upon an initial evaluation of PSPD reported in chapter 6, an experiment was conducted comparing the effects of screen size (i.e. small and large canvas sizes) on sketching informing the design of PSPD (see chapter 6).

Observing the occurrence of creativity in a real design setting required us to draw upon a number of ethnographic techniques: a diary study, field-based observations and lab-based observations (see chapter 4). A diary study allowed us to capture information related to creativity over a long period of time (i.e. across a software development process). Field-based observations allowed us to focus on the design phase of the software development process, capturing rich, contextual information. The lab-based observations allowed us to build upon our ethnographic observations, investigating the occurrence of creativity under more controlled conditions.

Utilising techniques such as personas and scenarios, we were able to evaluate an existing CST (see chapter 5) and our own (see chapter 6). Ethnographic observations were used to extract findings. Interactions (e.g verbal and gestures) [Jordon & Henderson, 1995] were encoded from the video data to complement our ethnographic observations. These data were further complemented by data loggers, questionnaires, retrospective analysis and focus groups. Our requirements identified in chapter 4 were also used as a set of heuristics to evaluate the CST. These techniques complemented and extended each other, allowing us to thoroughly explore the use and support provided by the CST.

1.4 Research contributions

This thesis makes two major contributions: a theoretical and practical contribution. Addressing our first RQ - *what is creativity in design?* - we make a theoretical contribution. This contribution comes in the form of a definition of creativity in design, metrics and measures of creativity and an understanding of the process of being creative in design. These contributions are developed throughout the thesis and are refined reflecting upon our practical studies.

Tackling our second RQ - *how can we support creativity in design?* - we make a practical contribution. This contribution is delivered in the form of a number of requirements for CST. These requirements were elicited from our review of existing literature and the application of our ethnographic techniques in practical design situations. These requirements were then reflected upon and refined in an evaluation of existing CST. Furthermore, they were used in the design, development and evaluation of our own CST: PSPD. The findings in particular from the evaluation of PSPD provided supportive evidence for the proposal of our requirements for CST.

A final contribution of this research is the many questions raised throughout the thesis - not all of which are answered. This thesis therefore provides a direction for future research in understanding and supporting creativity, in and beyond the domain of design in HCI.

The main contributions of this thesis are directed towards the field of HCI. In this thesis we try to understand a fundamental human phenomenon: creativity. This field of research is beginning to emerge in the interdisciplinary field of HCI research as a topic of great interest [e.g. Candy & Edmonds, 2002; Coughlan & Johnson, 2006; Fischer *et al*, 2005; Shneiderman, 2000; Shneiderman *et al*, 2006; Wolf *et al*, 2006]. Fundamentally, the question being asked is, how can we support creativity? In this thesis we build upon our understanding of the phenomenon of creativity, identifying requirements for the support of creativity, thereby designing, developing and evaluating our own CST: PSPD.

However, our contributions are not limited to the field of HCI alone. This thesis is scoped towards varieties of design that involve framing a design problem, and then generating and evaluating ideas towards the production of a design product. As such, the findings of this research are also valuable to the wider field of design research. The field of psychology can also benefit from this research. Nearly 100 years of research has contributed towards understanding creativity. Approaching this topic from the perspective of HCI and reflecting upon the support of creativity has further refined our understanding. The contribution of our understanding of how to support creativity is also advantageous to the field of Computer Supported Cooperative Work (CSCW), informing the design and development of future CST and other CSCW tools and applications. Finally, these fields of research together make up researchers who study the field of creativity. While we focus on the domain of design from the perspective of HCI in the thesis, the findings of this thesis contribute towards other fields of research studying creative activities such as the visual arts, music composition and engineering.

1.5 Thesis outline

Chapter 2 sets the scene for the rest of the thesis. It starts providing an understanding of the design process and the limitations of this understanding. Identifying creativity as an element of the design process, we review definitions, metrics and measures, and process models of creativity, thereby developing a theoretical understanding of creativity. We then move towards building a theoretical understanding of how to support creativity in design, eliciting three high-level requirements for supporting creativity in design. This chapter branches into chapters 3 and 4.

Chapter 3 builds upon chapter 2, reporting an experiment comparing four group compositions - nominal, nominal-real, real-nominal and real - to identify their effects on creativity in terms of the quantity of creative ideas, the divergence of creative ideas and the quality of creative ideas when social influences were controlled. This experiment addresses RO1.

Chapter 4 also builds upon chapter 2, eliciting requirements for CST (RO2). We achieve this by studying the occurrence of creativity in a real design setting, drawing upon a number of ethnographic techniques: a diary study, field-based observations and lab-based observations.

Chapter 5 reviews and critiques a number of existing CST. We also report an in-depth evaluation of the EDC. This addresses our third research objective allowing us to reflect upon and refine our requirements for CST (RO3). We evaluate the EDC against the requirements we identified in chapter 4. Drawing lessons learned from the evaluation allowed us to identify strengths and weakness of the EDC, suggesting improvements to the EDC and other CST, as well as allowing us to reflect upon and refine our requirements for CST.

Chapter 6 reports the design, development and evaluation of our own CST: PSPD. PSPD was designed and developed based on our requirements for CST developed throughout the thesis. We also report a number of evaluations of the PSPD environment. The final evaluation of PSPD produced findings supporting the proposal of our requirements for CST. This chapter addresses RO4.

Finally, chapter 7 concludes, summarising the contributions and findings of the thesis. This leads to us identifying directions for future work on understanding and supporting creativity in design.

Chapter 2

Creativity in Design: A Theoretical Perspective

In chapter 1 we stated our high-level goal of understanding and supporting creativity in design. This chapter sets the scene for the rest of the thesis. Section 2.1 presents a brief overview of design in the field of HCI. We start by considering a brief history of design, moving from interface design, to interaction design, to user-experience design. We further consider two design methodologies commonly used by HCI researchers, namely Participatory Design (PD) and User-Centred Design (UCD). From this review of design two fundamental questions are raised: *what is design?*; and *what is the process of design?* To answer these questions we survey a number of definitions of design and design process models. Despite such a review, much ambiguity still surrounds the topic, with the process of design being described as involving some 'mystical element', frequently referred to as 'creativity'.

Section 2.2 frames our first RQ: *what is creativity in design?* We start by reviewing a history of creativity definitions, considering the creative process, the creative person and the creative product. We unify these definitions and apply them to the domain of design in HCI. We next consider various metrics of creativity: quantity, divergence and quality. We then consider the process of being creative by reviewing and critiquing a history of creative process models. We then generalise these models of creativity to the domain of design in HCI. Hence, we move from the individual perspective of creativity to considering social creativity. This leads us to identify three high-level characteristics of creativity in design: (1) The externalisation of knowledge to members of the design team; (2) Individual and social creative activities; and (3) Social influences that inhibit the creativity of the design team.

Section 2.3 raises our second RQ *how can we support creativity in design?* Using our three high-level characteristics of creativity in design as a framework, we next consider how to support creativity in design from a theoretical perspective. This leads to the identification of three high-level requirements for supporting creativity in design.

Finally, section 2.4 reviews this chapter, presenting a number of RO and provides an overview for the rest of the thesis.

2.1 Design

Within the field of HCI, both researchers and practitioners engage in the activity of design to produce prototypes or design artefacts for laboratory and real-world use [Fallman, 2003]. Design in HCI has evolved over the years from interface design, to interaction design, to user-experience design [e.g. Grudin, 1990; Preece *et al*, 2002; Wright & McCarthy, 2004].

Interface design in HCI primarily emerged with the birth of the graphical user interface (GUI) in the late 1970s and early 1980s [Grudin, 1990]. Through the interface a user may interact with components (e.g. windows, menus, buttons, etc) to execute some underlying functionality. Researchers and practitioners were primarily concerned with the design and use of these components and their structure in the GUI, thus making the system as usable as possible [Shneiderman, 1998b].

Interaction design primarily came into focus in the late 1980s and early 1990s, moving beyond the interface of a product to the way in which a user interacted with it [Preece *et al*, 2002]. Some common examples of interaction design could be gesture and voice interaction [e.g. O'Neill *et al*, 2005]. As with the user interface (UI), researchers and practitioners were interested in designing interaction technologies and techniques that allowed users to interact with a system in a usable way [Preece *et al*, 2002].

User-experience design was born in the 2000s, where we no longer merely use systems, but rather they are embedded in our everyday life. No longer focussing on the interface or interaction alone, but rather encompassing all aspects of a product as experienced by a user [Wright & McCarthy, 2004]. This era of HCI has a focus on designing for use [Buxton, 2005a; Buxton, 2005b]. Researchers and practitioners are no longer designing systems that are usable and intuitive, but also deliver a desirable experience.

Such design activities utilise a number of design methods. Two such design methodologies commonly used by HCI researchers are PD [e.g. Bjerknes *et al*, 1987; Floyd *et al*, 1989; Greenbaum & Kyng, 1991] and UCD [e.g. Nielsen, 1993; Shneiderman, 1998b].

PD involves users as equal partners in the design team, allowing them to design the product in cooperation with the system designers [Greenbaum & Kyng, 1991]. Using techniques such as brainstorming, storyboarding, workshops, and pencil and paper exercises such as PICTIVE (Plastic Interfaces for Collaborative Technology Initiatives through Video Exploration) [Muller, 1991] and CARD (Collaborative Analysis of Requirements and Design) [Tudor, 1993] design ideas and solutions are prototyped. These prototypes are then evaluated with real users and the results from these evaluations are fed back into the design process. In the HCI tradition, this is very much an iterative process.

UCD involves placing the user at the centre of the design process [Nielsen, 1993]. Unlike PD, the user is not actively involved in the design team *per se*, but may be observed through techniques such as ethnography and questioned during interviews and focus groups to build up an understanding of the user, their tasks and their domain. The system designers may then design a product to meet the user's needs and expectations. Prototypes or finished products will then be evaluated with real users either in a lab or in the field. The findings of these evaluations are then fed back into the design process. This process is highly iterative.

Above we have provided a brief overview of a number of design activities in the field of HCI - interface, interaction and user-experience design - and a number of design methodologies adopted to engage in such design activities - PD and UCD. Fundamentally, our understanding of design so far is that system designers, and sometimes users, engage in some process of design (i.e. through design methodologies such as PD or UCD) to produce design ideas or solutions (e.g. an interface design, interaction design or user-experience). However, what is this process of design that leads to the creation of these design solutions? Fallman [2003] argues that our philosophical, theoretical and methodological underpinnings of design are relatively poor. To better understand design, in the next sections we shall consider what design is by reviewing definitions of design; and the process of design itself by reviewing models describing the phases of the design process.

2.1.1 What is design?

When understanding what design is, it is important to note that there is no single, universally accepted, definition of design [Atwood *et al*, 2002]. However, based on a review of views of design [Atwood *et al*, 2002], definitions of design commonly focus on a designer or designers engaging in some *process* to produce a *product*. Table 2.1 presents a sample of design definitions.

Table 2.1: Definitions of design.

Author	Definition
Alexander [1964]	'...the process of inventing physical things which display new physical order, organisation, form, in response to function.'
Coyne [1995]	'...to consciously aim to create and give form to previously non-existent artefacts.'
Ehn [1989]	'...a democratic and participatory process.'
Fallman [2003]	'...a matter of making...creating and giving form to something not previously there.'
Jones [1970]	'...initiating change in man-made things.'
Mayall [1979]	'...the creation of artefacts that are used to achieve some goal.'
Rasmussen *et al* [1994]/Vicente [1999]	'...creating complex sociotechnical systems that help workers adapt to the changing and uncertain demands of their job.'
Rittel [1984]	'...structuring argumentation to solve "wicked" problems.'
Schön [1983]	'...a reflective conversation with the materials of a design situation.'
Simon [1996]	'...devising courses of action aimed at changing existing situations into preferred ones.'

We can see from table 2.1 that all the definitions agree that design is a process: process of inventing [Alexander, 1964]; creating [Coyne, 1995]; democratic and participatory process [Ehn, 1989]; making/creating [Fallman, 2003; Rasmussen *et al*, 1994; Vicente, 1999]; initiating change [Jones, 1970]; creation [Mayall, 1979]; structuring argumentation [Rittel, 1984]; reflective conversation [Schön, 1983]; and courses of action [Simon, 1996]. In the majority of these definitions, some product results from the process: physical things [Alexander, 1964]; give form [Coyne, 1995; Fallman, 2003]; man-made things [Jones, 1970]; artefacts [Mayall, 1979]; sociotechnical systems [Rasmussen *et al*, 1994; Vicente, 1999]; and materials [Schön, 1983]. Furthermore, the deign process could either bring about *new* products: display new physical order, organisation, form [Alexander, 1964]; give form to previously non-existent artefacts [Coyne, 1995]; giving form to something not previously there [Fallman, 2003]; or the design process could *refine* existing products: initiating change in man-made things [Jones, 1970]; reflective conversation with the materials [Schön, 1983]; and changing existing situations into preferred ones [Simon, 1996].

From these definitions we can see that design is a *process* that produces a *new* or *refined product*. However, such definitions are still quite ambiguous. What is this process of design? In the next section we shall look to gain a deeper understanding of design by considering the process of design.

2.1.2 The process of design

Simon [1973] described design problems as ill-structured problems. The characteristics of an ill-strucutured design problem being:

> *Characteristic 1: Incomplete and ambiguous specification of goals.*
>
> *Characteristic 2: No predetermined solution path.*
>
> *Characteristic 3: The need for integration of multiple knowledge domains.*

We next describe each of these characteristics.

Incomplete and ambiguous specification of goals: An important initial phase of the design process is problem structuring, which allows incomplete and ambiguous goals to be specified. Simon [1973] argues that much of the effort in solving a problem is actually in structuring the problem. Design problems are inherently poorly defined and have no well-defined evaluation criteria. For example, Cross [2002] has interviewed many exceptional designers, one being Victor Scheinmann, an engineer designer with more than 20 years experience of designing mechanical and electro-mechanical machines, and robotic systems and devices. When given the novel design task of 'designing a carrying/fastening device that would enable you to fasten and carry a backpack on a mountain bicycle', he was reported to 'identify particular features of the problem that would influence his approach to developing a concept design' [Cross, 2002, p.16]. As Simon [1973] argues, it is important to define the problem space of the design problem, identifying missing information and criteria for the appropriation of a desired solution.

No predetermined solution path: The next phase of the design process is to generate a design solution, where no predetermined solution path yet exists. This design solution aims to meet the characteristics of a desired solution established in the problem structuring phase of the design process (i.e. the design requirements). However, in design there is often no predetermined solution path from the requirements to the finished artefact [Guindon, 1990; Simon, 1973]. Thus the design process involves a degree of novelty. As Guindon [1990, p.308] explains, 'Even though the designer may be thoroughly familiar with the design process itself, there may not be any precedent in the literature for the system to be designed - it may be a new technology. More frequently, the system may simply involve some novelty in an otherwise well-understood problem. The novelty may range from a novel combination of requirements for a familiar type of system in a familiar problem domain to an unfamiliar type of system in an unfamiliar problem domain'. Taking another example from Cross [2002], Gordon Murray is a designer with a long-established record as a highly successful and highly innovative designer of Formula One race cars. In 1981 the Formula One governing body, FISA, introduced a new requirement that all Formula One cars had a minimum ground clearance of 6cm, which was intended to reduce 'ground effect'. Gordon Murray was faced with the problem, 'How the hell can we get ground effect back?' [Cross, 2002, p.14]. There was no predetermined solution for this problem and it required Gordon Murray to design the hydro-pneumatic suspension system, which allowed the car to obtain ground effect when at speed and cornering, but return to the minimum 6cm ground clearance when stationary. Such a novel solution was evaluated against the characteristics of a desired solution developed during the problem structuring phase of the design process.

The need for integration of multiple knowledge domains: John-Steiner [2000] and Salomon [1993] argue that the individual mind is highly overrated. Alexander [1964] argues that design problems are reaching insolvable levels of complexity. Therefore, 'complex problems require more knowledge than any single person possesses, communication and collaboration among all the involved stakeholders is necessary' [Fischer, 1999b, p.116]. Fischer [2004] describes these groups of stakeholders as Communities of Practice (CoP) and Communities of Interest (CoI). CoP are groups of stakeholders who come from the same background, sharing similar perspectives and vocabularies. CoP consist of practitioners who commonly work together (e.g. designers in a design team), whereas CoI bring together stakeholders from different CoP (e.g. designers, users, HCI specialists, programmers, etc). An example of multiple knowledge domains being used is when end-users and designers work together (e.g. to design a system for the users' work place). The end-user has domain expertise in understanding the practice of the work place, while the system designer knows the technologies that could be available and how they are used. In this example, without either the end-user or the designer, the domain knowledge of the work practice or the technology is missing, whereas when the end-user and systems designer work together they have the relevant knowledge needed to solve their design problem.

These characteristics of ill-structured problems can be seen in researchers' observations of design. Design includes three essential phases: analysing a problem; synthesising a solution; and evaluating the outcome [e.g. Alexander, 1964; Carroll *et al*, 1979; Jones, 1970; Manhorta *et al*, 1980; Rosson *et al*, 1987]. Jones [1970] describes this process in simple terms as, 'breaking the problem into pieces', 'putting the pieces together in a new way' and 'testing to discover the consequences of putting the new arrangement into practice'. Alexander [1964] and Jones [1970] prescribed these three phases as a sequential and linear design method. This well-structured and methodological view of design is describe as the *conservative account* of design [Fallman, 2003], such as a scientific or engineering endeavour.

However, there has been much criticism of viewing the design process as a series of prescribed steps, even by the authors themselves [Alexander, 1971; Jones, 1970]. First, many failures using such a structured design methodology have been documented [e.g. Lawson, 1980; Rittel, 1972]. Secondly, there is much practical discontent as it is argued that designers do not work and can not work in such a prescribed manner [e.g. Alexander, 1971; Guindon, 1990; Lawson, 1980; Rosson *et al*, 1987]. Rather than a conservative view of design, some view design from the perspective of the *romantic account* of design [Fallman, 2003]. The process of design is viewed as mystical and by no means fully rational and explicable as suggested by the conservative account. The designer is someone who is able to generate creative designs, but is unable to explain how they came about. Such a view leans more towards the arts than the sciences.

Rosson *et al* [1987] interviewed 22 designers to probe for information about their design process. A finding of this work was that the design process was iterative. Similar to the work of Alexander [1964], Jones [1970] and Simon [1973], Rosson *et al* [1987] defined three general activities of the design process: logical analysis of the design problem (i.e. analysing and structuring the problem); discussion/consultation (i.e. acquiring multiple knowledge domains); and iterative development activities (i.e. synthesising solutions to meet the criteria of a desired solution). Similarly, Carroll *et al* [1979] and Manhorta *et al* [1980] found that design is a sequence of cycles consisting of activities of requirements elaboration (i.e. structuring the problem), solution generation (i.e. synthesising a solution) and solution evaluation (i.e. evaluating the outcome of the design process). As argued by Carroll & Rosson [1985] design involves the development of tentative interim and partial solutions and involves the discovery of new goals. Such a view is consistent with Fallman's [2003] *pragmatic account* of design. Coyne & Adrain [1991] describe design as a process of interpretation and creation of meaning, where designers interpret the effects of their designs on the situation at hand. Schön [1983; 1992] describes this process as 'seeing-drawing-seeing'. The designer sees what is there, draws reflecting upon what he has seen and then sees what he has drawn, which informs further designs as a reflective process. Similarly, Goldschmidt [1991] describes this reflective process as: 'seeing that' - a design is created based on current knowledge; and 'seeing as' - viewing and interpreting the design generates new knowledge for re-design. The iterative nature of design allows for incremental improvements in the design solution.

Design can be considered from many standpoints, such as from an engineering, architecture or HCI standpoint. In this section and for the remainder of this thesis, the dominant standpoint taken is on the process of design as it is expressed in HCI.

As established throughout this section design is considered as some process that produces a product, whether from the perspective of the conservative, romantic or pragmatic account of design. This process of design consists of three phases: structuring the problem; generating a solution; and evaluating the solution. Furthermore, this design process is highly iterative, where requirements, goals and the solution itself might change over time. Although we have deepened our understanding of the process of design, the question of how these design ideas/solutions/products are generated is still quite ambiguous. How did Gordon Murray come up with the idea for the hydro-pneumatic suspension system? How did Victor Scheinmann generate ideas for a carrying/fastening device that would enable you to fasten and carry a backpack on a mountain bicycle? As Fallman [2003, p.227] states, 'the process of design involves a certain mystical element'. What then is this mystical element in design?

2.2 Understanding creativity in design

Design is mysterious. Even after reviewing definitions of design and describing the phases of the design process much ambiguity still surrounds the topic. How do designers generate design ideas? Even designers find it difficult to articulate where their ideas come from, or even differentiate between the process of generating new ideas and refining them [Rosson *et al*, 1987]. This mystical element of design is often referred to using terms such as 'creativity': both in theory [e.g. Fallman, 2003; Guindon, 1990; Rosson *et al*, 1987] and practice [e.g. Alborzi *et al*, 2002; Buur & Bødker, 2002]. Therefore, to better understand design, we need to better understand creativity in design. This leads us to our first RQ:

RQ1: What is creativity in design?

In the following sections we review definitions of creativity, metrics of creativity and creative process models.

2.2.1 What is creativity?

Definitions of creativity have evolved over several decades. There have been three main concepts by which creativity has been defined: the creative process [e.g. Koestler, 1964; Boden 1994], the creative person [e.g. Guilford, 1950; Gough, 1979] and the creative product [e.g. Amabile, 1983]. In the following sections we shall address each of these concepts.

2.2.1.1 The creative process

Early definitions of creativity defined it in terms of the creative process [e.g. Wallas, 1926]. This process was viewed as an individual's internal cognitive process [e.g. Wallas, 1926; Koestler, 1964; Boden 1994], which could be either sub-conscious or conscious.

Boden [1994] describes this creative process as 'the exploration and transformation of conceptual spaces'. A conceptual space is a network of knowledge, where bundles of knowledge are connected to one another by associations [Gabora, 2002; Santanen *et al*, 2002]. Boden [1994] refers to the exploration of conceptual spaces as recalling these existing bundles of knowledge. A transformation occurs when a new knowledge structure is created in this conceptual space. Similarly, Koestler [1964] describes this creative process as a 'bi-sociative process' where an individual deliberately connects previously unrelated matrices of thought. Koestler's [1964] term, matrices of thought, refers to existing knowledge structures within the mind (i.e. bundles of knowledge). The creative process involves forming new relations between these existing, unrelated knowledge structures [Ward, 1997]. Gabora [2002] and Santanen *et al* [2002], expand upon the descriptions of Boden [1994] and Koestler [1964] providing further insights into the creative process.

The exploration of the conceptual space relates to recalling bundles of knowledge. This exploration is initiated by some stimulus (e.g. visual, auditory, etc), whether perceived consciously or sub-consciously, that activates one or more bundles of knowledge in one's conceptual space [Santanan *et al*, 2002]. The activated bundle(s) of knowledge then primes associated bundles of knowledge (e.g. when we hear the word transport, we may think of a bus, car, plane, etc), and so the process of exploration continues. The activation of primed bundles of knowledge tapers off (i.e. like a Gaussian distribution) as the mutual distance with the originally activated bundle of knowledge increases [Gabora, 2002]. When a stimulus is perceived and we are not conscious of it, activation and priming can occur without intention or conscious effort. Yet if a stimulus is perceived and we are conscious of it, one can deliberately consider potential associations during the exploration of one's conceptual space.

The process of transformation occurs when two or more previously unrelated bundles of knowledge give rise to a potential solution applicable to a new domain [Gabora, 2002; Santanen *et al*, 2002]. The transformation causes a new association to form: a new combination; the construction of a new knowledge structure; a new idea. If the process of exploration was sub-conscious, the transformation would be perceived as the perception of a sudden solution [Nemiro, 2004] - an eureka moment [Wallas, 1926]. Whereas, if the process of exploration was consciously perceived, the transformation process could be viewed as a deliberate act.

Santanen *et al* [2002] claim that the more mutually remote the bundles of knowledge forming the new combination, the more creative the resultant process or product. The further the mutual distance, the more unrelated the combination and therefore the greater the novelty [Santanen *et al*, 2002]. However, such combinations are not merely random. Sternberg [1998] argues how creativity is the result of the effortful application of knowledge through processes of encoding, selecting and comparing. Creativity is not merely attributed to novelty, but also value judgments [Amabile, 1983; Boden, 1994]. The creative process goes beyond pure inspiration, requiring much effort and deliberation. As George Bernard Shaw put it, 'creativity is 90% perspiration, 10% inspiration'.

2.2.1.2 The creative person

The creative process is the result of some internal cognitive process occurring in the mind of a creative person. Viewing creativity from the perspective of the creative person was a dominant approach in the 1950s due to the zeitgeist of the psychology researchers. The interest in the creative person and a contributing factor to the increased interest in research into creativity was due to Guilford's [1950] presidential address to the American Psychological Association.

Guilford [1950, p.444] defined the creative person thus: 'creative personality is then a matter of those patterns of traits that are characteristic of creative persons'. However, such a definition is circular. While the definition tells us that a person's traits are what makes them creative, it fails to describe the traits of a creative person.

Guilford [1950] was interested in identifying the different types of creative abilities unique to the creative person (e.g. the scientist, the technologist and the inventor) and the patterns of those abilities. At the time of Guilford's presidential keynote he had only hypothesised creative abilities that were unique to creative persons. However, after a number of studies, Guilford [1959] identified and expanded upon the unique abilities of the creative person. Guilford [1959] identified aptitude traits that belong to the area of creativity as: fluency of thinking - the ability to produce a large number of ideas per unit of time; flexibility of thinking - the ability to change mind set with ease; originality - the ability to generate uncommon, yet acceptable ideas; sensitivity to problems - the ability to find problems; redefinition - the ability to view problems from different perspectives; and elaboration - the ability to expand upon problems and solutions. A hypothesis that was not supported was that analysing and synthesing abilities would differ between creative and non-creative persons. In addition to these findings, Guilford [1959] found a number of relationships between non-aptitude traits and creative performance: flexible thinkers seem to be clearly the opposite to rigid thinkers; redefinition seems logically opposite to functional fixedness; and traits of temperament and of motivation have little relation to performance on tests for fluency, flexibility and some tests on originality. Guilford [1959] suggested that these abilities of individuals would differ and these differences could account for the differences in creative talent.

Similar to the studies of Guilford [1959], Gough [1979] wished to identify traits and patterns of traits dominant in creative persons. Gough's [1960] Adjective Check List is comprised of 300 descriptor words that a person checks as being self-descriptive. Based on 12 samples of 1,701 participants whose creativity had been assessed by expert judges, 30 adjectives reliably differentiated more creative people from less creative people. 18 adjectives positively related to creativity: capable, clever, confident, egotistical, humorous, individualistic, informal, insightful, intelligent, interests wide, inventive, original, reflective, resourceful, self-confident, sexy, snobbish and unconventional. 12 adjectives negatively related to creativity: affected, cautious, commonplace, conservative, conventional, dissatisfied, honest, interests narrow, mannerly, sincere, submissive and suspicious. Gough [1979] used the selected adjectives to devise a test to identify creative persons: The Creative Personality Scale - The Adjective Checklist. The test involves an individual describing themselves in terms of the 30 adjectives. For an adjective positively related to creativity a unit point is awarded. For an adjective negatively related to creativity a unit point is subtracted. Creative individuals tend to score more points than less creative individuals identifying the potential creative talent of an individual.

Is it the case then that the creative person is a certain 'brand' of individual? Or as Boden [1990] poses the question, 'elite or everyman?' Boden [1990, p.245] argues that creativity draws upon our ordinary abilities, 'noticing, remembering, seeing, speaking, hearing, understanding language and recognising analogies'. Therefore, does creativity involve some special abilities? Or a highly developed version of the abilities we all share? Boden [1990] describes a possible explanation for the exceptional creative talents of some persons due to their extensive knowledge within a domain. Similar, Csikszentmihalyi [1996] found in a study of 100 socially acknowledged creative individuals that the first and foremost characteristic of the individual was their mastery of a domain of knowledge. Boden [1990, p.252] argues that, 'the more richly structured (and well-signposted) the conceptual space, the more possibilities of storing items in a discriminating fashion, and of recognising their particularities in the first place'. Boden [1990, p.254] also argues that the domain in which one is creative goes beyond an 'interest' to that of a 'passion', where 'motivation is crucial'. Yet, Boden [1990] acknowledges that our traits can affect the way one explores and transforms their conceptual space. This could in turn have an affect on how creative one could possibly be. However, despite this, we all have the basic abilities to be creative and can do so with the relevant domain knowledge and motivation [Boden, 1990; Csikszentmihalyi, 1996].

2.2.1.3 The creative product

More recent definitions of creativity have defined it in terms of the creative product [e.g. Amabile, 1983]. The creative product is the result of the ideas produced by some creative process, undergone by a creative person. A creative product is often viewed as a tangible product: a piece of art, a music composition or an architectural structure to name a few examples.

Jackson & Mersick [1965] propose that a creative product has distinguishing signs of creativity. Such distinguishing signs have been described in terms of aesthetic responses brought about in an observer: surprise, satisfaction, stimulation and savouring [Jackson & Mersick, 1965]. Furthermore, researchers [e.g. Bruner, 1962; Jackson & Mersick 1965; Gilchrist, 1972; Amabile, 1983] have argued that such aesthetic responses are brought about due to characteristics of 'novelty' and 'appropriateness'. *Novelty* maps to responses of surprise and stimulation, while satisfaction and savouring map to the characteristic of *appropriateness*. However, what are these characteristics of novelty and appropriateness that cause the aesthetic responses brought about by creative products?

Novelty relates to the unusualness of the product [Jackson & Mersick 1965; Gilchrist, 1972]. Jackson & Mersick [1965] describe the assessment of unusualness as a two-step process, 'a comparison of the products in question with other products of the same class and a counting of those comparisons that yield similar or identical products' [Jackson & Mersick, 1965, p.312]. This unusualness or novelty of a product, results in a leap from the norm, causing surprise or stimulation in the mind of the observer.

Boden [1994] expands upon this notion, describing novelty as belonging to one of two categories: psychological novelty (p-novel) and historical novelty (h-novel). *P-novel* is an idea which is new to the mind in which it arose, though it may have been thought of by others before. *H-novel* is an idea which is p-novel and has never been thought of by anyone else before. Expanding upon the work of Boden [1994], rather than novelty being viewed as two categories, these categories could be considered as opposite ends of a spectrum. An idea that everyone has had would not be considered novel (i.e. a case of a p-novel idea), whereas an idea thought of by an individual for the first time ever would be considered highly novel (i.e. h-novel). Of course, the closer you get to the h-novel end of the spectrum, the more difficult it is to determine novelty, as it is impossible to review the spread of information across space and time.

As the novelty of a product changes, so does its creativity [Boden, 1994]. Similar to Boden's [1994] notion of p-novel and h-novel, she also categorises creativity as psychological creativity (p-creativity) and historical creativity (h-creativity). *P-creativity* is creativity that is creative to that individual, for example, personal creativity such as a child's painting. Whereas *h-creativity* is creativity that is creative to society, for example, Watson and Crick's discovery of DNA's double-helix. Similarly, Csikszentmihalyi [1996] use terms such as small 'c' creativity and big 'C' creativity; and Shneiderman [2000] uses terms such as 'impromptu or personal creativity' and 'revolutionary creativity'. Shneiderman [2000] furthermore defines a third level of creativity, namely evolutionary creativity, a middle ground between impromptu or personal creativity and revolutionary creativity. Evolutionary creativity is important at bringing about change with a purpose [Shneiderman, 2000]. It is impromptu or personal, and evolutionary creativity that are predominantly studied by the creativity researchers [e.g. Boden, 1990; Csikszentmihalyi, 1996; Shneiderman, 2000] as everyday forms of creativity, whereas revolutionary creativity is rare and seen as exceptional. That said, it is possible that evolutionary creativity can lead/help to produce revolutionary breakthroughs [Shneiderman, 2000].

While novelty is often referred to as synonymous with creativity, it is appropriateness that differentiates between the two. The role of appropriateness is to separate the creative from the bizarre and odd. The phase of problem structuring establishes characteristics of a desired solution [Simon, 1973]. Such characteristics can then act as a means of appropriation. This appropriation as referred to by Jackson & Mersick [1965] as subjective. There is no right or wrong answer: 'good' rather than 'correct'; 'poor' rather than 'wrong'. However, appropriateness is domain-specific [Amabile, 1983; Gilchrist, 1972]. Brannigan [1981] comments that value judgments are to some extent culture-related, since what is valued by one person or social group may or may not be valued by another, thereby bringing about differing degrees of satisfaction and savouring in the observer.

Guilford [1957] expands upon appropriateness, referring to factors of logical consistency, such as fact and less-than-logical consistency, such as experiences. For example, scientific discoveries are evaluated more by logical facts, compared to the appropriation of a piece of music or art which could be assessed more on experience. Such fact and experience vary in the degree to which they are satisfied: how many of the requirements does a creative product satisfy (i.e. logical) [Gilchrist, 1972]; and to what degree does the creative product satisfy the observer (i.e. experience) [Jackson & Mersick, 1965].

2.2.1.4 Towards a unified definition of creativity in design

In the above sections we have reviewed three categories of creativity definitions: the creative process [e.g. Koestler, 1964; Boden 1994], the creative person [e.g. Guilford, 1950; Gough, 1979] and the creative product [e.g. Amabile, 1983]. How then do these definitions of creativity apply to our understanding of design?

In section 2.1 we concluded that design was some process, whether the conservative, romantic or pragmatic account of design, that produced a new or refined product. Our understanding of how we go from a process to a product was quite ambiguous, with terms such as 'mystical element' and 'creativity' being used as a substitute for understanding [e.g. Fallman, 2003; Guindon, 1990; Rosson *et al*, 1987].

Definitions of the creative process describe this mystical element of creativity as the exploration of conceptual spaces (i.e. recalling existing bundles of knowledge) and the transformation of conceptual spaces (i.e. forming new knowledge structures), whether conscious or sub-conscious [Boden, 1994]. Therefore, a member of a design team can explore the knowledge in her mind and come up with new ideas by forming new combinations of existing knowledge [Boden, 1994; Koestler, 1964].

The creative person refers to an individual with creative traits [Guilford, 1950; Gough, 1979]. In design methods such as PD and UCD the creative person would be considered the stakeholders (e.g. system designers and users) - the people who engage in the process of design. While designers and users may have different creative traits and therefore may differ in creative ability, they each have the basic abilities to be creative. Furthermore, it is the creative person's knowledge that is most valuable to the creative process [Boden, 1994; Csikszentmihalyi, 1996], allowing design ideas to be generated and hence creative products created.

As the design product is the result of the design process, the creative product is the result of the implementation of creative ideas generated as a result of the creative process. The creative product embodies the creative ideas within it. The distinguishing characteristics of the creative product are novelty and appropriateness. Such characteristics are also true of design products. Design products often require the creation of a new solution (i.e. novelty) and need to meet the criteria of a desired solution (i.e. appropriateness) [Guindon, 1990].

'In our study of creativity in design then we need to examine not only products but also processes and persons' [Lawson, 1980]. While the focus of definitions of creativity has evolved over time, from the process, to the person, to the product, these are all essentially important components of creativity and design. Each individual (e.g. member of a design team), has certain creative abilities; she may explore and transform conceptual spaces, combine existing bundles of knowledge to generate new ideas (e.g. the design process); and these ideas may consist in or lead to the development of a creative product (e.g. a design product).

Drawing together the strands of previous research in creativity [e.g. Amabile, 1983; Boden 1994; Gough, 1979; Guilford, 1950; Koestler, 1964], we propose a unified definition of creativity in design to be used in this research [Warr & O'Neill, 2004; Warr & O'Neill, 2005a]:

> **'Creativity in design is the generation of ideas, which are a combination of two or more existing bundles of knowledge to produce a new knowledge structure. For this idea to be considered creative it should be: novel - unusual or new to the mind in which it arose; and appropriate - conform to the characteristics of a desired/accepted solution. Such creative ideas may then be implemented and embodied in a creative product'**

However, does creativity in design merely consist in the creation of an idea? Lamm & Trommsdorf (1973) and Mullen *et al* [1991] argue that the global phenomenon of creativity can not be measured by a single metric alone. To explore this issue further we shall next consider metrics of creativity.

2.2.2 Metrics and measurements of creativity

In the previous section we have seen a number of definitions of creativity. Unsurprisingly, there are also a number of measures of creativity. In an extensive review and critique of available tests to measure creativity, Hocevar [1981] categorises these tests into ten categories: tests of divergent thinking, attitude and interest inventories, personality inventories, biographical inventories, teacher nominations, peer nominations, supervisor ratings, judgments of products, eminence and self-reported creative activities and achievements. Hocevar [1981] critiques these tests in terms of their reliability, discriminate validity, dimensionality and convergent validity.

While the tests and associated categories themselves differ and each has its own methodological strengths and weaknesses [Hocevar, 1981], they do have three common characteristics: originality, fluency and flexibility. *Originality* considers the unusualness or creative strength of an idea. *Fluency* represents the total number of relevant ideas produced. *Flexibility* considers the number of different approaches or categories of ideas produced.

The characteristic of unusualness maps to our notion of novelty; and the ideas that are relevant are also considered appropriate [Torrance, 1966; Torrance, 1967]. An idea that is both novel and appropriate, measured in terms of its originality and fluency, is therefore a creative idea, according to our definition of creativity in design (see section 2.2.14).

It has been argued that a crude indicator of creativity is the ability to produce a large number of ideas per unit of time [Boden, 1994; Csikszentmihalyi, 1996; Guilford, 1959]. Hence, one measure of creativity is to count the number of creative ideas [Boden, 1994].

Flexibility considers the divergence of thinking [Torrance, 1966; Torrance, 1967]. de Bono [1967] places emphasis on 'lateral thinking' and Lawson [1980] talks about 'divergent thinkers'. Many researchers [e.g. de Bono, 1967; Lawson, 1980; Runco, 2003] have argued that the more lateral or divergent the thinking of an individual or group, the more creative they may be considered. Therefore, a second measure of creativity is to count the number of categories of creative ideas, thereby measuring the divergence of creativity.

The quantity of creativity ideas and divergence of thinking are quantitative measures of creativity, but they do not distinguish between 'good' and 'bad' creative ideas. What about qualitative measures of creativity? Quality was not a core characteristic of the creativity tests reviewed by Hocevar [1981], as it was not always applicable. For example, quality was not a characteristic of tests measuring divergent thinking and traits of creative persons. However, quality was considered in tests that assessed the creative products of individuals [Amabile, 1983; Hocevar, 1981]. For example, judgments of products directly assessed the creative products of individuals, while tests such as teacher, peer and supervisor nominations assessed the creativity of an individual by considering their creative products indirectly. It has been argued that the higher the quality of an idea the more creative it is considered [e.g. Boden, 1994]. Thus, our third measure of creativity is the quality of creative ideas.

So far we have seen that creativity is more than merely generating an idea, but rather involves producing large numbers of ideas [Boden, 1994; Csikszentmihalyi, 1996; Guilford, 1959], being divergent in the production of those ideas [de Bono, 1967; Lawson, 1980; Runco, 2003] and making sure they are of high quality [Amabile, 1983; Boden, 1994]. In the following sub-sections we review and critique methods for measuring the quantity, divergence and quality of creative ideas in more detail.

2.2.2.1 The quantity of creative ideas

To measure the number of creative ideas, previous researchers [e.g. Taylor *et al*, 1958] have simply counted the number of ideas generated in response to a given creative problem solving exercise, while removing duplicate ideas. For example, in Taylor *et al* [1958], a typewritten transcription of the recorded responses by participants was made. The transcripts were then analysed looking for solutions to the given problem, resulting in a master list. Finally, the master list was examined to make sure no ideas were duplicated.

Such an analysis is highly subjective. What does the judge consider a solution/idea to be? Is the idea both novel and appropriate? There is no distinction between creative and non-creative ideas, where every idea generated is considered creative. Furthermore, is this method of counting ideas reliable? For example, in the Taylor *et al* [1958] study, the counting of ideas was performed by a single judge. A second judge may have counted a different number of ideas. If multiple judges had counted the reported ideas, some inter-judge reliability could have been established. The reliability of identifying duplicated ideas is also questionable. In the Taylor *et al* [1958] study 483, 791 and 513 ideas were identified for each of their three creative problem solving exercises. Is it really possible to compare all the ideas to check for similarity with any reliability? That would mean $(n + n^2)/2$ reliable comparisons. What even constitutes a similar idea?

The validity and reliability of this previous research [e.g. Taylor *et al*, 1958] is highly subjective and questionable. Therefore, are there more objective and more reliable methods one might use to count the number of creative ideas?

A problem, for example, with the Taylor *et al* [1958] study was that a judge had to subjectively identify ideas from the transcript of a recording. This subjectivity is mitigated when brain-writing (i.e. writing ideas down) techniques are used to record ideas [Paulus & Dzindolet, 1993; Paulus & Yang, 2000]. For example, in studies by Paulus & Dzindolet [1993] and Paulus & Yang [2000] participants wrote each idea they had on a slip of paper. The number of ideas reported could be measured by counting the number of slips of paper with ideas on them. Hence, the participant herself identifies the ideas she generated, rather than a judge having to subjectively determine if an idea had been generated or not.

We argue that ideas can also be identified based upon sentence structuring analysis and copyright law [Warr & O'Neill, 2006b]. Sentence structuring allows an individual's responses to be analysed for the occurrence of nouns. Nouns are particularly useful at identifying ideas as they classify people, places and things. Furthermore, the identification of verbs can describe the actions or states of the nouns. Identifying the occurrence of nouns leads to a natural categorisation (i.e. a tree structure) and simplification of an individual's responses. This is similar to a method presented by Johnson *et al* [1995] for identifying task knowledge structures. For example, say we asked a participant to generate ideas for a scrolling technique that allowed a user or users to scroll up, down, left and right on a pervasive computing screen (a problem used in chapter 3, section 3.3.3) and one of the ideas generated was as follows:

> *'One idea to scroll the screen would be the movement of one's hand whilst wearing an interactive glove'*

We then identify the nouns in the idea (in bold):

> *'One idea to scroll the screen would be the* ***movement*** *of one's* ***hand*** *whilst wearing an interactive* ***glove****'*

Extracting the nouns from the idea we get the following structuring:

Movement -> Hand -> Glove

Copyright law [Copyright, Designs and Patents Act, 1988] reflects a history of careful thought on the nature of ideas and was useful when applied to our categorisation schema. Copyright law distinguishes between ideas and expressions of ideas. An *idea* is a response which is finite, while an *expression of an idea* is a response which comes from a large finite or infinite set. For example, when designing an interaction technique for scrolling, one can not copyright the idea of 'movement'. Whereas, an expression of an idea is potentially worthy of copyright. For example, someone could have the idea of designing an interaction technique using the movement of an interactive glove with specific features that the user wears on their hand. Applying this concept to our data, one noun specifies the idea (e.g. Movement), while multiple nouns which fall under the idea are denoted as expressions of ideas (e.g. Movement -> Hand -> Glove).

This categorisation also helps with the objective and reliable identification of duplicated ideas. If an idea is generated that produces an existing branch in the tree structure - a result of applying our sentence structuring schema - or a shorter branch that is a subset of a longer existing branch, the idea is considered a duplicate. For example, if the structure *Movement -> Hand -> Glove* and then the structure *Movement -> Hand* were generated, the latter would be considered a duplicate.

Therefore, we have determined how to identify and measure ideas, but how do we know if the ideas are creative? As stated above, previous research [e.g. Taylor *et al*, 1958] has merely considered every identified idea to be creative. However, in accordance with our definition of creativity in design (see section 2.2.1.4) and previous work [e.g. Amabile, 1983; Bruner, 1962; Gilchrist, 1972; Jackson & Mersick 1965], for an idea to be deemed creative it must be both novel and appropriate.

As discussed in the previous section, there are different degrees of novelty. However, the focus of this thesis is design, where we are considering impromptu or personal, and evolutionary creativity. As such, and as reflected in our definition of creativity in design (see section 2.2.1.4), we consider novelty as an idea that is unusual or new to the mind in which it arose (i.e. p-novel), rather than revolutionary creativity where an idea is new to society (i.e. h-novel). Therefore, the novelty of an idea can be determined using a retrospective protocol analysis, asking the originator of the idea whether they consider it unusual or new to them in the context of the problem. Such a schema has been used by Benami & Jin [2002] to determine novelty by classifying ideas based on participant's responses.

Furthermore, for a novel idea to be deemed creative, it must be appropriate. Lawson [1980] argues that appropriateness can be determined using a simple checklist that confirms that the generated idea conforms to the characteristics of a desired solution.

Having identified the ideas reported by a creative person, the ideas can be assessed to determine if they are novel and appropriate. Those ideas that are both novel and appropriate can then be objectively and reliably counted towards the measure of the quantity of creative ideas [Warr & O'Neill, 2005b; Warr & O'Neill, 2006b].

2.2.2.2 The divergence of creative ideas

In order to measure divergent thinking one has to count the number of categories of ideas generated in response to a given creative problem solving exercise [Torrance, 1966; Torrance, 1967]. The more categories of ideas generated, the more creative the person or group is considered [de Bono, 1967; Lawson, 1980; Runco, 2003], as this shows the ability to change mind set easily and therefore generate lots of different types of ideas to solve a problem [Guilford, 1959]. So, how then can we count the number of categories of creative ideas?

A point to note is that relatively few studies have been conducted looking at divergent thinking [e.g. Torrance, 1970], compared with studies measuring the quantity of ideas produced and the quality of creative ideas [e.g. Mullen *et al*, 1991]. This may be due to the problem, 'how do you categorise creative ideas?'

In the Taylor *et al* [1958, p.31] study, ideas were reported to be 'organised in terms of appropriate categories and sub-categories'. How though do you determine an idea to belong to a category or subcategory? In the Taylor *et al* [1958] study this categorisation was subjective. Hence, the categorisation of ideas could differ from one judge to another. So, are there more objective and more reliable methods one might use to count the number of categories of creative ideas?

Our method based on identifying the occurrence of nouns in reported ideas and our classification of novel and appropriate ideas (see section 2.2.2.1), can be used to determine the divergence of the creative ideas produced [Warr & O'Neill, 2006b]. The categorisation of creative ideas based on the identification of nouns leads to a natural set of tree structures. For example, if asked to come up with creative ideas for scrolling a pervasive computing screen, some possible ideas might be:

1. *'One idea to scroll the screen would be the movement of one's hand whilst wearing an interactive glove'*

2. *'You could scroll the screen based on the movement of one's foot'*

3. *'Scrolling could be controlled using directional buttons on the screen'*

4. *'Scrolling could be controlled using directional buttons on a remote control'*

Applying our categorisation of nouns to the ideas we get the following outputs:

1) Movement
1.1) Movement -> Hand
1.1.1) Movement -> Hand -> Glove
1.2) Movement -> Foot

2) Buttons
2.1) Buttons -> On-screen
2.2) Buttons -> Remote control

To count the number of categories of creative ideas, one simply counts the number of tree structures. Sub-categories can also be determined when a branch splits. Since this method is based directly on a creative person's responses, rather than those responses being subjectively interpreted by a judge, it allows divergent thinking to be objectively and reliably assessed [Warr & O'Neill, 2006b].

2.2.2.3 The quality of creative ideas

Amabile [1983] regards creativity as the quality of products or responses judged to be creative by an observer. Such an assessment is purely subjective with the observer rating the product or response based on some criteria they deem to constitute creativity. What then are the criteria of creative quality and is it possible to assess creative quality in terms of a set of criteria?

Ghiselin [1963] argues that it is possible to articulate criteria of creativity that are clearly stated and can be readily translated into an assessment method. The assessment of creative quality by using some criteria related to creativity has been adopted by many researchers [e.g. Diehl & Stroebe, 1987; Gurman, 1968, Milton, 1965, Taylor *et al*, 1958].

Taylor *et al* [1958] assessed creative quality on three levels: feasibility, effectiveness and generalisability. Each of the criteria were assessed on a five-point Likert scale. three independent judges rated the responses, with two different pairs of judges assessing each criterion. However, no inter-rater reliability was determined. Milton [1965] built upon the Taylor *et al* [1958] study using two independent, trained raters who rated the creative quality of ideas based on a nine-point Likert scale of effectiveness. However, a flaw with these studies is that there is no explanation as to where their criteria for creative quality came from.

As we have seen in section 2.2.1, several researchers [e.g. Amabile, 1987; Jackson & Messick, 1965] describe a creative idea or product in terms of novelty and appropriateness. Gurman [1968] used the very similar criteria of uniqueness and value. Similarly, Diehl & Stroebe [1987] used the criteria of originality and feasibility in their assessment of creative quality. Creative quality was based upon the degree of these criteria measured on a Likert scale by independent, expert judges. In addition, Diehl & Stroebe [1987] set a creative quality threshold value, so that they could assess the number of 'good' ideas generated. However, assessments using these Likert scales resulted in poor inter-rater reliability, probably due to the fact that the scales are highly subjective and hard to judge [e.g. Runco, 2003]. Gilchrist [1972], Guilford [1959] and Jackson and Mersick [1965] argue that we can more objectively and reliably measure the quality of creative ideas by measuring the degree of novelty and appropriateness of a creative idea. We describe below how this can be achieved.

As described in section 2.2.1, Boden [1994] describes novelty in terms of p-novelty and h-novelty. Boden [1994] argues that a h-novel idea is more novel than a p-novel idea. This suggests that we may consider and indeed measure the novelty of an idea. Therefore, novelty may be treated as a scale. At one end lies an idea which has never been thought of by anyone before and at the opposite end lies an idea which has been thought of by everyone before. By looking at the frequency of occurrence of an idea we can determine its novelty - the more frequent an idea the less novel it is, while the less frequent the idea the more novel it is. A problem with the concept of h-novelty is of course that it cannot be assessed. We cannot, for a given idea, determine that nobody else anywhere has ever come up with it. But over smaller temporal and spatial scales, for example, under controlled conditions such as an experiment, we can in principle determine how many times an idea occurs and thus gauge the novelty of an idea.

To complete our assessment of creative quality we needed to develop an approach to measure how appropriate an idea is. As reflected in our discussion of appropriateness above (see section 2.2.2.1), an idea or product is considered appropriate if it conforms to a set of predefined characteristics or requirements [Lawson, 1980]. In terms of developing more useful and usable products, this is determined by the users' needs and expectations. This underpins our approach to assessing how appropriate an idea is. The higher the number of users finding an idea or product appropriate for use, the more appropriate we consider it to be, while the lower the number of users finding an idea or product appropriate for use, the less appropriate we consider an idea to be [e.g. Johnson & Carruthers, 2006]. This assessment can be achieved using a retrospective protocol analysis.

With a measure of the degree of novelty and the degree of appropriateness we collate the two measures to give a measure of creative quality. Being consistent with previous research [e.g. Diehl & Stroebe, 1987; Gurman, 1968], novelty and appropriateness have an equal weighting.

Furthermore, Dorst & Cross [2001, p.431], argue 'it may be that creativity is normally regarded as a significant aspect of an overall "good" design. However, "creative" design is not necessarily "good" design'. Setting a threshold value on creative quality allows us a measure of the number of 'good' ideas produced [Diehl & Stroebe, 1987].

Hence, assessing the novelty of an idea based on the frequency of occurrence of an idea, and the appropriateness of an idea based on the number of users considering that idea to be appropriate, allows for a more data driven and objective approach to assessing creative quality, mitigating the problem of unreliable data due to the subjectivity of judges' ratings.

2.2.2.4 The multi-faceted nature of creativity in design

In this section we have reviewed and critiqued metrics of creativity - the quantity, divergence and quality of creative ideas - and discussed reliable measures of these metrics. We go on to apply such measures of creativity in chapter 3 (see section 3.4). Furthermore, we have developed our basic understanding of creativity. Creativity is a multi-faceted phenomenon, not able to be measured by a single metric [Lamm & Trommsdorff, 1973; Mullen *et al*, 1991]. Rather, the core facets of creativity have been identified as the ability to produce large numbers of creative ideas; produce many different categories of creative ideas; and produce high quality creative ideas.

These metrics of creativity also map on to our study of design. Tohidi *et al* [2006a, p.1243] quote Alistair Hamilton, VP Design of Symbol Corp saying, '... a designer that pitched only one idea would probably be fired. I'd say five is an entry point for an early formal review (distilled from 100's)'. We see that it is important for designers to produce many ideas. Designers should also be divergent thinkers [Lawson, 1980], exploring multiple solutions to design problems. Such exploration helps us find the *right design* [Tohidi *et al*, 2006a]. Furthermore, with respect to creative quality, designers are also interested in producing high quality designs, thereby getting the *design right* [Tohidi *et al*, 2006a].

How though does such creativity come about? A creative person undergoes some creative process, thereby generating a number of creative ideas - hopefully a large number, that are divergent and of high quality - that when implemented give rise to a creative product. To deepen our understanding of how this creativity comes about, we next consider models that describe the process of being creative.

2.2.3 The process of being creative

A long history of research [e.g. Wallas, 1926; Osborn, 1963; Ambile, 1983; Shneiderman, 2000] has described the phases that occur in the process of being creative, through creative process models. Such models are not intended to be step-wise, linear models, but rather models that show the various phases of the intertwined and iterative nature of creativity - descriptive rather than prescriptive.

One of the first models of the process of being creative was proposed by Wallas [1926], who described creativity as involving four phases: preparation, incubation, illumination and verification. *Preparation* is a phase in which one clarifies the problem and develops an understanding of it, so that one is prepared for what may be needed for potential solutions to the problem. This phase may involve gathering relevant data about a problem and reviewing it. *Incubation* is when one no longer consciously considers the problem. However, although conscious thought is suspended, the problem remains as an ambient thought (i.e. the exploration of one's conceptual space [Boden, 1994]) awaiting some creative insight - an 'eureka' moment. The *illumination* phase is when the creative insight occurs. Nemiro [2004, p.8] describes this as 'when there is a sudden change in perception, a new idea combination, or a transformation that produces an acceptable solution to the problem at hand'. This reflects both the view of the 'combinations of matrices of thought' by Koestler [1964] and the 'transformation of conceptual spaces' view by Boden [1994], giving rise to a novel idea. The final phase of *verification* involves making sure that one's novel idea is in fact an appropriate solution to the problem.

Later models moved away from proposing unconscious phases of incubation and illumination, towards a more conscious process of deliberately coming up with ideas. Osborn [1963] described the creative process comprising two main phases: idea generation and idea evaluation. *Idea generation* is made up of a further two sub-phases: *fact-finding* - the process of problem definition and preparation; and *idea-finding* -

the process of producing novel ideas through the combination of old, existing ideas. During the *idea evaluation* phase, the novel ideas produced during idea-finding are assessed for their appropriateness.

Amabile [1983] extended previous creative process models providing a framework, showing how domain-relevant skills, creative-relevant skills and task motivation contribute to the creative process. *Domain-relevant skills* are attributes such as factual knowledge and skills - attributes that will affect an individual's performance in a given domain. *Creative-relevant skills* include a person's cognitive style - this will influence the way the individual explores and transforms conceptual spaces. *Task motivation* determines how an individual approaches a task - an individuals enthusiasm for a task.

In Amabile's [1983] creative process model there are five phases: problem and task presentation, preparation, response generation, response validation and outcome. During *problem and task presentation* the individual is presented with the problem and what is involved. During this phase of the process, task motivation has to be high, so the individual has sufficient interest to pursue solving the problem. While Amabile [1983] does not acknowledge this, domain knowledge (i.e. does the individual understand the problem and what is involved) may also be important in this phase, having an influence on task motivation.

Preparation involves the individual building up knowledge about the problem and researching what a potential solution may necessitate. Domain-relevant skills are particular important during this phase, as domain knowledge will play an important part in generating an acceptable solution.

Response generation is heavily dependent on creative-relevant skills and task motivation. Creative-relevant skills could influence the quality of the novel ideas produced, as the better the individual is at exploring conceptual spaces, the more novel the solutions are likely to be. Task motivation could also have an influence on the quantity of ideas produced. Osborn [1963] argues that 'quantity breeds quality', therefore a high task motivation is required so that more ideas are produced, as the more interested an individual is in a problem the more time and effort she is likely to spend generating ideas to solve it.

Validation of the responses and solutions generated is heavily reliant on domain-relevant skills, as the individual must have knowledge by which to assess the appropriateness of the generated novel ideas.

Finally, one of three possible *outcomes* is achieved: a solution is obtained and the process has been a success; all ideas for a solution are rejected and therefore the process has failed; and the ideas generated have made a contribution to solving the problem, but it is not yet solved, in which case we return back to the first phase of the creative process and reassess the problem.

Shneiderman [1998a; 2000] uses a four phase model to describe the creative process as part of his GENEX framework (generator of excellence): collect, relate, create and donate. *Collect* is the initial phase of collecting information about the problem from information resources such as digital libraries and the Web. The *Relate* phase in the model is when one consults with peers and mentors. This phase should be performed throughout the model as an iterative cycle, interleaved with the other phases. *Create* is the phase in which one explores, composes and evaluates possible solutions. *Donate* is when the results of the creative process are disseminated to information resources. This phase may cause new needs to be identified or cause new ideas to be generated by the community who view the solutions, resulting in returning to previous phases in the model.

2.2.3.1 A comparison of creative process models

The models of the creative process all evolve around three main phases: problem framing, idea generation and idea evaluation. Table 2.2 provides an overview of the creative process models.

A common theme within all the creative process models is the phase of problem framing. Before the generation of ideas to solve a problem, one must understand the problem and the various characteristics of a desired solution [Wallas, 1926]. This involves building up one's domain knowledge [Amabile, 1983].

Once the individual understands the problem and has built up the relevant domain knowledge, the more specifically creative phase of the creative process model occurs - idea generation. Some models [e.g. Wallas 1926] view this phase as a subconscious activity involving phases of incubation and illumination. However, there have been many arguments against this inspirationalist view of creativity [e.g. Perkins, 1981; Plsek, 1996]. Perkins [1981] argues that while incubatory thinking may indeed happen, there is no firm evidence that it does, or is substantially related to creativity compared to any other forms of thought. For example, the sudden perception of an idea could be due to a stimulus, whether picked up consciously or unconsciously. As argued by Santanen *et al* [2002], such a stimulus could then trigger a transformation. The emergence of this insight is therefore due to serendipitous noticing, rather than incubatory thinking. Hence, some researchers have argued that the incubation

Table 2.2: A comparison of creative process models.

Models	Problem Framing		Idea Generation		Idea Evaluation	Donating
Wallas [1926]	Preparation		Incubation	Illumination	Verification	X
Osborn [1963]	Fact-finding	Idea Generation	Idea-finding		Idea Evaluation	X
Amabile [1983]	Problem or task presentation	Preparation	Response generation		Response Validation	Outcome
Shneiderman [2000]	Collect		Relate	Create		Donate

period may not be necessary [e.g. Weisberg, 1986]. More recent research [e.g. Osborn, 1963; Amabile, 1983; Shneiderman, 2000] argue that the phase of idea generation requires more of a deliberate act to generate new ideas through combining old, existing knowledge.

All the creative process models have an idea evaluation phase. This phase is concerned with determining if a novel idea is useful. This involves assessing a novel idea against the characteristics of a desired solution identified during the phase of problem framing.

Shneiderman's [2000] creative process model combines the phases of idea generation and idea evaluation into a create phase. The combination of these two phases is unusual as all the other models separate idea generation and idea evaluation. Osborn [1963] argues that the most important principle of idea generation is 'deferment of judgment'. Many studies [e.g. Collaros & Anderson, 1969; Diehl & Stroebe, 1987; Jablin *et al*, 1977] have shown in their studies how evaluation can decrease creativity in terms of the number of ideas generated. A decrease in the number of ideas produced will also violate another of Osborn's [1963] principles: quantity is wanted.

A new phase introduced by Amabile [1983] and Shneiderman [2000] is the outcome and donate phase. Such a phase considers the resultant creative product of the creative process. We make a distinction here between the outcome of idea generation - creative ideas; and the outcome of the creative process - a creative product (e.g. a piece of art, a music composition or an architectural structure). This phase also emphasises the iterative nature of the creative process. Creative products are disseminated, which may then be fed back into the creative process, inspiring new idea or prompting the refinement of ideas [Amabile, 1983; Shneiderman, 2000].

Many of the models [e.g. Amabile, 1983; Osborn, 1963; Wallas, 1926] consider the creative process from the perspective of the individual. Shneiderman [2000] categorises these as inspirationalist and structuralist perspectives on creativity. *Inspirationalists* focus on the individual coming up with ideas in a fashion like the 'eureka' moment [e.g. Wallas, 1926]. *Structuralists* focus on more systematic approaches to individual's exploring and transforming conceptual spaces [e.g. Osborn, 1963; Amabile, 1983]. Influenced by researchers such as Csikszentmihalyi [1996], who emphasises the importance of the social nature of creativity, Shneiderman [2000] brings a social influence to the creative process model. The latter *situationalist* perspective on creativity moves away from the individual perspective on creativity and views creativity as more of a social process, placing more importance on interaction and collaboration with other individuals and the surrounding environment.

2.2.3.2 The creative process of design

There is an obvious parallel between the process of being creative and the process of design. The phases of the creative process: problem framing, idea generation and idea evaluation [e.g. Amabile, 1983; Osborn, 1963; Shneiderman, 2000; Wallas, 1926] map to the phases of the design process: analysing a problem; synthesising a solution; and evaluating the outcome [e.g. Alexander, 1964; Carroll *et al*, 1979; Jones, 1970; Manhorta *et al*, 1980; Rosson *et al*, 1987]. Beyond Alexander [1964] and Jones's [1970] rational and well-structured view of the design process as a sequential series of steps, these phases are considered descriptive, rather than prescriptive, emphasising the iterative nature of both creativity and design. This creative process of design is illustrated in figure 2.1.

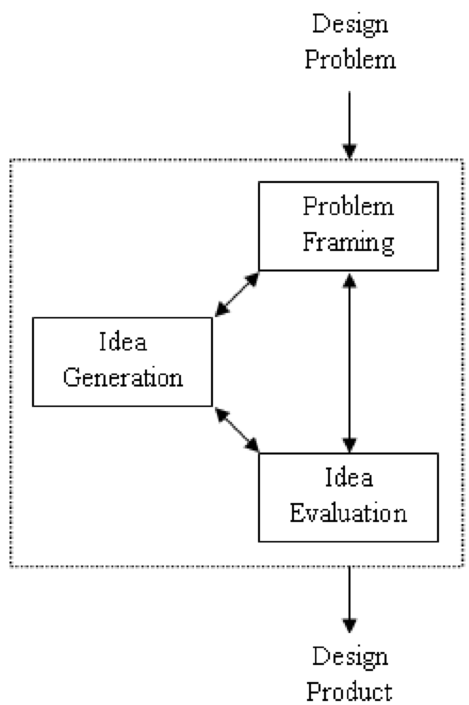


Figure 2.1: The creative process of design (version 1).

Furthermore, we can also see how Shneiderman's [2000] categorisation of creative process models maps to Fallman's [2003] accounts of design. The inspirationalist coming up with ideas in an 'eureka' fashion maps to the romantic account of design.

The structuralist who applies a more systematic approach maps to the conservative account of design. While the situationalist who places importance on people, artefacts, places and practices maps to the pragmatic account of design.

As noted above, most of the models of the creative process have considered creativity from the perspective of the individual [e.g. Amabile, 1983; Osborn, 1963; Wallas, 1926]. However, design involves discussion and consultation with colleagues, experts and users [Rosson *et al*, 1987]. This collaboration is essential in design methods such as PD and UCD, where stakeholders (e.g. designers and users) are both actively and passively present in the design process. In recent years, researchers who study creativity [e.g. Csikszentmihalyi, 1996; Edmonds *et al*, 1999; Mamykina *et al*, 2002; Shneiderman, 2000] have put more emphasis on collaboration and the social nature of creativity. In the next section we consider the social nature of creativity and its application to design.

2.2.4 The social nature of creativity

Much research on creativity to date has focussed on the individual: definitions of creativity [e.g. Guilford, 1950; Koestler, 1964; Gough, 1979; Amabile, 1983; Boden 1994]; metrics and measures of creativity [e.g. Amabile, 1983; Hocevar, 1981; Torrance, 1966; Torrance, 1967]; and creative process models [e.g. Wallas, 1926; Osborn, 1963; Amabile, 1983]. However, John-Steiner [2000] and Salomon [1993] argue that the individual mind is highly overrated. Even in cases of individual creativity [e.g. Cross, 2002; Csikszentmihalyi, 1996; Gardner, 1995], much of our intelligence and creativity results from interactions and collaborations with other individuals [Candy, 1997; Csikszentmihalyi, 1996; Csikszentmihalyi & Sawyer, 1995; Sawyer, 2003]. As noted by Fischer *et al* [2005, p.484], 'The analysis of creative people and creative objects, however, has demonstrated that most scientific and artistic innovations emerge from joint thinking, passionate conversations and shared struggles among different people, emphasising the importance of the social dimension of creativity'. Such a perspective on creativity has been adopted by many researchers within the field of HCI [e.g. Candy, 1997; Fischer *et al*, 2005; Shneiderman, 2000], where it is the interactions with other people, tools and the environment that facilitate the creative process. Theoretical perspectives, such as distributed cognition [Hollan, 2000; Hutchins, 2000], move away from the individual mind and focus on the inclusion of significant features in the environment that support cognition. 'Distributed cognition emphasises that the heart of intelligent human performance is not the individual human mind but groups of minds in interaction with each other and minds in interaction with tools and artefacts' [Edmonds *et al*, 1999, p.38]. One's mind is a container of knowledge, however, there is a wealth of knowledge available to us through other people, tools and the environment that we may interact with.

Each individual has their own set of interests, skills and knowledge. Polanyi [1966] argues that the key to social creativity is the externalisation of an individual's and group's tacit knowledge, as a group has more information and knowledge than each of its members [Stein, 1975]. When working alone an individual only has the knowledge in their head available to them. However, when interacting with other individuals and/or when interacting with other tools and artefacts, a wider domain of knowledge is available to the individuals' in a group [Jones & Greene, 2000]. As argued by Fischer *et al* [2004, p.358], 'externalisations of individuals knowledge make it possible to accumulate the knowledge held by the group'. Similarly Nakakoji *et al* [2000] refers to this process as *collective creativity* where concepts and understandings emerge in people's mind through interacting with externalisations, other people, computer systems and the world. To illustrate the concepts of both individual and social creativity we present two simplest case scenarios.

Say we have two individuals working independently. Each individual has a domain of knowledge, with so many bundles of knowledge available to them - two in this simplest case scenario. Figure 2.2 illustrates this.

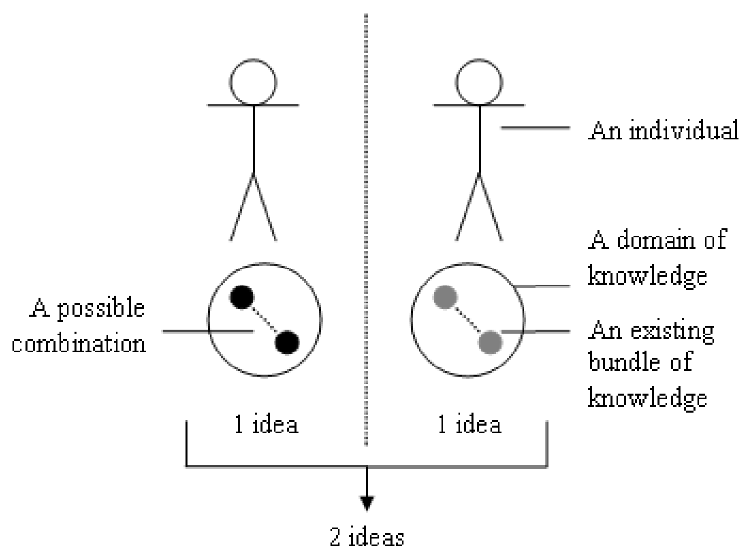


Figure 2.2: A simple case scenario of individual creativity.

Building upon our definition of creativity in design (see section 2.2.1.4) each of the individuals can combine the two bundles of knowledge to produce a creative idea. (We assume for this simplest case scenario that the combination of these bundles of knowledge will produce an idea which is both novel and appropriate and therefore considered creative.) Hence, in this scenario each individual generates one creative idea by combining their two bundles of existing knowledge together. Therefore, a total of two creative ideas are generated between the individuals.

Now let us consider a scenario where two individuals collaborate. Once again each individual has a domain of knowledge, with so many bundles of knowledge available to them - two in this simplest case scenario. Figure 2.3 illustrates this.

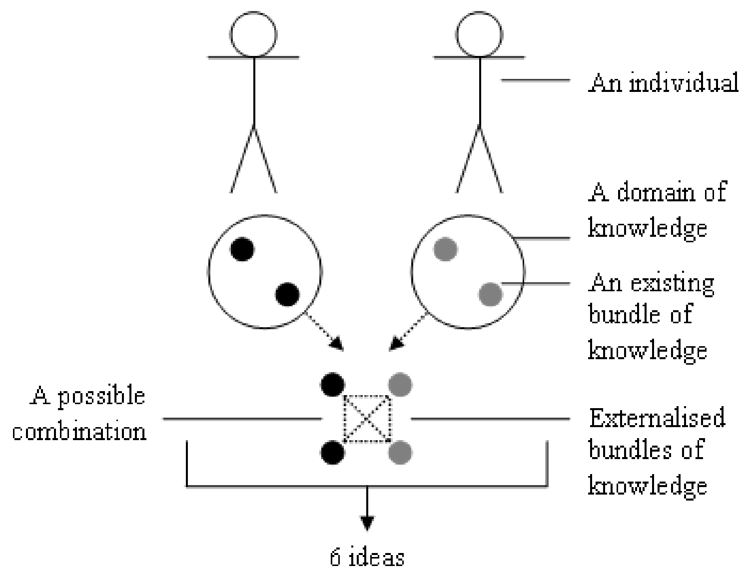


Figure 2.3: A simple case scenario of social creativity.

The individuals in this scenario are able to interact with each other and externalise their knowledge. With this knowledge externalised there is a greater potential to combine existing bundles of knowledge to produce new creative ideas. (Once again we assume that we can combine these bundles of knowledge to produce an idea that is both novel and appropriate and therefore creative.) Hence, in this scenario through the individuals collaborating together they can each externalise their bundles of knowledge. Therefore, by combining the four externalised bundles of knowledge a total of six creative ideas are produced.

As we can see from our simplest case scenarios, social creativity allows for a higher potential of creativity - quantity of creative ideas produced - than when individuals work alone. The ability for groups to interact with each other to externalise bundles of knowledge increases the resources available to the group, giving them the opportunity to form new knowledge structures and so produce creative ideas. Although some combinations of bundles of knowledge may not be possible, this is true for both individuals working alone and groups, making the possible combinations for groups significantly higher. While we focussed on two individuals here, the scenario holds for larger numbers of individuals. In addition to individuals, artefacts that reflect knowledge (e.g. a book, a computer with access to the Internet) could also increase the potential for creativity.

For this theoretical potential to be realised there needs to be effective and efficient methods available for externalising knowledge and making it available to the members of a group. Fischer *et al* [2005, p.484] refers to this externalisation of knowledge as occurring through, 'joint thinking, passionate conversations and shared struggles'. Similarly, Mamykina *et al* [2002, p.98] states, 'Fluid and open communication is a necessary condition for reaching a shared vision'. The externalisation of tacit knowledge allows shared understanding to be developed [Fischer *et al*, 2004]. Similarly, Clark & Brennan [1991] describes how mutual assumptions, beliefs and knowledge are shared and developed whilst collaborating in a group. These shared understandings can then lead to new insights, new ideas and new artefacts [Fischer *et al*, 2004].

So far we have emphasised the importance of social creativity. However, this is not to say that individual creativity it not as important. As argued by Fischer *et al* [2005, p.484], 'human interaction is not only needed but central to social creativity; however, people participate in such collaborative inquiry and creation as individuals, and individuals need the reflection time... without such individual reflection, it is difficult to think about contributions to social inquiry or creativity'. Similarly Edmonds *et al* [1999, p.36] note, 'having a bright idea may be an individual act, but bringing it to fruition may be a much larger effort, requiring many contributors, sustained mental efforts and sustainable community efforts are prerequisite for social creativity'. This indicates that there is an 'and' rather than a 'verse' relationship between individual and social creativity [Edmonds *et al*, 1999]. Hence, creativity involves both individual *and* social activities.

2.2.4.1 The effect of social influences on creativity

In section 2.2.4 we have shown the theoretical potential of social creativity over individual creativity alone. However, in reality is this theoretical potential realised?

Osborn [1957] claimed that groups following his brainstorming rules: *Criticism is ruled out* - Adverse judgement of ideas must be withheld. No one shall criticism anyone else's ideas. Say anything you think of; *Freewheeling is welcomed* - the wilder the idea the better. It is easier to tame down than think up. Do not be afraid to say anything that comes to mind. The further out the idea the better, this will stimulate more and better ideas; *Quantity is wanted* - the greater the number of ideas, the greater the likelihood of winners. Come up with as many as you can. *Combination* *and improvement are sought* - suggest how the ideas of others can be joined into still better ideas; would think up twice as many ideas when working within a group (i.e. social creativity) than when working alone (i.e. individual creativity). Taylor *et al* [1958] empirically tested Osborn's [1957] claim in a study that compared real groups with nominal groups. In the Taylor *et al* [1958] study a *real* group was a randomly selected group of four students who were asked to collaboratively work together on a problem solving exercise. Whereas, a *nominal* group was a randomly selected group of four individuals who had worked on the problem solving exercises separately. The output from each of the four individuals contributed to the output of the nominal group. Taylor *et al* [1958] found that nominal groups produced nearly twice as many non-duplicated ideas as real groups, thereby refuting Osborn's [1957] claim.

Although Taylor *et al* [1958] were the first to contradict Osborn's [1957] claim, many psychology researchers have investigated why real group creativity is not as effective as nominal group creativity. Demhis & Valacich [1993] stated that over the previous four decades, more than 50 studies had shown nominal groups to outperform real groups [Mullen *et al*, 1991]. Due to the abundance of research showing nominal groups to outperform real groups some researchers [e.g. Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973; Mullen *et al*, 1991] have recommended creative activities be performed by nominal groups only.

Why should it be the case that real group creativity is not as effective as nominal group creativity? Similar to our theoretical view of the potential of social creativity, McGlynn *et al* [2004] acknowledges the potential for groups to generate more and better ideas. So why is it that the majority of the empirical investigations performed over the last half century has shown this potential is not realised?

Many researchers [e.g. Lamm & Trommsdorff, 1973; Mullen *et al*, 1991] have attempted to explain the mass of evidence contradicting Osborn's [1957] claim that real group creativity is more effective than nominal group creativity. Many factors affecting social creativity have been explored over the years [e.g. Ambile, 1983; Enayati, 2002; Lamm & Trommsdorff, 1973]: group cohesiveness [e.g. Cohen *et al*, 1960]; group compatibility [e.g. Schutz, 1958]; homogeneity and heterogeneity with respect to ability, sex, race and personality [e.g. Shaw, 1983]; group size [e.g. Bouchard *et al*, 1970]; knowledge [e.g. Teigland & Wasko, 2000]; representations [e.g. Madsen & Finger, 1978; van der Lugt, 2002]; tasks [e.g. Harari & Graham, 1975]; motivation [e.g. Milton, 1965]; training [e.g. Cohen *et al*, 1960; Kramer *et al*, 1997]; facilitation [e.g. Kramer *et al*, 2001; Offner *et al*, 1996] and the social influences of production blocking [e.g. Diehl & Stroebe, 1987; Diehl & Stroebe, 1991], evaluation apprehension [e.g. Maginn & Harris, 1980; Jablin *et al*, 1977] and free riding [e.g. Paulus & Dzindolet, 1993; Shepherd *et al*, 1995].

In this research we focus on the three social influences that have been argued to be the most important factors explaining why nominal groups are more creative than real groups [e.g. Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973; Mullen *et al*, 1991]: production blocking, evaluation apprehension and free riding. We next provide an overview of these social influences and their reasons for having inhibiting effects on social creativity.

Production blocking has been argued to be the most important cause of nominal groups creatively outperforming real groups [e.g. Diehl & Stroebe, 1987; Diehl & Stroebe, 1991; Lamm & Trommsdorff, 1973]. Production blocking is common when ideas are expressed verbally within a group. Verbally expressing ideas is a form of asynchronous interaction in which group members are prevented from simultaneously expressing their ideas [Schegloff, 2002]. They may subsequently forget their ideas or suppress them because they may feel their ideas are less relevant as time passes or as the discussion moves on. Another problem is that they may rehearse their ideas internally, preventing them from concentrating on what other members say. Finally, if group members are prevented from expressing their ideas as they occur, they may be discouraged from producing further ideas.

Hence, production blocking can have a major negative impact on social creativity. However, the ecological validity of focussing on verbal interaction has been questioned. In practice (e.g. design), it is very rare for a group to concentrate solely on verbally expressing their ideas and then transcribe them at a later date. It is more common for individuals within a group to externalise their ideas using paper, whiteboards or even computers as an external shared medium, interleaving such representations dynamically with their verbal contributions. However, the same problem of production blocking can exist with visual representations, if ideas can only be expressed asynchronously.

Evaluation apprehension occurs when group members fear criticism from others within the group. Although one of Osborn's [1957] brainstorming rules is 'the deferment of judgment', members of a group may still fear criticism from other group members, preventing them from expressing ideas and externalising their knowledge. The negative effect of evaluation apprehension reduces the potential creativity of the group.

Researchers [e.g. Collaros & Anderson, 1969; Diehl & Stroebe, 1987; Jablin *et al*, 1977] have performed studies observing the effects of evaluation apprehension by manipulating the perceived expertise of group members. In a study by Diehl & Stroebe [1987], evaluation apprehension was manipulated by comparing groups who had judges assessing a group's work, or where group members were informed that others within the group had expert knowledge in the field of the problem they were given - the high evaluation condition. Within the low evaluation condition, the group's work was not assessed by judges and all members of the group where perceived as equals. The results of this research showed that groups under the high evaluation condition produced significantly fewer ideas than groups in the low evaluation condition. This finding has supported past findings [e.g. Collaros & Anderson, 1969; Jablin *et al*, 1977].

However, contradicting these findings was a study by Maginn & Harris [1980] who manipulated evaluation apprehension when individuals were working on brainstorming tasks and found no effect on the productivity of ideas. Maginn & Harris [1980] argued that their judges did not produce significant evaluation apprehension because they were not in the same room as the subjects. So perhaps evaluation apprehension is actually induced by physically present peers rather than remote judges. Diehl & Stroebe [1987] looked at the difference between judges and peers in their evaluation apprehension condition, but failed to find any significant differences. However, there was a tendency for peers to induce higher evaluation apprehension for controversial problems, whilst judges caused higher evaluation apprehension for uncontroversial problems [Diehl & Stroebe, 1987].

Free-riding, otherwise known as social loafing, is the result of group members relying on others and not contributing as many ideas as they could. Diehl & Stroebe [1987] argue that free riding is the result of pooled assessment in groups compared to individual assessment when working alone. Some group members expect their ideas to be pooled and therefore assessed as a group. Individuals working alone expect their efforts to be monitored and are thus unable to avoid their poor performance being detected.

However, it should be acknowledged that low productivity may not always be the result of free-riding. Personality types and cultural differences may result in some group members being withdrawn from the group. Furthermore, although a group member may make a small contribution, that contribution may be very valuable, while someone who is actively involved in the group's discussion may not make any valuable contribution. Although a group member may not be actively involved in solving the problem, she may be internally reflecting upon the problem, awaiting the appropriate time to make a valuable contribution to the group.

2.2.4.2 Social creativity in design

Design is a social creative process [Warr & O'Neill, 2005a]. As argued by Nakakoji *et al* [1999, 167], 'creativity results from the collective memory of communities of practice and of the artefacts and technologies surrounding them - what we call "collective creativity"'. Design methods such as PD and UCD involve interactions between members of a design team (i.e. CoP) and the artefacts they use. As such, design teams who engage in these design methods have the potential to be highly creative. For example, expanding upon our simplest case scenario presented above, both users and system designers have knowledge of their work practices and available technologies, respectively. Externalising this knowledge allows users and system designers to be more creative than either stakeholder working alone. For this potential to be realised design teams need to have effective and efficient methods for externalising knowledge and making it available to the members of the design team. This is achieved through fluid and open communication [Fischer *et al*, 2005; Mamykina *et al*, 2002] and the externalisation of tacit knowledge [Fischer *et al*, 2004].

While knowledge may be externalised to the design team, it may be used by the entire team or even individual team members. Design involves both individual and social creativity [Fischer *et al*, 2005]. An individual designer may frame, generate and evaluate ideas, but also engage in this process when interacting with others [Buxton, 2005c].

However, in this social creative process of design, social influences may inhibit a design team's creativity [Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973; Mullen *et al*, 1991]. Members of a design team who verbally communicate their ideas can prevent others in the design team from expressing their ideas (i.e. production blocking). This can also be true when visually representing ideas or interacting with tools and artefacts. In a group setting such as that of PD, designers and users may suffer from fear of criticism (i.e. evaluation apprehension). As described by O'Neill [2000], in the early phases of the PD process, designers and users fear criticism from one another. Finally, it may be the case that in design teams, some members do not fully contribute and rely on the productivity of others (i.e. free-riding). For example, in a PD setting a user may rely on a designer to come up with all the ideas as they perceive the designer to be more creative. These social influences can have a detrimental effect on creativity in design.

In summary, we can see that social creativity in design has three core characteristics:

> **Characteristic 1: The externalisation of knowledge to members of the design team.**
>
> **Characteristic 2: Individual and social creative activities.**
>
> **Characteristic 3: Social influences that inhibit the creativity of the design team.**

Each of these characteristics have an effect on creativity in design. Without the externalisation and presentation of knowledge, the design team would not have the potential to be highly creative; without individual or social creative activities members of the design team would not have room for individual reflection and creativity, whereas without social creative activities individual members of the design team would not be able to take advantage of others' knowledge and skills; and with social influences inhibiting the design teams creativity, the creative potential of the design team is reduced. How then do we induce a positive effect on creativity in design?

2.3 Supporting creativity in design

In the previous section we described the social nature of creativity and its application to design. We identified three core characteristics of creativity in design and described the effect each has on the creativity of a design team.

So far in this chapter we have shown creativity to be a core feature in the process of design. As described by Fallman [2003, p.227], 'creativity and imagination are hence seen to be the human abilities that impel design'. Hence, we need to induce a positive effect on creativity in design in order to 'impel it'. This leads us to our second RQ:

RQ2: How can we support creativity in design?

More specifically based on our three core characteristics of social creativity in design:

RQ2.1: How can we support the externalisation of knowledge to members of a design team?

RQ2.2: How can we support individual and social creative activities in design?

RQ2.3: How can we support the control of social influences detrimental to creativity in design?

In the following sections we build an understanding of how to support creativity in design, with respect to the three core characteristics we have identified, eliciting high-level requirements for supporting creativity.

2.3.1 Supporting the externalisation of knowledge

Multiple stakeholders working together (e.g. users and system designers collaborating) have the potential to be more creative than individual stakeholders working alone. This potential is achieved through the externalisation of tacit knowledge [Fischer *et al*, 2004], which requires fluid and open communication [Fischer *et al*, 2005; Mamykina *et al*, 2002].

The externalisation of knowledge is crucial throughout the creative process: problem framing - framing a problem and developing a shared understanding [e.g. Fischer, 1999b]; idea generation - generating, refining and combining ideas [e.g. Warr & O'Neill, 2005a; Warr & O'Neill, 2006c]; externalising [e.g. Fischer, 1999b], organising, manipulating [e.g. Abrams *et al*, 2002] and disseminating them [e.g. Shneiderman, 2000]; and idea evaluation - evaluating those generated ideas [e.g. Fischer, 2004; Fischer *et al*, 2005; Wolf *et al*, 2006]. As already noted, these phases of the creative process are highly iterative and intertwined. Therefore, externalisations also need to be able to traverse the phases of the creative process.

Verbal communication is a human's primary means of communication [Schegloff, 2002]. As such, it is no surprise that it is through verbal communication that stakeholders build up an understanding of a problem, express their ideas and critique their generated ideas. However, verbal communication is an intangible means of externalising one's knowledge. Therefore, to complement verbal communication, the creation of visual representations using paper, whiteboards, computers and other tangible means of externalising one's knowledge are used [Scrivener & Clark, 1994]. 'It's harder to keep ideas alive when they're not embedded in tangible objects' [Hargadon & Sutton, 2000, p.161], this is especially true in group situations [Johnson & Carruthers, 2006]. As described by Schön [1983], 'Drawing and talking are parallel ways of designing, and together make up what I will call the *language of design*'. Schön [1983; 1992] describes this as a process of 'seeing-drawing-seeing'. Building upon Schön [1983; 1992] work, Tohidi *et al* [2006b] argue that sketching is fundamental to the design process, allowing ideas to be developed, explored, communicated and evaluated. Suwa & Tversky [2002, p.342] argue, '... designers do not draw sketches to externally represent ideas that are already consolidated in their minds. Rather, they draw sketches to try out ideas, usually vague and uncertain ones. By examining the externalisations, designers can spot problems they may not have anticipated. More than that, they can see new features and relations among elements that they have drawn, ones not intended in the original sketch. These unintended discoveries promote new ideas and refine current ones. This process is iterative as design progresses'. Similarly, Fischer [1999b] argues that externalisations can facilitate social creativity supporting new forms of knowledge creation, integration and dissemination. Furthermore, through using multiple representations (i.e. sketches and text), knowledge can be more effectively externalised compared to using a single representation alone [van der Lugt, 2002].

Fischer [1999b] places particular emphasis on the creation of boundary objects (e.g. sketches) as a means of facilitating social creativity. *Boundary objects* are externalisations that are used to communicate and facilitate shared understandings between CoP [Bowker & Star, 1999; Star, 1989]. Building upon Schön's [1983] theory of Reflection-in-Action (i.e. the pragmatic account of design), Fischer [1999b] describes a boundary object as an artefact that talks back to the group: initiators of communication amongst the group allowing shared understandings to develop, the creation of new knowledge and the critique and negotiation of this knowledge. As boundary objects evolve they become more understandable and meaning as they are interacted with, reacted to, negotiated round and built upon [Fischer & Ostwald, 2005]. Thus, boundary objects act as referential anchors, allowing a CoP with different backgrounds and experience to establish common ground [Clark & Brennan, 1991; Tang, 1991], allowing a CoI to better understand the problem and in turn generate and reflect upon new ideas. Hence, Fischer [2005] has argued that in order to support social creativity we must support mutual learning through the creation, discussion and refinement of boundary objects that facilitate communication and interaction between CoP.

Hence, a high-level requirement for supporting creativity is:

> **High-level requirement 1: Support the creation and dissemination of externalisations to support the phases of the creative process.**

2.3.2 Supporting individual and social creative activities

As discussed above, many researchers have either studied individual [e.g. Guilford, 1950; Koestler, 1964; Gough, 1979; Amabile, 1983; Boden 1994] or social [e.g. Csikszentmihalyi, 1996; Fischer *et al*, 2005; Shneiderman, 2000] creativity. However, as argued by Fischer [2005] and Edmonds *et al* [1999] the relationship between individual and social creativity should be viewed as an *and* rather than an *or* relationship. Streitz *et al* [1997] has even provided empirical evidence showing groups engaging in individual and social activities achieve better results than individuals working alone or groups working together the entire time.

Kostakos *et al* [2006] and O'Neill *et al* [2004] argue for the support of individual and social activities by providing interaction spaces that support participation frameworks. An interaction space is described as a volume of space created by physical artefacts (e.g. a piece of paper or a computer monitor used for externalising knowledge). The interaction space defines the boundaries within which the artefact is usable [O'Neill *et al*, 1999]. Participation frameworks are established through group member's interactions (e.g. bodily alignment, eye contact, etc) [Goffman, 1981]. O'Neill *et al* [1999] argue that for successful collaboration between group members, the interaction space must contain the participation framework. If participation framework extends beyond the interaction space of an artefact, collaboration will be hindered [O'Neill *et al*, 1999]. Furthermore, objects (i.e. another person) can obstruct the interaction space, thereby creating an interference space [Reeves *et al*, 2006]. These concepts are illustrated in figure 2.4.

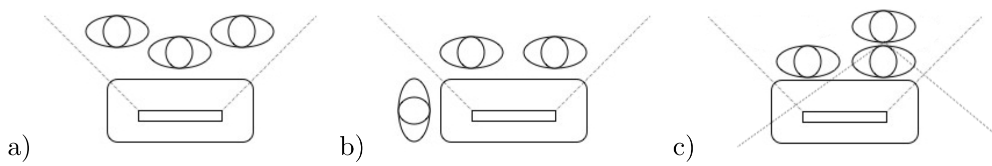


Figure 2.4: The (a) successful; (b) unsuccessful; and (c) obstructed use of an interaction space.

As we can see in figure 2.4a everyone is able to view and interact with the artefact (e.g. a monitor on a table) as they are all inside the interaction space of that artefact. However, in figure 2.4b one member is outside the volume of the interaction space, which could result in breakdowns in communication. Finally, as shown in figure 2.4c, objects, such as other people, can create interference spaces inhibiting effective collaboration with other people and artefacts.

The properties of these interaction spaces can be used to support individual and social activities. An artefact that has a large interaction space is suitable for social creative activities involving more than one person, as the large interaction space will be able to support more than one person, while an artefact that has a small interaction space could constrain the number of people able to successful engage with it, thereby being more suitable for individual creative activities [Kostakos *et al*, 2006]. For example, in the Streitz *et al* [1997] study, a LiveBoard (i.e. a large interactive screen) provides a large interaction space that includes all the members of a group, thereby supporting social creative activities, while a workstation provides a constrained interaction space suitable for individual creative activities.

Therefore, a requirement for supporting creativity is:

High-level requirement 2: Support the various compositions of a group using appropriately sized interaction spaces.

2.3.3 Supporting the control of social influences

The social influences of production blocking, evaluation apprehension and free-riding have been shown to have a detrimental effects on social creativity [e.g. Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973; Mullen *et al*, 1991]. Therefore, a high-level requirement for supporting creativity is:

> **High-level requirement 3: Support the control of social influences.**

We shall now explore how to support each of the three social influences detrimental to creativity.

2.3.3.1 Supporting the control of production blocking

To mitigate the effects of production blocking, researchers [e.g. Prante *et al*, 2002; Valacich *et al*, 1994] have moved towards using synchronous interaction techniques to prevent production blocking in real time collaboration. This has been done by writing ideas down on cards [e.g. Paulus & Yang, 2000] or by using electronic brainstorming systems [e.g. Demhis & Valacich, 1993; Nunamaker *et al*,1991; Valacich *et al*, 1994]. Hence, a high-level requirement for supporting creativity is:

> **High-level requirement 3.1: Support the control of production blocking by providing synchronous forms of interaction.**

Paulus *et al* [1996] propose a combination of verbally and visually representing ideas, since verbalisations lead to more positive feelings about performance and may allow for cognitive stimulation from others' ideas [Paulus *et al*, 1993].

Furthermore, while providing synchronous interaction techniques may reduce the affects of production blocking, the social influence of evaluation apprehension is also affected (discussed in more detail below). Writing ideas down instead of saying them can anonymise one's ideas [Paulus & Yang, 2000], potentially lessening the effects of evaluation apprehension.

2.3.3.2 Supporting the control of evaluation apprehension

To overcome the negative effects of evaluation apprehension, it has been suggested by some researchers [e.g. Paulus & Yang, 2000] that anonymous means of expressing ideas will remove an individual's identification with an idea and therefore help encourage people to express their ideas without fear of criticism. Therefore, a high-level requirement for supporting creativity is:

> **High-level requirement 3.2: Support the control of evaluation apprehension by anonymising one's externalisations.**

Some technologies, such as group decision support systems (GDSS) [e.g. Demhis, & Valacich, 1993; Prante *et al*, 2002] allow for anonymising individual input, thereby mitigating evaluation apprehension. This has been achieved by providing an electronic communication channel [Nunamaker *et al*, 1991]. An individual can externalise their ideas using a GDSS, pooling the group's ideas, while removing an individual's identification with their reported ideas. As an individual can not be identified with an idea (unless they identify themselves), they should not fear criticism from others within the group.

2.3.3.3 Supporting the control of free-riding

two main approaches have been suggested to reduce the effects of free-riding in real groups: identifiability and social stimulation.

Diehl and Stroebe [1987] highlighted the implications of identifiability in groups - the larger the group, the higher the temptation to free-ride. If participants were identifiable with their ideas, they would be less likely to free-ride as their lower performance would be apparent to other group members. However, it is desirable to remove identification from one's ideas in order to mitigate the effects of evaluation apprehension. Hence, there is a trade off between free-riding and evaluation apprehension. This trade off can be seen in a study by Paulus and Yang [2000] who claimed that writing ideas down rather than verbally communicating them provided anonymity. However, participants were asked to use coloured pens to identify themselves with their ideas in order to reduce free-riding. It is an open question whether evaluation apprehension or free riding is more detrimental to creativity.

Paulus [2000] refers to social stimulation as a way of minimising the effect of free-riding - encouraging a high motivation level in groups by increasing accountability for individual performance. Various studies [e.g. Paulus & Dzindolet, 1993; Shepherd *et al*, 1995] have shown that providing groups with a comparison standard increases a group's performance. It is unclear what is the best way to provide such explicit feedback, and so increase individual and group performance by reducing free riding, while not causing a negative effect on creativity by increasing evaluation apprehension. Hence, a high-level requirement for supporting creativity is:

> **High-level requirement 3.3: Support the control of free-riding by making individuals accountable for their own performance.**

2.3.4 High-level requirements for supporting creativity in design

Based on the review above, three high-level requirements for supporting creativity in design have emerged:

> **High-level requirement 1: Support the creation and dissemination of externalisations to support the phases of the creative process.**
>
> **High-level requirement 2: Support the various compositions of a group using appropriately sized interaction spaces.**
>
> **High-level requirement 3: Support the control of social influences.**
>
>> **High-level requirement 3.1: Support the control of production blocking by providing synchronous forms of interaction.**
>>
>> **High-level requirement 3.2: Support the control of evaluation apprehension by anonymising one's externalisations.**
>>
>> **High-level requirement 3.3: Support the control of free-riding by making individuals accountable for their own performance.**

2.4 Summary

This chapter began with a look at design in the field of HCI. Activities of design in HCI have evolved from interface design, to interaction design, to user-experience design, with design methods such as PD and UCD being used. The fundamental concept of design is that designers, and sometimes users, engage in some process of design (e.g. PD or UCD) to produce design ideas or a design solution (e.g. an interface design, interaction design or user-experience). However, this gets us no closer to understanding what design is; or the process of design itself.

Reviewing a history of design definitions, we refined our understanding of design to a process that produces a new or refined product. To further reduce the ambiguity surrounding the topic we reviewed a number of design process models. Here we identified three characteristics of design problems: incomplete and ambiguous specification of goals, no predetermined solution path and the need for integration of multiple knowledge domains. Furthermore, we identified three phases of the design process: problem structuring, solution generation and solution evaluation. However, the question of how these design solutions were generated still remained. The generation of these solutions was consider as a 'mystical element' of the design process, often referred to using terms such as 'creativity'.

Here we identified our first RQ:

> **RQ1: What is creativity in design?**

To begin to answer this question we reviewed a history of definitions of creativity, from the creative process, to the creative person, to the creative product. Of course, the process, person and product all contribute to the overall phenomenon of creativity. This led to our unified definition of creativity in design:

> **'Creativity in design is the generation of ideas, which are a combination of two or more existing bundles of knowledge to produce a new knowledge structure. For this newly generated idea to be considered creative it should be: novel - unusual or new to the mind in which it arose; and appropriate - conform to the characteristics of a desired/accepted solution. Such creative ideas may then be implemented and embodied in a creative product'**

To further deepen our understanding of creativity we considered the various metrics of creativity. We established that creativity goes beyond the mere production of novel and appropriate ideas and includes the ability to produce large numbers of creative ideas; produce many different categories of creative ideas; and produce high quality creative ideas. Having reviewed and critiqued a number of methods for measuring these metrics of creativity, we identified and described a number of objective and reliable measures to be used in this research.

Reviewing the various definitions and metrics of creativity gave us a firmer understanding of what creativity is. We next reviewed a number of creative process models. We identified three phases of the creative process: problem framing, idea generation and idea evaluation. These phases closely parallel the process of design, allowing us to model the creative process of design, as shown in figure 2.1. However, the creative process model considers creativity as primarily an individual activity, whereas design is more of a social activity.

In recent years there has been a push towards viewing creativity as a social process, involving interactions with other people and artefacts. This led to the identification of three characteristics of social creativity.

> **Characteristic 1: The externalisation of knowledge and subsequent presentation of this knowledge to members of the design team.**
>
> **Characteristic 2: Individual and social creative activities.**
>
> **Characteristic 3: Social influences that inhibit the creativity of the design team.**

Theoretically the potential for creativity is increased when individuals interact with others, allowing their knowledge to be externalised and shared. This creative process involves both individual *and* social activities. However, in reality the theoretical potential of social creativity is not realised due to the three social influences of production blocking, evaluation apprehension and free-riding. Therefore, design teams are not being as creative as they could be.

This led to our second RQ:

> **RQ2: How can we support creativity in design?**

Exploring each of our three characteristics of social creativity in design we identified three requirements for supporting creativity in design:

> **High-level requirement 1: Support the creation and dissemination of externalisations to support the phases of the creative process.**
>
> **High-level requirement 2: Support the various compositions of a group using appropriately sized interaction spaces.**
>
> **High-level requirement 3: Support the control of social influences.**
>
>> **High-level requirement 3.1: Support the control of production blocking by providing synchronous forms of interaction.**
>>
>> **High-level requirement 3.2: Support the control of evaluation apprehension by anonymising one's externalisations.**
>>
>> **High-level requirement 3.3: Support the control of free-riding by making individuals accountable for their own performance.**

This chapter has set the scene for the thesis and gone part of the way to answering our two RQ. In the remainder of the thesis, we aim to build upon the theoretical foundation established in this chapter addressing a number of RO, with the aim of answering our two RQ.

In this chapter we reported that real group creativity is not as effective as nominal group creativity. Our first RO is to extend upon our theoretical foundation understanding the effects of group composition on creativity **(RO1)**. In chapter 3, we observe the effects of group composition on creativity in design are social influences were controlled.

Our second RO aims to build upon our high-level requirements for supporting creativity in design established in this chapter, eliciting requirements for CST **(RO2)**. This RO is addressed in chapter 4, where we apply a number of ethnographic techniques to the domain of design in HCI.

Our third RO is to reflect upon and refine our requirements for CST **(RO3)**. Chapter 5 presents a review and critique of existing CST and an in depth evaluation of the Envisionment Discovery Collaboratory (EDC), identify strengths and weakness of the EDC, suggesting improvements to the EDC and other CST, as well as allowing us to reflect upon and refine our requirements for CST.

Finally, our fourth RO is to build on the findings of this theoretical and practical work, designing, developing and evaluating a CST for the domain of design **(RO4)**. Chapter 6 presents the design, development and evaluation of our CST: PSPD. The design and development of PSPD illustrates the practical application of our requirements for CST. While the evaluation of PSPD provides evidence to support or reject the proposal of our requirements for CST.

Chapter 3

The Effects of Group Composition on Creativity

In chapter 2 we reported a finding from creativity researchers [e.g. Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973; Mullen *et al*, 1991] that real groups were not as creative as nominal groups because of three social influences [Diehl & Stroebe, 1987]: production blocking, evaluation apprehension and free-riding. In this chapter we report an experiment, observing the effects of group composition on creativity, while social influences are controlled. Hence, this chapter will address our first research objective for the thesis (RO1).

Section 3.1 briefly reviews the literature discussed in chapter 2 related to social influences (see section 2.2.4.2). This leads to a review and critique of GDSS, which have been shown to increase the productivity of real groups by controlling social influences detrimental to creativity [e.g. Demhis & Valacich, 1993; Nunamaker *et al*,1991; Valacich *et al*, 1994]. However, in our critique of GDSS we identify a number of methodological concerns with GDSS and their related studies: their control of social influences, their subjective methods for measuring creativity and their use of a limited number of metrics associated with creativity. Furthermore, we raise a number of concerns regarding the implications of this work to the domain of design: the use of non-design tasks, the use of homogeneous groups and large group sizes. We address these concerns in our experiment.

Section 3.2 sets the scene for the experiment specifying our experimental hypotheses and provides our rationale.

In section 3.3 we specify the experimental methodology, including details of our independent and dependent variables, the participants who took part in the experiment, the equipment we used and the procedure for the experiment. In this section we show how our experiment addresses the limitations of previous research [e.g. Demhis & Valacich, 1993; Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973; Mullen *et al*, 1991; Nunamaker *et al*, 1991; Valacich *et al*, 1994].

Section 3.4 reports the results from the experiment, using each of our metrics of creativity identified in chapter 2 (see section 2.2.2): the quantity, divergence and quality of creative ideas.

Finally, section 3.5 discusses the results reported in section 3.4 and concludes with a general discussion.

3.1 Supporting the control of social influences

Taylor *et al* [1958] conducted a study comparing real groups (i.e. face-to-face interacting groups) with nominal groups (i.e. individuals working on their own and then collating their outputs to form a cumulative output), to test Osborn's [1957] claim that 'the average person can think up twice as many ideas when working within a group than when working alone'. Taylor *et al* [1958] found that nominal groups produced nearly twice as many non-replicated ideas as real groups, thereby refuting Osborn's claim. Since the Taylor *et al* [1958] study, over 50 years of empirical studies have shown nominal groups to generate more creative ideas than real groups [e.g. Demhis & Valacich, 1993; Mullen *et al*, 1991]. This has led to the recommendation that creative activities, such as idea generation, should be performed by nominal groups alone [e.g. Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973].

Many researchers [e.g. Lamm & Trommsdorff, 1973; Mullen *et al*, 1991] have attempted to explain the mass of evidence contradicting Osborn's [1957] claim and the belief that real group creativity is more effective than nominal group creativity [e.g. McGlynn *et al*, 2004; Warr & O'Neill, 2005a]. The difference between real and nominal group creativity has been explained by three social influences [e.g. Diehl & Stroebe, 1987]: production blocking, evaluation apprehension and free-riding.

However, some researchers [e.g. Demhis & Valacich, 1993; Nunamaker *et al*, 1991; Valacich *et al*, 1994] have shown that through the use of GDSS, real group creativity can be increased, as social influences are controlled. In the following sub-sections we review and critique GDSS informing the design of the experiment reported in this chapter.

3.1.1 A review of group decision support systems

A GDSS is a computer-based system for use by groups of people who are jointly responsible for making decisions [DeSanctis & Gallupe, 1985]. GDSS evolved from decision support systems that had shown software tools to increase individual creativity [e.g. Elam & Mead, 1990; Marakas & Elam, 1997]. When support tools, such as GDSS are used in a face-to-face setting they provides an extra channel of communication: an electronic one [George & Carlson, 1999]. The basic activities of the group GDSS are intended to support are: *information retrieval* - collecting information from available resources (e.g, other group members, the internet, etc); *information sharing* - displaying information to the entire group, or send information to selected group members; and *information use* - manipulating the data, applying procedures and group problem-solving techniques to reach a group decision [Huber, 1984].

A typical GDSS set-up has four components: hardware, software, people and procedures [DeSanctis & Gallupe, 1985]. The *hardware* consists of a number of workstations that each group member can interact with using input and output devices, and a common viewing screen used for displaying information to the group (the screen should be large enough to be seen by all group members). In some cases graphics tablets maybe desired. The set-up allows each group member to work independently of other group members, to publicly disseminate personal work, see the work of other individuals and the group's collective work. The *software* should allow for information creation, manipulation, dissemination and storage. Such information could take the form of text, diagrams and other graphical visualisations. Furthermore, the software should provide information on votes, decisions made, the viewing of comments and communication between group members, thereby providing support for the decision-making process. The *people* component of GDSS includes the group members and a group facilitator. The facilitator may act as an interface between the group's members and the GDSS or merely take a technical support role. The *procedures* component of the GDSS intends to enable the ease of operation and effective use of the technology by the group members. The GDSS may be designed to accommodate specific group decision-making techniques [McFadzean, 2000]. Figure 3.1 presents an example GDSS.

With group meetings having been shown to be less effective than they could be [e.g. Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973; Mullen *et al*, 1991], some researchers [Demhis & Valacich, 1993; Nunamaker *et al*, 1991; Valacich *et al*, 1994] have provided supporting empirical evidence that GDSS can increase the productivity of group meetings by controlling the effects of social influences on creativity. Providing an electronic communication channel [George & Carlson, 1999] enables parallel communication [Nunamaker *et al*, 1991]. This allows for synchronous forms of communication, thereby reducing production blocking. Nunamaker *et al* [1991] also argue that the effects of free-riding may also be reduced as group members no

Figure 3.1: An example of a group decision support system.

longer need to compete for 'air time' and domination of communication channels may be reduced, as it becomes difficult for one member to preclude other group members from contributing. Furthermore, GDSS can monitor group members' performance and provide social comparisons through graphical feedback - a recommendation made by previous researchers to reduce the effects of free-riding [e.g. Paulus & Dzindolet, 1993; Shepherd *et al*, 1995]. Finally, the electronic channel may also provide a degree of anonymity, thereby mitigating the effects of evaluation apprehension [Nunamaker *et al*, 1991]. Nunamaker *et al* [1991] argue that this may lead to increased productivity and more objective evaluation. In additional to controlling the effects of social influences on creativity, Nunamaker *et al* [1991] also argue that GDSS: support a group memory allowing group members to reflect upon information; provide a permanent storage of information; help the group focus on key issues and can prevent irrelevant digressions; and can provide additional information and approaches to analysing data. Overall it has been argued that GDSS can significantly improve a group's productivity, both in terms of processes and outcomes [Connolly *et al*, 1990; Nunamaker *et al*, 1991].

Through empirical investigations, Demhis & Valacich [1993] and Valacich *et al* [1994] have shown that groups of 3 - 12 participants using GDSS produce as many ideas, of the same average quality, as equally sized nominal groups. Furthermore, Demhis & Valacich [1993] and Valacich *et al* [1994] have shown that as the group size increases (12+ participants), groups using GDSS actually produce more ideas, with a higher total quality, than equally sized nominal groups. The major explanation for these results is that GDSS successfully eliminate production blocking [Valacich *et al*, 1994]. Other studies have also empirically shown the importance of GDSS productivity gains when controlling evaluation apprehension [Connolly *et al*, 1990] and free-riding [Shepherd *et al*, 1995]. Thus, many researchers [e.g. Demhis & Valacich, 1993;

Connolly *et al*, 1990; Shepherd *et al*, 1995; Valacich *et al*, 1994] have drawn strong empirical conclusions that GDSS can improve upon the baseline creativity of nominal groups, without damaging idea quality or participant satisfaction.

3.1.1.1 A critique of group decision support systems

GDSS have been shown to be very helpful in improving the productivity of real groups, by controlling social influences that otherwise inhibit creativity. However, we have two criticisms of this work: methodological issues with the studies themselves and their implications for the domain of design. We now address these criticisms of GDSS and their related studies.

During the studies of GDSS [Demhis & Valacich, 1993; Valacich *et al*, 1994] it is questionable how social influences were controlled. Their predominant focus has been on controlling production blocking by providing synchronous forms of communication [Valacich *et al*, 1994]. How was evaluation apprehension controlled? Nunamaker *et al* [1991] argue that GDSS supports a 'degree of anonymity'. To what 'degree' does a GDSS control evaluation apprehension? Furthermore, Nunamaker *et al* [1991] argue that free-riding is controlled by providing parallel communication channels, reducing the competition for 'air time' and reducing domination of 'air time'. However, Diehl & Stroebe [1987] has argued that free-riding is controlled when group members are accountable for their own performance. Finally, Valacich *et al*, [1994] state that as group size increases, so does individual anonymity, and hence the potential for free-riding also increases. This implies a confounding variable in their studies.

Another criticism of these studies [Demhis & Valacich, 1993; Valacich *et al*, 1994] is the way creativity was measured. As discussed in chapter 2 (see section 2.2.2), many of the applied measures of creativity consider all unique ideas to be creative and are highly subjective [e.g. Lamm & Trommsdorff, 1973; Mullen et al, 1991]. Like most other studies, Demhis & Valacich [1993] and Valacich *et al* [1994] did not assess their participants responses for novelty and appropriateness. However, to counter the subjectivity of their measures they did introduce inter-judge reliability tests. A further criticism are the metrics used to measure creativity. Creativity has been described as a multi-faceted phenomenon, not amenable to being measured by a single metric [Lamm & Trommsdorff, 1973; Mullen et al, 1991]. However, in the Demhis & Valacich [1993] study, the only metric of creativity reported was the quantity of ideas produced. In the Valacich *et al* [1994] study both the quantity of ideas and the quality of the ideas were measured. Yet, no attempt was made to report on divergent thinking, which has also been argued to be an indicator of creativity [e.g. de Bono, 1967; Lawson, 1980; Runco, 2003]. Therefore, measures of creativity and the quality of these measures could be improved upon.

Our final criticisms of GDSS and related studies are on their relation to design. First, the tasks used by Demhis & Valacich [1993] and Valacich *et al* [1994] were not design tasks. In the Valacich *et al* [1994] study, a business task was given, asking the participants to identify individuals, groups and organisations that would be affected by a policy requiring all business students to own or have access to a personal computer and discuss how whose individuals, groups and organisations would be affected. It could be argued that this task is not even a creative task as it requires analytical thinking regarding who may be affected by such a policy. This task therefore seems to be more concerned with framing information, rather than generating creative ideas. Furthermore, like many other studies [e.g. Taylor *et al*, 1958], Demhis & Valacich [1993] used a marketing task for one of their tasks (e.g. generate ideas to draw tourists to the city which they lived in). The use of design tasks might change the outcomes of these studies and deepen our understanding of creativity in design.

Secondly, in the Demhis & Valacich [1993] and Valacich *et al* [1994] studies, business students were used. Similarly, in studies such as the Taylor *et al* [1958] study, psychology students were used. Such groups are therefore homogeneous, whereas design teams, such as those engaged in Participatory Design (PD), are heterogeneous. It has been empirically shown that heterogeneous groups perform better than homogeneous groups [e.g. Shaw, 1983]. As noted by Nunamaker *et al* [1991], this change in situation could have an effect on the group processes and outcomes.

Thirdly, based on their studies, Valacich *et al* [1994] recommend that groups using GDSS should consist of 12 or more members to outperform nominal groups. However, it is rarely the case that design teams are that large. Hare [1981] argues that the optimal group size is perhaps only five members. While GDSS may be useful for their suggested contexts of business meetings, workshops and the like [Nunamaker *et al*, 1991] where group sizes tend to be quite large, they may not be so applicable in a design setting where such large groups may become harder to manage [Hare, 1981; Shaw, 1983].

Finally, while GDSS may support the requirement of controlling social influences, they do not support two of our other high-level requirements, as described in chapter 2 (see section 2.3.4) - supporting multiple means of representing externalisations of knowledge; and supporting individual and social creative activities using appropriate interaction spaces.

While many valuable lessons have be learnt from GDSS, such as how to control social influences, their support may not be rich enough for the domain of design. It is therefore possible that GDSS could actually constrain creativity in design.

3.2 Experimental overview

As discussed in the previous section, we identified a number of methodological issues with GDSS [e.g. Nunamaker *et al*, 1991] and their related studies [e.g. Demhis & Valacich, 1993; Valacich *et al*, 1994]:

1. *There was a focus on controlling production blocking with a lack of focus on controlling evaluation apprehension and free riding.*

2. *Subjective and sometimes unreliable measures of creativity were used.*

3. *There was a primary focus on measuring the quantity of ideas produced and sometimes the quality of the ideas.*

Furthermore, we identified concerns over the implications of the above research for the domain of design:

1. *There was a lack of focus on the domain of design (i.e. design tasks were not used).*

2. *Homogeneous groups were used, consisting of participants from a similar background (e.g. business or psychology students), unlike design teams which are heterogeneous.*

3. *Large groups consisting of 12+ members were used, which is greater than most design teams.*

If we were to replicate these past studies, improving upon the methodological issues identified and our concerns with their relevance to the domain of design, what effect would group composition have on creativity? The experiment we report in this chapter aims to answer this question, observing the effects of groups composition on creativity in design when social influences are controlled.

To determine the effects of group composition on creativity when social influences are controlled, our independent variable was group composition, which consisted of four levels: nominal, nominal-real, real-nominal and real group compositions. Most other studies consider nominal and real group compositions [e.g. Demhis & Valacich, 1993; Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973; Mullen *et al*, 1991; Valacich *et al*, 1994]. However, for completeness in this study we also extended these conditions to consider two hybrid conditions as reported in a study by Rotter

& Portugal [1969]: nominal-real and real-nominal compositions. In this experiment a *nominal* group is a group of individuals who do not see the ideas generated by other group members during the experiment. A *real* group is a group of individuals who see the ideas of other group members as they are reported during the experiment. A *nominal-real* group is a group of individuals who do not see the ideas reported by other group members for half of the time of the experiment. Half way through the experiment, the individuals' ideas are collated and distributed to each group member. For the remainder of the experiment the group members see the ideas of others as they are reported. A *real-nominal* group is a group of individuals who see the ideas generated by other group members for half the time of the experiment. For the remainder of the experiment the group members do not see the ideas reported by other group members. The outputs of these group compositions is the cumulative output of ideas reported by each of the members forming a group.

Our hypotheses for this experiment are based upon our three metrics of creativity identified in chapter 2 (see section 2.2.2) - the quantity, divergence and quality of creative ideas. Furthermore, we consider these three measures including and excluding duplicated creative ideas. Previous research [e.g. Demhis & Valacich, 1993; Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973; Mullen *et al*, 1991; Nunamaker *et al*, 1991; Valacich *et al*, 1994] has excluded duplicated ideas. However, we decided to additionally include measures including duplicated creative ideas to provide deeper insights into the creative process of group members' in different group compositions.

3.2.1 The quantity of creative ideas

Our first hypotheses were based on our theory of social creativity [Warr & O'Neill, 2005a], presented in chapter 2 (see section 2.2.4). In a real group condition participants are able to share their ideas, thereby stimulating ideas in others and potentially allowing for a great number of possible combinations than nominal groups. However, in the nominal group condition, individuals are constrained to their own domain of knowledge, thereby constraining their creative output. Therefore, in our study it was hypothesised that:

> *The quantity of creative ideas generated in the real group condition would be greater compared to the nominal group condition, including (H1a) and excluding (H1b) duplicated creative ideas.*

Furthermore, Rotter & Portugal [1969] argued that the expression of an idea in a group would cause all the members to think along the same lines, leading to the duplication of ideas. In contrast, we argue that being in a setting which allows other members to see what ideas are being generated would cause less duplication as members would be aware of what ideas had already been reported. Hence, it was also hypothesised that:

> *The quantity of duplicated creative ideas generated in the nominal group condition would be greater compared to the real group condition (H1c).*

3.2.2 The divergence of creative ideas

Our rationale for our hypothesis considering the number of categories of creative ideas was that in the nominal group condition, a participant would be forced to improve and combine ideas within her own domain of knowledge. Whereas, in the real group condition a participant would be able to take advantage of the externalisation of other participants' knowledge and ideas. As argued by Bonnardel [1999, p.159], 'different designers dealing with the same problem develop different ideas and reach different solutions'. Therefore, in our study it was hypothesised that:

> *The number of categories of creative ideas (i.e. divergence) generated in the real group condition would be greater compared to the nominal group condition (H2a).*

While the above hypothesis considers divergent thinking, it fails to consider convergent thinking, as many studies before have [e.g. Demhis & Valacich, 1993; Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973; Mullen *et al*, 1991; Nunamaker *et al*, 1991; Valacich *et al*, 1994]. However, divergent and convergent thinking are part of the same continuum [Eysenck, 2003]. Therefore, we specify a number of hypotheses related to convergent thinking.

As a participant in the nominal group would be constrained to her own domain of knowledge, it was believed she would be forced to refine her own ideas (i.e. improve upon her existing ideas). Whereas, a participant in the real group condition would refine fewer ideas, as they would have the potential to be more divergent due to the availability of multiple domains of knowledge. Hence, it was also hypothesised that:

> *The number of refined creative ideas generated in the nominal group condition would be greater compared to the real group condition, including (H2b) and excluding (H2c) duplicated creative ideas.*

To extend our analysis of the refinement of creative ideas and obtain a purer measure of refinement (i.e. considering the number of refined ideas in relation to the number of creative ideas generated), it was also hypothesised that:

> *The percentage of refined creative ideas generated in the nominal group condition would be greater compared to the real group condition, including (H2d) and excluding (H2e) duplicated creative ideas.*

Furthermore, while a participant in a nominal group would of course refine her own ideas, it was believed that group-think [Janis, 1982] would be the result of the refinement of ideas in the real group condition (i.e. a participant refining other participants' ideas). As participants would be exposed to other participants' ideas they would potentially be able to refine and build upon them, further generating more ideas. Therefore, it was hypothesised that:

> *The number of refined creative ideas generated in the real group condition would be the result of group-think (H2f).*

Finally, as nominal groups had a more constrained domain of knowledge, it was believed nominal groups would refine their ideas more than participants in the real group condition. Whereas, real groups would not refine their ideas as much, as they would be able to take advantage of the groups collated domains of knowledge to produce more divergent ideas. It was therefore hypothesis that:

> *The degree of refinement of creative ideas generated in the nominal group condition would be greater compared to the real group condition, including (H2g) and excluding (H2f) duplicated creative ideas.*

3.2.3 The quality of creative ideas

Our hypotheses for the quality of creative ideas is broken down in three categories [Lamm & Trommsdorff, 1973] - the average quality of creative ideas, the quantity of highly creative ideas and the total quality of creative ideas. *The average quality of creative ideas* is the total creative quality of the ideas generated by a group divided by the number of creative ideas generated by the group. *The quantity of highly creative ideas* is the number of creative ideas generated with a creative quality above a given threshold (e.g. 70% [e.g. Diehl & Stroebe, 1987]). Finally, *The total quality of creative ideas* is the total creative quality of ideas generated by a group.

Furthermore, as discussed in chapter 2 (see section 2.2.2.3), the creative quality of an idea is determined by the degree of novelty and appropriateness of that idea [Gilchrist, 1972; Guilford, 1959; Jackson & Mersick, 1965]. Therefore, for each of the three categories identified by Lamm & Trommsdorff [1973] we consider the creative quality and its components of novelty and appropriateness.

3.2.3.1 The average quality of creative ideas

In the real group condition a participant would be able to combine knowledge and ideas from a collated domain of knowledge (i.e. traverse a greater distance across conceptual spaces [Santanen *et al*, 2002]). Therefore, the greater conceptual distance traversed, the greater the novelty of the idea [Santanen *et al*, 2002]. Whereas, a participant in the nominal group condition would be constrained to her own domain of knowledge, thereby inhibiting the novelty of her creative ideas. Hence, it was hypothesised in our study that:

> *The average novelty of creative ideas generated in the real group condition would be greater compared to the nominal group condition, including (H3a) and excluding (H3b) duplicated creative ideas.*

Furthermore, in the real group condition a participant would be able to reflect upon, appropriate and improve upon others' ideas, thereby generating more appropriate ideas. In the real group condition a participant can compare and critique her ideas against other participants'. This type of comparative reflection is not possible in the nominal group condition. It was therefore hypothesised that:

> *The average appropriateness of creative ideas generated in the real group condition would be greater compared to the nominal group condition, including (H3c) and excluding (H3d) duplicated creative ideas.*

As it was hypothesised the average novelty and appropriateness (the components of creative quality) would be greater in the real group condition compared to the nominal group condition, it was also hypotheisised that:

> *The average quality of creative ideas generated in the real group condition would be greater, compared to the nominal group condition, including (H3e) and excluding (H3f) duplicated creative ideas.*

3.2.3.2 The number of highly creative ideas

As stated in hypotheses H3a - H3f, it was believed there would be a greater average novelty, appropriateness and quality of creative ideas generated by real groups, compared to nominal groups. Therefore, it was logical to assume there would be more highly novel, appropriate and creative ideas generated by real groups, compared to nominal groups. In our study it was hypothesised that:

> *The number of highly novel creative ideas generated in the real group condition would be greater compared to the nominal group condition, including (H3g) and excluding (H3h) duplicated creative ideas.*

> *The number of highly appropriate creative ideas generated in the real group condition would be greater compared to the nominal group condition, including (H3i) and excluding (H3j) duplicated creative ideas.*

> *The number of highly creative ideas generated in the real group condition would be greater compared to the nominal group condition, including (H3k) and excluding (H3l) duplicated creative ideas.*

3.2.3.3 The total quality of creative ideas

As stated in hypotheses H1a and H1b, it was believed there would be a greater quantity of creative ideas generated by real groups, compared to nominal groups. Furthermore, in hypotheses H3a - H3f it was hypothesised there would be a greater average novelty, appropriateness and quality of creative ideas generated by real groups, compared to nominal groups. It was therefore logical that the total novelty, appropriateness and quality of creative ideas generated would also be greater for real groups compared to nominal groups. In our study it was thus hypothesised that:

> *The total novelty of creative ideas generated in the real group condition would be greater compared to the nominal group condition, including (H3m) and excluding (H3n) duplicated creative ideas.*

> *The total appropriateness of creative ideas generated in the real group condition would be greater compared to the nominal group condition, including (H3o) and excluding (H3p) duplicated creative ideas.*

The total quality of creative ideas generated in the real group condition would be greater compared to the nominal group condition, including (H3q) and excluding (H3r) duplicated creative ideas.

3.3 Method

The experiment had a between participants design. The experiment manipulated the independent variable of group composition, which consisted of four levels: nominal, nominal-real, real-nominal and real group compositions. The dependent variable was creativity, where we consider three metrics of creativity: the quantity, divergence and quality of creative ideas.

3.3.1 Participants

96 participants took part in the experiment, 24 per condition. 68 of the participants were male and the other 28 female. The participants varied in age from 18 to 46, with a mean of 22.9 years. All participants were from the University of Bath, consisting of undergraduate students, postgraduate students and university staff, from a variety of disciplines. The participants were recruited from lecture rooms and mailing lists and were paid £5 for participating in the experiment.

3.3.2 Equipment

On each participant's desk was a 12" display IBM x31 ThinkPad and a USB Microsoft IR Mouse (see figure 3.2). Each of the ThinkPads had an internal 802.11g wireless connection which allowed it to communicate with a server. An A4 piece of paper was stuck to the desk, giving information relevant to the experiment: Osborn's four brainstorming rules [Osborn, 1957], the rules of the experiment and the design problem. The latter was covered by an overlay until the experiment started (see section 3.2.3). Each participant's desk was shielded by tall dividers to prevent direct communication between participants.

Each ThinkPad was running a custom built stand-alone Windows application: the Idea Generator (see figure 3.3). In the top right of the screen was the generated ideas textbox: this is where a participant would write her idea when she thought of one. Ideas were externalised as text to be consistent with previous experiments [e.g. Lamm & Trommsdorff, 1973; Mullen *et al*, 1991]. To submit an idea, participants could either press the submit button located in the bottom right of the screen, or press the enter key on the keyboard. The generated ideas textbox could be cleared by pressing the clear button in the bottom right of the screen. In the

Figure 3.2: A participant's desk in the effects of group composition on creativity experiment.

bottom left of the screen was a condition label that indicated to the user which condition they were currently in: individual (i.e. nominal) or group (i.e. real). In the top left of the screen was the pooled ideas textbox. This textbox displayed recorded ideas dependent on the current condition and could not be edited. In the nominal condition, only a participant's own ideas could be viewed. In the real condition, all participants could see the ideas generated by themselves and others. In the nominal-real condition, when the condition changed from the nominal sub-condition to the real sub-condition all ideas generated by each participant during the nominal sub-condition were pooled into the pooled ideas textbox. In the real-nominal condition, when the sub-condition changed from the real sub-condition to the nominal sub-condition, all ideas generated by the group during the real sub-condition remained in the pooled ideas textbox during the nominal sub-condition.

In a separate room to the participants was the experimenter's desk. The experiment was recorded here. In the participants room were two cameras built into the usability lab, which each viewed two participants. The output from these cameras was fed through a monitor displaying a real-time image to the experimenter. The image was also captured via a digital video recorder for future analysis. The experimenter also had access to a HP tablet personal computer (PC) that ran the Windows Remote Desktop application to access the server remotely. This allowed the experimenter to change the sub-condition during the nominal-real and real-nominal experimental conditions.

The server was a standard desktop PC that ran Windows Server 2003 and Microsoft's SQL Enterprise Server version 8.0. A SQL database ran on this server, storing ideas generated by the participants and other information: who generated the idea, the condition in which the idea was generated and the date and time the idea was recorded. The server was also used to play audio files of instructions to the participants via Windows Media Player.

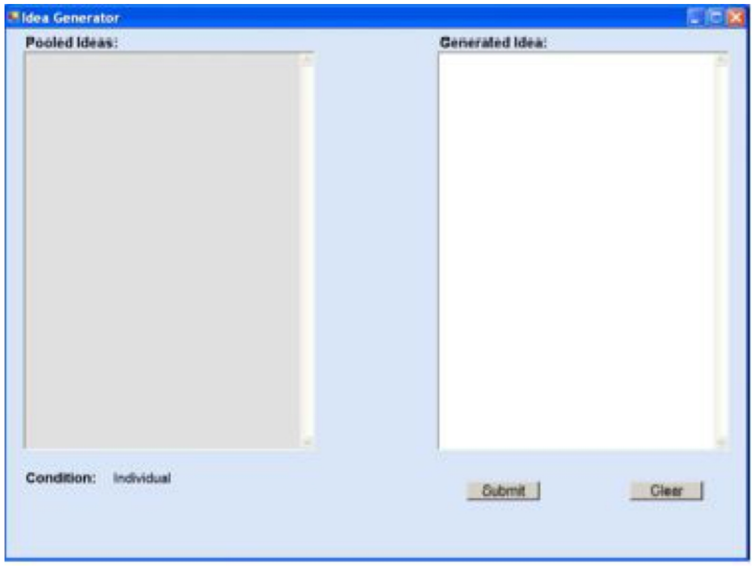


Figure 3.3: The Idea Generator software.

3.3.3 Procedure

Participants were randomly assigned and run in groups of four in a sound-proof usability lab. As participants were recruited from a variety of disciplines and were randomly assigned to groups, their composition was heterogeneous - a characteristic of many design teams. At the outset the participants were taken to the back of the lab where the pre-recorded instructions were played. Pre-recorded instructions were used to minimise the experimenter's contact with the participants, avoiding any possible bias between groups. The start of the pre-recordings gave an overview of the experiment, the condition the participants had been assigned to, a description of Osborn's [1957] brainstorming rules, some rules to abide by during the experiment, a description of the software, the warm-up exercise and the design problem for the actual experiment. After each audio file the experimenter asked the participants if they had any questions and tried to answer them to best of his ability. Creativity was never mentioned, as Amabile [1983] argues that participants' performance changes if they are aware that they are being assessed on creativity.

The groups were assigned to one of four conditions:

1. *Nominal condition: Participants worked individually for 16 minutes.*

2. *Nominal-real condition: Participants worked individually for 8 minutes and then as a group for 8 minutes.*

3. *Real-nominal condition: Participants worked as a group for 8 minutes and then individually for 8 minutes.*

4. *Real condition: Participants worked as a group for 16 minutes.*

As discussed above, most other studies have considered nominal and real group compositions [e.g. Demhis & Valacich, 1993; Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973; Mullen *et al*, 1991; Valacich *et al*, 1994]. However, for completeness in this study we also extended these conditions to consider two hybrid conditions as reported in a study by Rotter & Portugal [1969]: nominal-real and real-nominal compositions. Although it should be acknowledged that in the Rotter & Portugal [1969] study when transitioning to either the nominal or real sub-conditions, the ideas from the previous sub-condition were not brought forward to the latter sub-condition. In this experiment however, the ideas are passed from one sub-condition to the next. The reason for this decision was that the nominal and real group conditions accumulate their ideas over the duration of the experiment, so the nominal-real and real-nominal conditions should also be able to. Furthermore, the Rotter & Portugal study does not reflect the transition between group compositions in the domain of design [e.g. Olson *et al*, 1992]. For example, if an individual is working on some ideas for a meeting (i.e. a nominal group composition), they may take some of those ideas to a meeting (i.e. a real group composition); or if a group are working on some ideas in a meeting (i.e. a real group composition), individual members of the meeting may take up some of those ideas in their individual work (i.e. a nominal group composition).

Osborn's [1957] brainstorming rules were given to the participants to help them with the idea generation process:

1. *Criticism is ruled out: Adverse judgement of ideas must be withheld. No one shall criticism anyone elses ideas. Say anything you think of.*

2. *Freewheeling is welcomed: The wilder the idea the better. It is easier to tame down than think up. Do not be afraid to say anything that comes to mind. The further out the idea the better, this will stimulate more and better ideas.*

3. *Quantity is wanted: The greater the number of ideas, the greater the likelihood of winners. Come up with as many as you can.*

4. *Combination and improvement are sought: Suggest how the ideas of others can be joined into still better ideas.*

In contrast to previous experiments, these brainstorming rules were included on the information sheet attached to each participant's desk. This was done to relieve the cognitive load on each participant, so they could focus on the design problem at hand.

Based on previous research [e.g. Diehl & Stroebe, 1987], participants were told three rules by which to abide in order to control confounding variables:

1. *You may not communicate with anyone else once the experiment has started - to control production blocking.*

2. *All ideas contributed will be anonymous - to control evaluation apprehension.*

3. *We are assessing the ideas of individuals, not the group collectively - to control free-riding.*

Once again, unlike other experiments, instead of just verbalising this information it was also included on the information sheet attached to the participant's desk so they could reference it when desired.

After the background information had been provided to the participants, they were asked to gather round one of the ThinkPads which was running the Idea Generator software. While an audio recording played a description of the software (see section 3.2.2), the experimenter pointed to the relevant parts of the screen.

The warm-up exercise was used to accustom the participants to the experiment and the software they would be using. The exercise lasted two minutes and was based on an adaptation of the tourism problem [Taylor *et al*, 1958] for Europeans:

> *Each year a great many European tourists go to America to visit. But now suppose that Europe wanted to get many more Americans to come to Europe during their vacations. What steps can you suggest to get many more Americans to come to Europe as tourists?*

The experimenter asked all the participants if they understood the problem and gave an example idea of 'providing cheaper trans-Atlantic flights'. Once all queries had been dealt with, the experimenter asked the participants to take a seat at a desk and open up the Idea Generator software. When everyone was ready, the two minute warm-up exercise began.

After two minutes all participants were asked to come to the back of the lab. The experimenter checked for inappropriate responses (e.g. personal comments, criticisms), closed the Idea Generator software on each IBM ThinkPad and cleared the SQL Server of all ideas from the warm-up exercise. If the experimenter found inappropriate responses, he explained to all the participants why they were inappropriate. After dealing with all queries by the participants and upon being satisfied that everyone was content, the experimenter began the design problem experiment.

Unlike other experiments which gave non-specialist problems such as the tourist problem [e.g. Taylor *et al.*, 1958], it was decided to give a design problem within the domain of HCI. A design problem would allow the results to be more easily generalised to the domain of design in HCI. Furthermore, many existing measures of creativity (e.g. the assessment of creative ideas), as report in chapter 2 (see section 2.2.2), required expert judges, whom we had access to. The problem we defined was named the 'Pervasive Computing Scrolling Problem' and was like other design problems as it was open-ended and ill-defined:

> *You have been asked to design an interaction technique for scrolling on a pervasive computer system with a 61 plasma screen. The technique should allow the user or users to scroll up, down, left and right.*

The experimenter asked all the participants if they understood the problem and answered any questions without giving information as to possible solutions to the problem. Once all queries had been dealt with, the experimenter asked the participants to take a seat at a desk and open up the Idea Generator software by selecting the appropriate icon on the desktop. Participants were then informed that they could remove an overlay on the information sheet that revealed the experimental problem. This allowed the participants to reference the problem as they worked. The experimenter told the participants that the experiment would last 16 minutes. This duration for the experiment is consistent with previous research [e.g. Rotter *et al*, 1969; Taylor *et al*, 1958]. Finally, before the experiment started the experimenter began recording the participants and then informed them that they could begin.

For those participants who were in the nominal-real or real-nominal condition, the experimenter changed the condition after eight minutes via the experimenter's computer. Upon the change in condition, the label on the participant's computer changed to indicate which condition the participant was in, and the experimenter also verbally communicated this from the experimenter's room to make the participants aware of the change in condition.

After the 16 minutes were completed, the experimenter asked all participants to stop typing, close down the Idea Generator software and remain seated. The experimenter then stopped the recording and handed each participant a questionnaire (see appendix B).

While the participants were completing the questionnaire, the experimenter printed off a form for a post-analysis of each participant's ideas (an excerpt can be found in appendix B). The post-analysis was designed to assess if the ideas generated were novel. The experimenter went round each participant and asked them to say for each of their ideas whether it was: (i) a new idea - a combination of two or more existing ideas; (ii) an old, existing idea applied to a new context; or (iii) other, and if other could they specify. This classification of ideas is similar to that used by Benami and Jin [2002], to assess p-novelty [Boden, 1994].

3.4 Results

The dependent variable we observed in the experiment was creativity. As discussed in chapter 2 (see section 2.2.2.4), creativity is a multi-dimentional phenomenon that can not be measured by a single metric alone [Lamm & Trommsdorff, 1973; Mullen *et al*, 1991]. In chapter 2 we presented three metrics of creativity that have been identified to be accurate indicators of creativity - the quantity, divergence and quality of creative ideas (see section 2.2.2). In this section we shall report our results based on these three metrics.

As described in chapter 2 (see section 2.2.2), before we could count the number of creative ideas we had to make sure they were creative, by identifying the ideas and assessing if they were both novel and appropriate.

Ideas were identified through our work on sentence structuring and copyright law [Warr & O'Neill, 2006b], as described in chapter 2 (see section 2.2.2). Identifying the occurrence of nouns led to a natural categorisation (i.e. a tree structure) and simplification of ideas from an individual's responses. These ideas could then be assessed to see if they were novel and appropriate. (It should be noted that our categorisation of ideas from the responses based on sentence structuring and copyright law merely categorised and provided a simplified representation of the ideas and did not manipulate them. We therefore assume that the novelty of a response indicated by a participant also holds for the categorised ideas.)

Novelty (i.e. p-novelty [Boden, 1994]) was determined through the retrospective protocol administered after the experiment. Each participant was asked to categorise their ideas as: (i) a new idea - a combination of two or more existing ideas; (ii) an old, existing idea applied to a new context; or (iii) other. If the participants choose other, they were asked to specify why. This schema was used by Benami & Jin [2002] in their research. An idea was considered novel if the participant had not thought of this idea before for the context of the given problem. As the participants had not seen this problem before, the majority of ideas were in fact considered novel.

Appropriateness was assessed by applying a simple checklist of criteria for a desired solution that was embedded in the problem specification. The criteria of a desired solution were that the solution should allow the *user* or *users* to scroll *up*, *down*, *left* and *right*. If the solution satisfied these criteria it was considered appropriate.

Ideas that were considered novel and appropriate were deemed creative ideas. This provided the basis for our measurement of creativity to proceed. (Example calculations of the results reported in the following sub-sections (e.g. full data tables and the results of statistical analyses and pre-tests) can be found in appendix B.)

3.4.1 The quantity of creative ideas

Previous research [e.g. Lamm & Trommsdorff, 1973; Mullen *et al*, 1991] has counted the number of non-duplicated ideas as a measure of creativity. In our analysis of the quantity of creative ideas we extend the analysis to consider: the number of creative ideas, including duplicated ideas; the number of creative ideas, excluding duplicated ideas; and the number of duplicated creative ideas.

The number of creative ideas was assessed for each group in each condition: nominal (N), nominal-real (N-R), real-nominal (R-N) and real (R). This was achieved by counting the number of creative ideas generated by each group. Table 3.1 presents the mean (and standard deviation (SD)) number of creative ideas, including duplicated ideas; the number of creative ideas, excluding duplicated ideas; and the number of duplicated creative ideas.

The data were analysed using a t-test to identify differences between the nominal and real group conditions:

> No significant difference was found between the nominal and real group conditions for the number of creative ideas generated, including duplicated creative ideas ($t = 0.74$, $p = 0.24$). Therefore hypothesis H1a

Table 3.1: Mean (and SD) number of creative ideas, including and excluding duplicated creative ideas; and the number of duplicated creative ideas.

	N	N-R	R-N	R
Number of creative ideas (including duplicates)	40.33 (7.52)	37.17 (9.62)	37.33 (9.04)	36.33 (10.91)
Number of creative ideas (excluding duplicates)	28.50 (5.68)	28.67 (6.98)	28.50 (7.37)	30.67 (6.34)
Number of duplicated creative ideas	11.83 (5.11)	8.50 (3.21)	8.83 (2.40)	5.67 (5.99)

was not supported: the quantity of creative ideas generated in the real group condition would be greater compared to the nominal group condition, including duplicated creative ideas.

No significant difference was found between the nominal and real group conditions for the number of creative ideas generated, excluding duplicated creative ideas ($t = -0.62$, $p = 0.27$). Therefore hypothesis H1b was not supported: the quantity of creative ideas generated in the real group condition would be greater compared to the nominal group condition, including duplicated creative ideas.

A significant difference was found between the nominal and real group conditions for the number of duplicated creative ideas generated ($t = 1.92$, $p = 0.04$). Therefore hypothesis H1c was supported: the quantity of duplicated creative ideas generated in the nominal group condition would be greater compared to the real group condition.

Analysis of variance (ANOVA) tests were also run on the data reported in this section to determine differences across all four conditions. However, no significant differences were found.

3.4.2 The divergence of creative ideas

Divergent thinking has predominately been measured by counting the number of categories of ideas [e.g. Torrance, 1966; Torrance, 1967]. However, this is rather limited and other interesting measures can be made. In this analysis of the divergence of creative ideas we extend our analysis to include measures of: the number of categories of ideas; the number of refined ideas, including duplicated ideas; the number of refined ideas, excluding duplicated ideas; the percentage of creative ideas that were refined, including duplicated ideas; the percentage of creative ideas that were refined, excluding duplicated ideas; the influence of group-think; the degree of refinement (i.e. how much a creative idea was refined), including duplicated ideas; and the degree of refinement, excluding duplicated ideas.

The number of categories of creative ideas was assessed for each group. This was achieved by counting the number of tree structures of creative ideas produced by each group for each condition as a result of our sentence structuring schema (see chapter 2, section 2.2.2.2). Table 3.2 presents the mean (and SD) number of categories of creative ideas.

Table 3.2: Mean (and SD) number of categories of creative ideas.

	N	N-R	R-N	R
Number of categories of creative ideas	16.83 (2.71)	16.33 (4.89)	17.50 (2.59)	18.00 (3.03)

The data were analysed using a t-test to identify differences between the nominal and real group conditions:

> No significant difference was found between the nominal and real group conditions for the number of categories of creative ideas generated ($t = -0.70$, $p = 0.25$). Therefore, hypothesis H2a was not supported: the number of categories of creative ideas (i.e. divergence) generated in the real group condition would be greater compared to the nominal group condition.

The number of refined creative ideas was assessed for each group. This was achieved by counting the number of times an existing branch in the tree structure was extended by each group for each condition. Table 3.3 presents the mean (and SD) number of refined creative ideas, including duplicated creative ideas; and number of refined creative ideas, excluding duplicated creative ideas.

The data were analysed using a t-test to identify differences between the nominal and real group conditions:

Table 3.3: Mean (and SD) number of refined creative ideas, including and excluding duplicated creative ideas.

	N	N-R	R-N	R
Number of refined creative ideas (including duplicates)	8.50 (3.39)	9.17 (4.22)	10.67 (4.76)	13.00 (6.89)
Number of refined creative ideas (excluding duplicates)	7.50 (3.94)	7.50 (3.51)	9.33 (4.93)	11.50 (5.96)

No significant difference was found between the nominal and real group conditions for the number of refined creative ideas generated, including duplicated creative ideas (t = -1.43, p = 0.09). Therefore, hypothesis H2b was not supported: the number of refined creative ideas generated in the nominal group condition would be greater compared to the real group condition, including duplicated creative ideas.

No significant difference was found between the nominal and real group conditions for the number of refined creative ideas generated, excluding duplicated creative ideas (t = -1.37, p = 0.10). Therefore, hypothesis H2c was not supported: the number of refined creative ideas generated in the nominal group condition would be greater compared to the real group condition, excluding duplicated creative ideas.

To get a clearer measurement of the number of refined creative ideas in relation to the number of creative ideas generated, the percentage of refined creative ideas generated was assessed for each group. This was achieved using our existing data and a simple formula ((the number of refined creative ideas/the number of creative ideas) x 100). Table 3.4 presents the mean (and SD) percentage of refined creative ideas, including duplicated creative ideas; and the percentage of refined creative ideas, excluding duplicated creative ideas.

The data were analysed using a Mann-Whitney test to identify differences between the nominal and real group conditions:

Table 3.4: Mean (and SD) percentage of refined creative ideas, including and excluding duplicated creative ideas.

	N	N-R	R-N	R
Percentage of refined creative ideas (including duplicates)	21.06 (8.67)	25.31 (13.12)	27.94 (8.02)	35.88 (10.65)
Percentage of refined creative ideas (excluding duplicates)	25.55 (12.81)	25.71 (12.29)	32.50 (13.07)	37.34 (9.86)

> A significant difference was found was found between the nominal and real group conditions for the percentage of refined creative ideas, including duplicated creative ideas (Mann-Whitney U = 5.50, p = 0.02). However, hypothesis H2d was not supported, as the difference was is the opposite direction to that hypothesised: the percentage of refined creative ideas generated in the nominal group condition would be greater compared to the real group condition, including duplicated creative ideas.
>
> No significant difference was found was found between the nominal and real group conditions for the percentage of refined creative ideas, excluding duplicated creative ideas (Mann-Whitney U = 8.50, p = 0.06). There, hypothesis H2e was not support supported: the percentage of refined creative ideas generated in the nominal group condition would be greater compared to the real group condition, excluding duplicated creative ideas.

The data were next analysed to identify if this refinement was due to self-think or group-think. This was achieved by counting whether an idea refined one's own previously generated idea (i.e. self-think) or refined another member of the group's previously generated idea (i.e. group-think). This analysis could only be performed for the real group condition. All ideas generated by the nominal group must be the result of self-think. It was not possible to identify self-think and group-think in the nominal-real and real-group conditions, due to the change in composition and pooling of ideas. Table 3.5 presents the mean (and SD) frequency of creative ideas as the result of self-think and group-think in the real group condition.

The data were analysed using a Chi-square test to identify difference between self-think and group-think categorisations:

Table 3.5: Mean (and SD) frequency of creative ideas generated as the result of self-think and group-think in the real group condition.

	Self-think	Group-think
Number of refined creative ideas	3.00 (2.09)	9.67 (4.37)

> A significant difference was found between the frequency of refined creative ideas caused by self-think and group-think (Chi-squared = 11.31, $p \leq 0.001$). Therefore, hypothesis H2f was supported: the number of refined creative ideas generated in the real group condition would be the reult of group-think.

The data were next analysed to assess the degree of refinement for creative ideas for each group. This was achieved by counting the number of nodes in a branch for every creative idea generated by each group for each condition. Table 3.6 presents the mean (and SD) degree of refinement for creative ideas, including duplicated creative ideas; and the degree of refinement for creative ideas, excluding duplicated creative ideas.

Table 3.6: Mean (and SD) degree of refinement for creative ideas, including and excluding duplicated creative ideas.

	N	N-R	R-N	R
Degree of refinement for creative ideas (including duplicates)	2.40 (0.27)	2.31 (0.25)	2.11 (0.28)	2.00 (0.38)
Degree of refinement for creative ideas (excluding duplicates)	1.70 (0.29)	1.80 (0.29)	1.61 (0.23)	1.70 (0.25)

The data were analysed using a t-test to identify differences between the nominal and real group conditions:

> A significant difference was found was found between the nominal and real group conditions for the degree of refinement of creative ideas generated including duplicated creative ideas ($t = 2.12$, $p = 0.03$). Therefore,

hypothesis H2g was supported: the degree of refinement of creative ideas generated in the nominal group condition would be greater compared to the real group condition, including duplicated creative ideas.

No significant difference was found was found between the nominal and real group conditions for the degree of refinement of creative ideas generated excluding duplicated creative ideas ($t = 0.01$, $p = 0.49$). Therefore, hypothesis H2h was not supported: the degree of refinement of creative ideas generated in the nominal group condition would be greater compared to the real group condition, excluding duplicated creative ideas.

ANOVA and Kruskal-Wallis tests were also run on the parametric and non-parametric data reported in this section to determine differences across all four conditions. However, no significant differences were found.

3.4.3 The quality of creative ideas

As discussed in chapter 2 (see section 2.2.2.3), we argue following Gilchrist's [1972], Guilford's [1959] and Jackson & Mersick's [1965] work that creative quality can be objectively measured by assessing the degree of novelty and the degree of appropriateness.

The degree of novelty of each idea was determined by measuring the frequency of occurrence of each idea within the scope of the experiment for each group. Of course, the ultimate novelty of an idea would have to consider the occurrence of an idea outside the experiment, as described by Boden's [1994] concept of h-novelty. However, as noted in chapter 2 (see section 2.2.2.3), it is impossible to assess this ultimate novelty as you would have to transcend both space and time. We are constrained to the domain of the lab. The frequency of ideas was observed with respect to groups (i.e. four participants). An idea could be generated by all four participants in the nominal condition as they were not aware of other participants' ideas. However in a real group, creative ideas tended not to be duplicated due to an awareness of existing ideas [Warr & O'Neill, 2005b], as empirically shown in section 3.2.2. Observing the occurrence of ideas from the perspective of the group, regardless of condition, while removing duplicated ideas within the group, removed this factor of awareness. This allowed an accurate measure of the frequency of creative ideas generated across groups for all conditions. The degree of novelty of an idea was determined as a percentage using the following formula:

Degree of novelty for a creative idea = ((Highest possible frequency - frequency of idea) x 100) / Highest possible frequency

The actual frequency of a particular idea was subtracted from the highest possible number of occurrences (i.e. from the number of groups: 24 in our experiment), allowing less frequently occurring ideas (i.e. high novelty) to receive a high score, while more frequently occurring ideas (i.e. low novelty) received a low score. This was then divided by the highest possible frequency (again 24) and multiplied by 100 to give a percentage for the novelty of an idea. Highly novel ideas had a high percentage, while less novel ideas had a low percentage.

The degree of appropriateness for an idea was calculated by asking people who were not involved in the experiment whether they considered each idea to be appropriate for use in the real world. This assessment was achieved using a simple 'yes' or 'no' questionnaire. Half the questionnaires were in reverse order (i.e. ideas 1 - 49) to the other half (i.e. ideas 49 - 1), to counterbalance possible biasing when completing the questionnaire. Full details of the experiment were given to the questionnaire respondents so they had knowledge of where the ideas came from. (An excerpt of the questionnaire can be found in appendix B.) 63 people completed the questionnaire. They varied in age from 19 to 59, with a mean of 32.11 years. They were recruited from mailing lists and noticeboards, with participants from academia and industry located internationally. Questionnaires were either completed electronically and e-mailed to the experimenter, or completed by hand and mailed to the experimenter. For each idea, the respondents were asked to give a simple 'yes' or 'no' response to whether or not the idea met the requirements of the problem statement, thereby giving us a measure of appropriateness.

The degree of appropriateness for an idea was again determined as a percentage using the following formula. The number of 'yes' responses by all participants for a particular idea was divided by the total number of responses, and then multiplied by 100 to give a percentage of appropriateness.

Degree of appropriateness for a creative idea = (Number of yes responses / Number of completed questionnaires) x 100

With a measure for the degree of novelty and the degree of appropriateness for each idea, we can determine the creative quality for each idea. The creative quality of each idea was calculated as a percentage by adding the percentages for novelty and appropriateness together and dividing by two (no weighting was given to favour either novelty or appropriateness as they are both attributes of creative ideas).

Having developed a systematic method for assessing the quality of creative ideas, we applied this method to analysing the data from our experiment. We examined the effect of group composition on the creative quality of ideas generated [Lamm & Trommsdorff, 1973]: the average quality of the creative ideas, which gives a 'pure' measure of quality [Lamm & Trommsdorff, 1973]; the number of 'good' ideas generated, determined by setting a quality threshold and counting the number of creative ideas above that threshold [Diehl & Stroebe, 1987]; and the total quality of creative ideas. As discussed in chapter 2 (see section 2.2.2.3), the creative quality of an idea is determined by the degree of novelty and appropriateness of that idea [Gilchrist, 1972; Guilford, 1959; Jackson & Mersick, 1965]. Therefore, for completeness we considered the creative quality and its components of novelty and appropriateness.

The average novelty, appropriateness and quality of creative ideas were assessed for each group, for each condition. This was achieved by calculating the novelty, appropriate and quality of each idea, totaling these measures for the creative ideas generated and then dividing this total by the number of ideas generated by the group. Table 3.7 presents the mean (and SD) for the average novelty, appropriateness and quality of the creative ideas: including duplicated creative ideas; and excluding duplicated ideas.

Table 3.7: Mean (and SD) average novelty, appropriateness and quality of the creative ideas, including and excluding duplicated ideas.

	N	N-R	R-N	R
Average novelty of creative ideas (including duplicates)	55.20 (7.65)	54.17 (4.97)	54.45 (5.40)	56.96 (4.28)
Average novelty of creative ideas (excluding duplicates)	60.73 (6.97)	60.88 (5.36)	60.22 (5.89)	60.66 (3.36)
Average appropriateness of creative ideas (including duplicates)	64.39 (7.51)	60.74 (6.15)	60.05 (5.06)	58.33 (3.68)
Average appropriateness of creative ideas (excluding duplicates)	61.48 (7.57)	59.95 (5.56)	56.82 (4.89)	57.34 (4.25)
Average quality of creative ideas (including duplicates)	59.68 (1.93)	57.31 (3.68)	57.14 (2.13)	57.64 (2.00)
Average quality of creative ideas (excluding duplicates)	60.90 (1.10)	60.35 (3.90)	58.39 (2.52)	59.00 (1.23)

The data were analysed using a Mann-Whitney test to identify differences between the nominal and real group conditions:

No significant difference was found between the nominal and real group conditions for the average novelty of creative ideas, including duplicated creative ideas (Mann-Whitney U = 13.00, p = 0.24). Therefore, hypothesis H3a was not supported: the average novelty of creative ideas generated in the real group condition would be greater compared to the nominal group condition, including duplicated creative ideas.

No significant difference was found between the nominal and real group conditions for the average novelty of creative ideas, excluding duplicated creative ideas (Mann-Whitney U = 15.00, p = 0.35). Therefore, hypothesis H3b was not supported: the average novelty of creative ideas generated in the real group condition would be greater compared to the nominal group condition, excluding duplicated creative ideas.

A significant difference was found between the nominal and real group conditions for the average appropriateness of creative ideas, including duplicated creative ideas (Mann-Whitney U = 7.00, p = 0.04). However, hypothesis H3c was not supported, as the direction of difference was in the opposite direction to that hypothesised: the average appropriateness of creative ideas generated in the real group condition would be greater compared to the nominal group condition, including duplicated creative ideas.

No significant difference was found between the nominal and real group conditions for the average appropriateness of creative ideas, excluding duplicated creative ideas (Mann-Whitney U = 11.00, p = 0.15). Therefore, hypothesis H3d was not supported: the average appropriateness of creative ideas generated in the real group condition would be greater compared to the nominal group condition, excluding duplicated creative ideas.

No significant difference was found between the nominal and real group conditions for the average quality of creative ideas, including duplicated creative ideas (Mann-Whitney U = 9.00, p = 0.09). Therefore, hypothesis H3e was not supported: the average quality of creative ideas generated in the real group condition would be greater compared to the nominal group condition, including duplicated creative ideas.

A significant difference was found between the nominal and real group conditions for the average quality of creative ideas, excluding duplicated creative ideas (Mann-Whitney U = 3.00, p = 0.007). However, hypothesis H3f was not supported, as the direction of difference was in the opposite direction to that hypothesised: the average quality of creative ideas generated in the real group condition would be greater compared to the nominal group condition, excluding duplicated creative ideas.

Highly novel, appropriate and creative ideas were assessed for each group. This was achieved by calculating the novelty, appropriate and quality of each idea, and then identifying those creative ideas above the threshold of 70%, for each group. Table 3.8 presents the mean (and SD) number of creative ideas with a high novelty, appropriateness and creative quality: including duplicated creative ideas; and excluding duplicated ideas.

Table 3.8: Mean (and SD) highly novel, appropriate and creative ideas: including and excluding duplicated ideas.

	N	N-R	R-N	R
Highly novel creative ideas (including duplicates)	12.83 (6.11)	12.67 (5.09)	13.83 (6.05)	13.50 (4.37)
Highly novel creative ideas (excluding duplicates)	11.50 (6.69)	10.67 (3.67)	12.50 (5.79)	13.17 (3.92)
Highly appropriate creative ideas (including duplicates)	14.83 (5.98)	10.17 (3.25)	12.17 (2.32)	9.17 (3.60)
Highly appropriate creative ideas (excluding duplicates)	8.67 (2.94)	8.17 (2.04)	8.33 (2.07)	8.00 (1.41)
Highly creative ideas (including duplicates)	4.83 (3.06)	3.67 (1.97)	5.33 (1.21)	4.17 (1.17)
Highly creative ideas (excluding duplicates)	3.50 (1.04)	3.50 (1.87)	4.67 (1.51)	4.00 (0.89)

The data were analysed using a t-test to identify differences between the nominal and real group conditions:

No significant difference was found between the nominal and real group conditions for the highly novel creative ideas, including duplicated creative ideas ($t = -0.21$, $p = 0.42$). Therefore, hypothesis H3g was not supported: the number of highly novel creative ideas generated in the real group condition would be greater compared to the nominal group condition, including duplicated creative ideas.

No significant difference was found between the nominal and real group conditions for the highly novel creative ideas, excluding duplicated creative ideas ($t = -0.52$, $p = 0.31$). Therefore, hypothesis H3h was not supported: the number of highly novel creative ideas generated in the real group condition would be greater compared to the nominal group condition, excluding duplicated creative ideas.

A significant difference was found between the nominal and real group conditions for the highly appropriate creative ideas, including duplicated creative ideas ($t = 1.98$, $p = 0.03$). However, hypothesis H3i was not supported as it was in the opposite direction to that hypothesised: the number of highly appropriate creative ideas generated in the real group condition would be greater compared to the nominal group condition, including duplicated creative ideas.

No significant difference was found between the nominal and real group conditions for the highly appropriate creative ideas, excluding duplicated creative ideas ($t = -0.21$, $p = 0.42$). Therefore, hypothesis H3j was not supported: the number of highly appropriate creative ideas generated in the real group condition would be greater compared to the nominal group condition, excluding duplicated creative ideas.

No significant difference was found between the nominal and real group conditions for the highly creative ideas, including duplicated creative ideas ($t = 0.50$, $p = 0.32$). Therefore, hypothesis H3k was not supported: the number of highly creative ideas generated in the real group condition would be greater compared to the nominal group condition, including duplicated creative ideas.

No significant difference was found between the nominal and real group conditions for the highly creative ideas, excluding duplicated creative ideas ($t = -0.88$, $p = 0.20$). Therefore, hypothesis H3l was not supported: the number of highly creative ideas generated in the real group condition would be greater compared to the nominal group condition, excluding duplicated creative ideas.

The total novelty, appropriateness and quality of creative ideas were assessed for each group. This was achieved by calculating the novelty, appropriateness and quality of each creative idea, and then totaling these measures for the creative ideas generated by each group, for each condition. Table 3.9 presents the mean (and SD) for the total novelty, appropriateness and quality of the creative ideas: including duplicated creative ideas; and excluding duplicated ideas.

Table 3.9: Mean (and SD) total novelty, appropriateness and quality of the creative ideas: including and excluding duplicated creative ideas.

	N	N-R	R-N	R
Total novelty of creative ideas (including duplicates)	2215.49 (476.83)	2018.30 (634.90)	2070.37 (676.07)	2074.81 (657.58)
Total novelty of creative ideas (excluding duplicates)	1740.11 (486.61)	1750.95 (490.68)	1751.98 (591.75)	1864.60 (474.46)
Total appropriateness of creative ideas (including duplicates)	2595.85 (562.60)	2221.40 (489.64)	2214.03 (407.12)	2095.14 (527.69)
Total appropriateness of creative ideas (excluding duplicates)	1729.31 (284.56)	1692.75 (356.15)	1601.91 (336.16)	1733.39 (262.15)
Total quality of creative ideas (including duplicates)	2405.82 (442.21)	2130.22 (556.13)	2142.20 (525.46)	2084.97 (582.34)
Total quality of creative ideas (excluding duplicates)	1734.71 (344.64)	1725.74 (407.25)	1676.94 (451.27)	1798.99 (360.56)

The data were analysed using a Mann-Whitney test to identify differences between the nominal and real group conditions:

> No significant difference was found between the nominal and real group conditions for the total novelty of creative ideas generated including duplicated creative ideas (Mann-Whitney U = 16.00, p = 0.40). Therefore, hypothesis H3m was not supported: the total novelty of creative ideas generated in the real group condition would be greater compared to the nominal group condition, including duplicated creative ideas.

No significant difference was found between the nominal and real group conditions for the total novelty of creative ideas generated excluding duplicated creative ideas (Mann-Whitney $U = 14.00$, $p = 0.27$). Therefore, hypothesis H3n was not supported: the total novelty of creative ideas generated in the real group condition would be greater compared to the nominal group condition, excluding duplicated creative ideas.

No significant difference was found between the nominal and real group conditions for the total appropriateness of creative ideas generated including duplicated creative ideas (Mann-Whitney $U = 10.00$, $p = 0.12$). Therefore, hypothesis H3o was not supported: the total appropriateness of creative ideas generated in the real group condition would be greater compared to the nominal group condition, including duplicated creative ideas.

No significant difference was found between the nominal and real group conditions for the total appropriateness of creative ideas generated excluding duplicated creative ideas (Mann-Whitney $U = 17.00$, $p = 0.47$). Therefore, hypothesis H3p was not supported: the total appropriateness of creative ideas generated in the real group condition would be greater compared to the nominal group condition, excluding duplicated creative ideas.

No significant difference was found between the nominal and real group conditions for the total quality of creative ideas generated including duplicated creative ideas (Mann-Whitney $U = 10.00$, $p = 0.12$). Therefore, hypothesis H3q was not supported: the total quality of creative ideas generated in the real group condition would be greater compared to the nominal group condition, including duplicated creative ideas.

No significant difference was found between the nominal and real group conditions for the total quality of creative ideas generated excluding duplicated creative ideas (Mann-Whitney $U = 17.00$, $p = 0.47$). Therefore, hypothesis H3r was not supported: the total quality of creative ideas generated in the real group condition would be greater compared to the nominal group condition, excluding duplicated creative ideas.

ANOVA and Kruskal-Wallis tests were also run on the parametric and non-parametric data reported in this section to determine differences across all four conditions. However, no significant differences were found.

3.5 Discussion

In this section we shall discuss our results reported above, discussing each measure of creativity independently - the quantity of creative ideas; the divergence of creative ideas; and the quality of creative ideas. Finally, we draw together these results and discuss their implications for creativity in design.

3.5.1 The quantity of creative ideas

The majority of previous research [e.g. Lamm & Trommsdorff, 1973; Mullen *et al*, 1991] has found nominal groups to outperform real groups with respect to the number of ideas produced. The major explanation for this difference has been explained by three social influences that have a detrimental effect on social creativity [e.g. Diehl & Stroebe, 1987]: production blocking, evaluation apprehension and free-riding. Some researchers have used GDSS to reduce the impact of these social influences, thereby increasing the productivity of real groups [e.g. Demhis & Valacich, 1993; Nunamaker *et al*,1991; Valacich *et al*, 1994]. In our study, we built upon this previous research to identify the effects of group composition - nominal, nominal-real, real-nominal and real group compositions - on the quantity of creative ideas produced in a design activity when social influences were controlled.

Compared to previous research [e.g. Demhis & Valacich, 1993; Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973; Mullen *et al*, 1991; Nunamaker *et al*,1991; Valacich *et al*, 1994] we extended our analysis to include measures of the quantity of creative ideas including and excluding duplicated creative ideas, as well as the number of duplicated creative ideas produced. It was hypothesised that the quantity of creative ideas generated in response to a given design problem would be greater when participants worked in the real group condition, rather than the nominal group condition, including (H1a) and excluding (H1b) duplicated creative ideas. Furthermore, it was hypothesised that the nominal group condition would duplicate more creative ideas compared to the real group condition (H1c).

We found that there were no significant differences between any of the four conditions in terms of the quantity of creative ideas generated, including and excluding duplicated creative ideas. Therefore, hypothesis H1a and H1b were not supported. Whilst significant differences were not found, this is still an important finding, since through the control of social influences we have substantially increased the creative performance of real groups. Like those studies reporting the effectiveness of GDSS [e.g. Demhis & Valacich, 1993; Nunamaker *et al*,1991; Valacich *et al*, 1994], we have produced a change from the creativity of real groups being statistically less significant than that of nominal groups, as reported by previous studies [e.g. Lamm & Trommsdorff, 1973; Mullen *et al*, 1991], to there being no statistical differences between these conditions.

The experimental hypotheses H1a and H1b were based on our theory [Warr & O'Neill, 2005a] that real groups should be able to generate more creative ideas due to more effective sharing of domains of knowledge (see chapter 2, section 2.2.4). Despite increasing the creative performance of real groups, we did not confirm our experimental hypothesis that the real group condition would be most creative. Hence, we must ask why there were no significant differences in the quantity of creative ideas generated as predicted?

Group size has been reported to affect the quantity of ideas produced between nominal and real groups using GDSS [e.g. Demhis & Valacich, 1993; Nunamaker *et al*, 1991; Valacich *et al*, 1994]. Groups consisting of approximately four members have been shown to reproduce an equal number of ideas, when comparing nominal and real groups using GDSS [Demhis & Valacich, 1993; Valacich *et al*, 1994]. Whereas, groups of 12+ members produce more ideas when in a real group using a GDSS, compared to 12+ members working in a nominal group [Valacich *et al*, 1994].

Another reason may have been that the representation of knowledge/ideas (i.e. a list of ideas represented as text) may not have been effective enough. Text is merely one-way of representing one's ideas [van der Lugt, 2002], while representing knowledge and ideas in design is commonly achieved using combinations of text and sketches [Goldschmidt, 1991; van der Lugt, 2002]. Such richer representations for externalising one's knowledge and ideas may have been more effective. Of course, the creation of these richer representations may require more time, possibily causing a ceiling effect in the 16 minute time frame used in this and other experiments [e.g. Rotter & Portugal, 1969; Taylor *et al*, 1958].

Another possible explanation relates to the time taken by the groups. Perhaps the time allowed was not sufficient for the participants in each of the conditions to reach their maximum threshold of productivity, therefore resulting in equal productivity across conditions; or it could also have been the case that participants were suffering from fatigue and had lost the motivation to continue [e.g. Amabile, 1983; Selker, 2005].

Furthermore, when considering the hybrid conditions, the changeover may have had effects on the participants' production of ideas. While the change itself was minimally disruptive, as described above, each participant in the nominal-real condition was suddenly faced at the beginning of the real sub-condition with the accumulated ideas from the other participants in the nominal sub-condition. The participants may have concentrated on catching up on the others' ideas, thus incurring a form of production blocking.

While there were no significant differences between the quantity of creative ideas produced, a significant difference was found between the nominal group condition and the real group condition with respect to the number of duplicated creative ideas produced, thereby supporting hypothesis H1c. Rotter & Portugal [1969] argued that the expression of an idea in a group causes all the members to think along the same lines, leading to the duplication of creative ideas. However, this study has contradicted this explanation by Rotter & Portugal [1969], having shown real groups to duplicate fewer ideas than nominal groups. This suggests an awareness of ideas generated by other participants inhibited duplication in the real group condition. Based on this finding it was no surprise that there was no significant difference between the nominal-real and the real-nominal group conditions, since each condition had an equal amount of time in the nominal condition and the real condition, causing the effects of duplicated creative ideas for each sub-condition to cancel each other out.

Therefore, although we have shown that there were no significant differences between the quantity of creative ideas produced by the groups, including and excluding duplicated creative ideas, we have shown a significant change in the performance of real groups compared to previous research [e.g. Lamm & Trommsdorff, 1973; Mullen *et al*, 1991]. We have also extended the results of previous research [e.g. Demhis & Valacich, 1993; Lamm & Trommsdorff, 1973; Mullen *et al*, 1991; Nunamaker *et al*,1991; Valacich *et al*, 1994] having shown real groups to be more effective when compared to the nominal groups, as real groups duplicate significantly fewer creative ideas.

3.5.2 The divergence of creative ideas

Relatively few studies comparing nominal and real groups have considered divergent thinking as a metric of creativity [e.g. Torrance, 1970]. However, as argued by de Bono [1967], Lawson [1981] and Runco [2003], the more lateral or divergent the thinking of the group, the more creative they can be considered. Our research has extended previous research [e.g. Demhis & Valacich, 1993; Lamm & Trommsdorff, 1973; Mullen *et al*, 1991; Nunamaker *et al*, 1991; Valacich *et al*, 1994] showing the effect of group composition on creativity in terms of divergent thinking in a design activity, when social influences were controlled.

Creativity in terms of the divergence of creative ideas generated was measured as a result of manipulating the independent variable of group composition. More specifically, this analysis included measuring the number of categories of creative ideas; the number of refined ideas; the percentage of creative ideas that were refined; the influence of group-think; and the degree of refinement. It was hypothesised that: real groups would generate more categories of creative ideas compared to nominal groups (H2a); nominal groups would refine more ideas than real groups, including (H2b) and excluding (H2c) duplicated creative ideas. We also hypothesised the percentage of creative ideas that were refined would be great for nominal groups than real groups, including (H2d) and excluding (H2e) duplicated creative ideas. It was also hypothesised that the majority of ideas refined by the real groups would be caused by group-think [Janis, 1982] (H2f); and nominal groups would refine their creative ideas more than real groups, including (H2g) and excluding duplicated creative ideas (H2h).

It was found that there were no significant differences between any of our four conditions in terms of the number of categories of creative ideas generated. Therefore, hypothesis H2a was not supported. This finding indicates that nominal groups and real groups were equally as divergent as each other when social influences were controlled.

The experimental hypothesis H2a was based on the belief that real groups would be more divergent thinkers as they would have multiple domains of knowledge available to them. While nominal groups would be more convergent thinkers as each individual would be constrained to their own domain of knowledge. To further explore this, we considered the refinement of creative ideas.

No significant differences were found between the nominal and real group conditions, when measuring the number of refined ideas, including and excluding duplicated creative ideas. Therefore, hypotheses H2b and H2c were not supported. This finding shows us that nominal groups and real groups were equally as convergent as each other when social influences were controlled.

However, when considering the percentage of refined creative ideas, real groups refined significantly more of their creative ideas compared to nominal groups, including duplicated creative ideas. This was in the opposite direction to that hypothesised. Furthermore, no significant difference were found when duplicated creative ideas were removed. Hence, hypotheses H2d and H2e were not supported. Why was it the case that real groups refined more of their creative ideas than nominal groups, including duplicated creative ideas?

Through our analysis of the refined ideas generated by real groups we deepened our understanding of the operation of group norms. We have argued that the major benefit of working in real groups is the access that group members have to each other's ideas and concepts, allowing the members of a real group to go beyond the confines of their personal experiences, ideas and knowledge to produce ideas inspired and informed by other group members. Through further analysis of the refined ideas produced by the real groups, we identified whether this refinement was due to self-think (i.e. a refined idea following on from the participant's own ideas) or group-think (i.e. a refined idea following on from another group member's idea). Our results showed us that the major contributor to the refinement of creative ideas in real groups was due to group-think. Hence, hypothesis H2f was supported. Rather than multiple domains of knowledge leading to the generation of many different categories of creative ideas (i.e. divergent thinking), group members conformed to the generation of creative ideas similar to those generated by their peers (i.e. convergent thinking).

Rotter & Portugal [1969] argued that real groups would duplicate more ideas than nominal groups due to group-think [Janis, 1982] or group norms [Terry & Hoog, 2000]. We have shown that duplication is more likely to occur in nominal groups than in real groups. Rather than duplicating ideas, group members who participated in the real condition *refined* their own ideas and the ideas of others within the group. For example, a participant within one group generated the idea of 'voice interaction by speaking commands aloud to the screen', while another participant proposed that 'the user could speak commands into a microphone on a headset'. These were considered different ideas, but belonged to the same category. The externalisation of ideas in the real group condition led to participants generating refinements of those ideas.

Finally, when considering the degree to which a creative idea was refined, a significant difference was found, with nominal groups refining their creative ideas more than real groups, when including duplicated creative ideas. Therefore, hypothesis H2g was supported. However, no significant difference was found when comparing nominal groups and real groups with respect to the degree of refinement, when excluding duplicated creative ideas. Hence, hypothesis H2h was not supported. This indicated that this difference was due to the higher duplication of creative ideas by nominal groups.

So why is it the case that real groups were not as divergent as predicted? A possible explanation could be one of Osborn's [1957] brainstorming rules: improvement and combination are sought. While this rule may be argued to have a positive effect on creativity through the generation of ideas, it has an inhibiting effect on the divergence of thinking, resulting in group-think. While Rotter & Portugal [1969] argued that group-think would cause duplication of ideas, we have shown that the influence of group-think actually leads to the refinement of ideas.

The representation of ideas could be another reason for the lack of divergent thinking. The ambiguity of sketches allows them to be re-interpreted in different ways [Buxton, 2006; Oxman, 1997]. This ambiguity can lead to 'new ways of seeing' or 'focus shifts' [van der Lugt, 2002], thereby promoting divergent thinking.

Another possible explanation is the organisation of the ideas. As with many GDSS [Demhis & Valacich, 1993; Nunamaker *et al*, 1991; Valacich *et al*, 1994] our software pooled the reported ideas into a list. This representation of ideas may not have been effective for divergent thinking. Mark *et al* [1995] has shown that the organisation of ideas can have an effective on the idea generation process and the structuring of the creative ideas produced.

We have shown that there were no significant differences between the number of categories of creative ideas reported. Nominal groups and real groups are therefore considered equally divergent when social influences are controlled. We have also shown real groups to refine more of their creative ideas compared to nominal groups due to group think, while the degree of refinement for nominal groups is higher than real groups, when duplicated creative ideas are included. Overall, this analysis has extended previous research [e.g. Demhis & Valacich, 1993; Lamm & Trommsdorff, 1973; Mullen *et al*, 1991; Nunamaker *et al*,1991; Valacich *et al*, 1994] providing a deeper understanding of creativity in terms of divergent thinking across various group compositions.

3.5.3 The quality of creative ideas

As with the quantity of ideas generated, nominal groups have been found to outperform real groups with respect to the quality of ideas produced [e.g. Lamm & Trommsdorff, 1973; Mullen *et al*, 1991]. Furthermore, Valacich *et al* [1994] has shown that when using GDSS, idea production is increased with no penalty on the quality of the ideas. In this study we have built upon previous research [e.g. Lamm & Trommsdorff, 1973; Mullen *et al*, 1991; Valacich *et al*, 1994] to study the effect of group composition on creativity in terms of the quality of creative ideas generated during a design activity, when social influences were controlled.

More specifically we measured: the total quality of creative ideas generated; the average quality of the creative ideas generated; and the number of highly creative ideas, as the recommended measures of quality [Lamm & Trommsdorff, 1973]. Furthermore, we broke the measurement of quality of creative ideas down to the degree of novelty and the degree of appropriateness of a creative ideas, in order to understand the components influencing the quality of a creative idea. It was hypothesised that real groups would score higher than nominal groups with respect to: the average novelty of creative ideas, including (H3a) and excluding (H3b) duplicated creative ideas; the average appropriateness of creative ideas, including (H3c) and excluding (H3d) duplicated creative ideas; the average quality of creative ideas, including (H3e) and excluding (H3f) duplicated creative ideas; the number of highly novel creative ideas, including (H3g) and excluding (H3h) duplicated creative ideas; the number of highly appropriate creative ideas, including (H3i) and excluding (H3j) duplicated creative ideas; the number of highly creative ideas, including (H3k) and excluding (H3l) duplicated creative ideas; the total novelty of creative ideas, including (H3m) and excluding (H3n) duplicated creative ideas; the total appropriateness of creative ideas, including (H3o) and excluding (H3p) duplicated creative ideas; and the total quality of creative ideas, including (H3q) and excluding (H3r) duplicated creative ideas;.

It was found that there was a significant difference in terms of the average quality of creative ideas reported excluding duplicated creative ideas, with nominal groups producing a higher creative quality of ideas compared to real groups. However, this was in the opposite direction to that hypothesised. Furthermore, no significant difference was found in terms of the average quality of creative ideas reported including duplicated creative ideas. Hence, hypothesis H3e and H3f were not supported. This finding suggests that the average creative quality of nominal groups creative ideas was higher than those creative ideas generated by real groups when duplicated creative ideas were included.

Our experimental hypotheses for real groups being more creative in terms of the quality of their ideas was based on an belief that real groups would generate more novel and appropriate creative ideas. More novel ideas were predicted as real groups would have a large collected domain of knowledge to traverse, and therefore could potential make more unusual combinations of ideas, or combine more distant bundles of knowledge [Santanen *et al*, 2002]. Yet, it was also believed real groups would generate more appropriate ideas, as group members would be able to reflect and improve upon each other's ideas. To explore this issue further, we consider the components of creative quality - the degree of novelty and the degree of appropriateness.

From our result, we can see that the only other significant difference found was that nominal groups produced, on average, more appropriate ideas when compared to real groups when duplicated creative ideas were included. Once again, this was in the opposite direction to that hypothesised (H3c). This will have been a factor in contributing towards a significant difference between the nominal and real group conditions. Of course, this is not enough alone to cause a significant difference in the average quality of creative ideas. While for the most part significant differences were not found between the nominal and real groups in terms of novelty and appropriateness, nominal groups did tend to have a higher degree of novelty and appropriateness compared to real groups. Therefore, when these data were used to calculate the average quality of the creative ideas a significant difference was found between nominal and real group conditions.

While a significant difference was found between the nominal and real group conditions for the average quality of creative ideas when duplicated creative ideas were included, this difference was relatively small - less than 2% difference between the average quality of creative ideas for the nominal groups and real groups. No significant differences were found when considering the total quality of creative ideas and the number of highly creative ideas. Hence, this difference in creative quality is relatively small. However, why is it the case that real groups did not produce creative ideas of a higher quality when compared to nominal groups as hypothesised?

Reflection time is a possibility for the observed difference. As participants in the nominal group were not distracted by others' ideas, they could reflect upon their ideas more, allowing them to appropriate them. Coughlan & Johnson [2006] have shown that during individual creative activities it is common for individuals to reflect/internally evaluate their creative output.

An explanation for the reduced novelty of creative ideas produced by real groups is group-think [Janis, 1982]. As discussed in section 3.5.2, real groups refined their ideas rather than producing many different categories of ideas. This suggests that the real groups did not fully traverse the collected domain of knowledge they had available to them. This would prevent remote combinations between bundles of knowledge being made, and therefore highly novel ideas being produced.

Finally, the representation of one's creative ideas may not have been appropriate. We have already discussed how text is only one means of externalising one's ideas, while representations such as sketching are more common in design activities [Goldschmidt, 1991; Schön, 1983; Tohidi *et al*, 2006b]. Representations such as sketches may have allowed for a greater exploration of the design space leading to more novel ideas, as sketches are considered ambiguous [Buxton, 2005b; Buxton, 2006]. Furthermore, the process of producing a sketch is a reflective process [Goldschmidt, 1991]. This reflective process may have increased the appropriateness of the creative ideas produced. Hence, if the novelty and appropriateness of creative ideas were increased through representations such as sketches, the creative ideas may have been of a higher quality. Of course, this is true for both the nominal and real groups.

We have shown in this section that nominal groups' creative ideas had a higher average quality than real groups, including duplicated creative ideas. However, this difference was relatively small and no significant differences were found between the nominal and real groups with respect to the total creative quality and the number of highly creative ideas produced. It is therefore debatable what impact this small difference in creative quality would have on the creative process of design.

3.5.4 General discussion

In this experiment we compared four conditions - nominal, nominal-real, real-nominal and real group compositions - to identify the effect on creativity - the quantity of creative ideas, the divergence of creative ideas and the quality of creative ideas - when group composition was manipulated and social influences were controlled. This addresses RO1.

Overall, our findings from this experiment showed that there were no significant differences between nominal group and real group creativity. The results from this research extend and contradict previous research showing nominal groups to be more creative than real groups [e.g. Lamm & Trommsdorff, 1973; Mullen *et al*, 1991] and complements research from GDSS researchers [e.g. Demhis & Valacich, 1993; Nunamaker *et al*,1991; Valacich *et al*, 1994]. Furthermore, our research has extended this previous research applying more objective methods of measuring creativity, while extending our analysis of creativity (e.g. the number of duplicated creative ideas, the refinement of creative ideas and the degree of novelty and appropriateness) to provide a deeper understanding of nominal and real group creativity.

Several lessons can be taken from this experiment and fed into the design and development of future CST. First, in order to effectively support social/group creativity we need to control the social influences of production blocking, evaluation apprehension and free-riding (as stated by our high-level requirement 3 in chapter 2, section 2.3.4). Providing such support thereby refutes the claim of previous research that creative activities such as idea generation should be performed by nominal groups alone [e.g. Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973]. Secondly, the nominal and real group compositions have different advantages throughout the creative process. For example, the nominal group composition provides a setting for individuals to reflect upon their ideas. While the real group composition has the added benefit of exposing individual members of a design team to other members' knowledge and ideas. Furthermore, we can see from our results that the change-over between the nominal and real group compositions (i.e. nominal-real and real-nominal group compositions) had no negative effect (nor a positive effect) on creativity in terms of the quantity, divergence and quality of the creative ideas. Future work could explore the transition period between the nominal and real group compositions, or vice versa, thereby exploring the effects of this transitioning phase on creativity. Overall, the creative process involves individual and group creative activities, as well as transitions between these activities. Therefore to effectively support the creative process we need to support these individual and group creative activities and the transitions between them (as stated by our high-level requirement 2 in chapter 2, section 2.3.4).

An issue this study, as for of any experimental study, is its ecological validity. The tightly controlled environment of the lab is very different from a real-world design environment. However, the results from this experiment should be viewed as proof of concept. By controlling social influences and supporting individual and group creative activities we can support creativity in design. To explore this further we need to extend our studies beyond the lab into a real design setting (see chapter 4).

Another constraint/limitation of this experimental design was the use of textual representations to externalise one's ideas. As frequently mentioned above, sketches are a common means of externalising design knowledge/ideas [Goldschmidt, 1991; Schön, 1983; Tohidi *et al*, 2006b]. Sketches also have distinct features compared to words, which means they are more easily accessible and likely to stimulate increased use [van der Lugt, 2002]. Furthermore, sketches and text used together have been empirically shown to be more effective than either representation used alone [van der Lugt, 2002]. As identified in chapter 2 (see section 2.3.1), in order to support creativity we need to provide multiple representations of ideas to support the various phases of the creative process (high-level requirement 1). We next need to consider the use of such representations supporting creativity in design (see chapter 4). However, it should be noted that the process of brainstorming (i.e. textually or verbally externalising ideas) and brainsketching (i.e. sketching ideas) are quite different [van der Lugt, 2002]. Brainstorming involves continuous idea generation, whereas brainsketching involves rounds of idea generation. These means that it is difficult to make generalisations between brainsketching and the previous brainstorming research.

In order to complement the results obtained from our experiment and address the limitations raised, in the next chapter we report the results of three ethnographic studies aimed at understanding the occurrence of creativity in a real design setting - a diary study, field-based and lab-based observations. Through these studies we wish to better understand creativity in design and move towards identifying requirements for CST.

Chapter 4

Creativity in Design: An Empirical Perspective

In the preceding chapter we reported an experiment observing the effects of group composition - nominal, nominal-real, real-nominal and real group compositions - on creativity when social influences - production blocking, evaluation apprehension and free-riding - were controlled. However, experiments by their very nature are tightly constrained and have varying ecological validity. Hollan *et al* [2000] argues that ethnographic studies should be conducted when trying to understand a phenomenon. More specific to the study of design, Tang & Leifer [1988] argue that a better understanding of design activities could also lead to insights as how to improve the design process. Therefore, in this chapter we report three ethnographic studies - a diary study, a field-based observations and lab-based observations of design activities - aimed at building upon our theoretical perspective of creativity established in chapter 2 and our experiment reported in chapter 3. From these three studies we elicit a substantial list of requirements for CST. While many researchers have contributed requirements for groupware systems [e.g. Grudin, 1994; Guindon, 1990; Mandviwalla & Olfman, 1994], the need for requirements specific to CST has been acknowledged [Shneiderman *et al*, 2006]. Hence, these requirements identified in this thesis were specifically aimed towards the design, development and evaluation of CST. Hence, we address RO2.

Section 4.1 reports the results of a diary study that was administered to 12 groups across a 9 week software development life-cycle. Each member of a group documented her idea generation process throughout the project. Collating and analysing the data captured during the diary study allowed us to identify features of the creative process across the software development life-cycle.

Complementing the diary study, section 4.2 presents a set of field-based observations that were conducted during a design meeting of each of the 12 groups who participated in the diary study. Each design group was observed in their natural environment, where group members collaborated together and used artefacts to facilitate their creative process. Interactions were captured using video equipment allowing rich contextual data to be gathered.

Section 4.3 built upon the diary study and field-based observations, reporting 12 lab-based studies. Participants were observed engaging in individual and collaborative creative design tasks. These observations allowed the creative process to be observed under more tightly controlled conditions, refining our understanding of idea generation during the design process.

In section 4.4 we conclude this chapter by providing a collated list of the requirements for CST, elicited from our three studies.

4.1 A diary study

The software development life-cycle is a creative process - identifying problems and generating ideas/solutions to solve problems. However, our understanding of the occurrence of this creative activity is quite limited. In this section we report a diary study that was conducted with 12 undergraduate groups taking a user interface programming course. Documenting the idea generation process across their software development life-cycle's we were able to capture information regarding the generation and development of ideas (i.e. new and refined ideas), as well as the origin of those ideas (i.e. by an individual or the group). This study intended to give us a broad overview of the occurrence of creativity across the software development life-cycle.

4.1.1 Method

The diary study involved undergraduate computer science students documenting their idea generation process over a nine week software development project. The diary study captured information on the context in which ideas were generated (e.g. was the idea generated by an individual or within a group of people; and was the idea a new idea, a refined idea, or other), as well as capturing details about the idea itself, which could be expressed through a number of different representations (e.g. sketches, annotations and text). The diary entries were entered into a spreadsheet and visualised, allowing patterns to be identified.

4.1.1.1 Participants

66 participants took part in the study, forming 12 groups. The number of participants in a group ranged from 4 to 7, with a mean of 5.5. 58 of the participants were male and the other 8 female. The participants varied in age from 18 to 25, with a mean of 19.6 years. All participants were second year undergraduate students from the Department of Computer Science at the University of Bath studying a user interface programming course. Participants received 5% of their marks for the coursework part of the module by completing the diary study.

4.1.1.2 Materials

Diary entries were recorded on a diary sheet: a single A4 piece of paper (see appendix C). Each diary sheet initially captured some generic information about the participant - their name and their group. Further information, such as the date and time the idea generated was captured; the context of the idea - whether generated by an individual or the group; and the type of the idea - a new idea, a refined idea or other. Finally a blank space was provided for participants to record their idea(s) allowing for sketches, annotations and text. If the participants needed more space they were prompted to use the other side of the diary sheet or additional sheets of paper.

4.1.1.3 Procedure

When the coursework was assigned for the user interface programming course, the students were assigned to randomly selected groups and asked to:

> *'Design, implement and evaluate a novel and usable interaction technique.'*

Each student was asked to complete a diary study documenting their idea generation process throughout the coursework. This involved reporting new ideas, through to documenting how and why ideas developed. An example diary sheet was given to the students to illustrate what would be involved. Teaching assistants were also on hand during three weekly lab sessions to answer any questions the students had.

Diary sheets were provided to the students: printed copies could be found in the Department of Computer Science in a designated box and an electronic copy of the diary sheet could be found on the course web site. Each week at the specified hand in time, each student would hand in their diary sheets. Diary study sheets could be completed using a pencil, pen or a personal computer. This continued each week over the nine week period of the coursework.

4.1.2 Findings

The findings we present here are drawn from an analysis of the diary study. All the diary entries were entered into a spreadsheet and visualised, allowing patterns to be identified. (An excerpt from the spreadsheet can be found in appendix C.) We pay particular attention in the following sections to the generation of ideas across the software development process, which includes the generation of both new and refined ideas; and the origin of the generated ideas - whether generated by an individual or the group. We further report the relationship between the type of ideas generated (i.e. new or refined) and the origin of the ideas (i.e. an individual or the group).

4.1.2.1 Idea generation

The primary aim of the diary study was to record the occurrence of idea generation across the software development process. Figure 4.1 presents a graph showing the average number of ideas generated by all 12 groups across their 9 week software development projects.

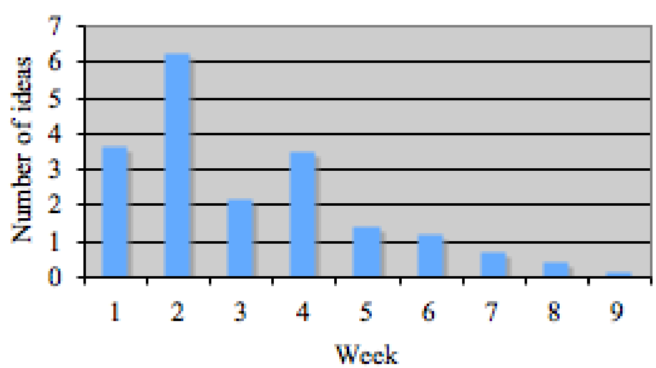


Figure 4.1: The average number of ideas generated by all 12 groups across their 9 week software development projects.

As can be seen from figure 4.1 most ideas were generated in the earlier phases of the software development process: weeks 1 and 2. This phase of idea generation was primarily during the design phase of the software development process. As argued by Boden [1994], the number of ideas generated has a crude relationship with creativity. Therefore, it could be argued that the design phase was the most creative phase of the software development process. Towards the latter phases of the software development process (weeks 3 to 9), idea generation was less common as the groups implemented and evaluated their chosen design ideas. To explore the process of idea generation in more detail we next consider the number of new and refined ideas generated.

4.1.2.2 New and refined ideas

A new idea was an idea that had not been expressed to the group (i.e. novel to the group) [Warr & O'Neill, 2004]. We determined the number of new ideas expressed to a group by counting the number of instances of new ideas generated as indicated by our participants on their diary sheets. Figure 4.2 presents a graph showing the average number of new ideas generated by all 12 groups across their 9 week software development projects.

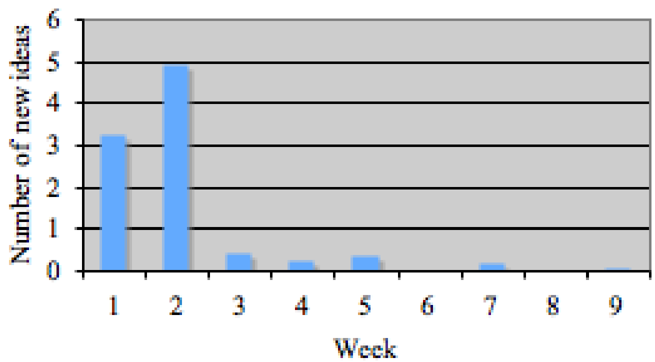


Figure 4.2: The average number of new ideas generated by all 12 groups across their 9 week software development projects.

A refined idea was an idea that extended upon a idea previously generated within a group. We determined the number of refined ideas expressed to a group by counting the number of instances of refined ideas generated as indicated by our participants on their diary sheets. Figure 4.3 presents a graph showing the average number of refined ideas generated by all 12 groups across their 9 week software development projects.

Figure 4.2 shows us that most new ideas were generated in the early stages of the software development process: weeks 1 and 2. It was during this phase of the software development process that the groups were trying to come up with a novel and usable interaction technique to be designed, implemented and evaluated for their coursework. This phase of the software development process predominantly involved

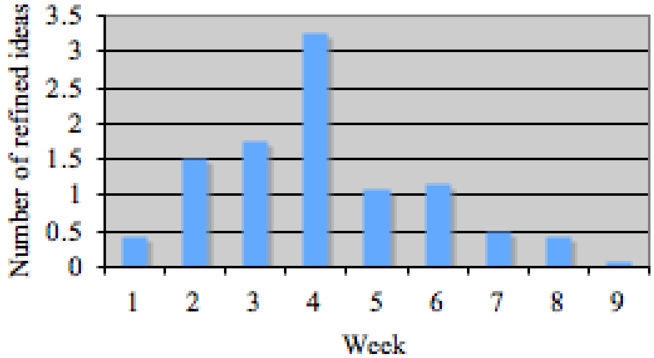


Figure 4.3: The average number of refined ideas generated by all 12 groups across their 9 week software development projects.

divergent thinking (i.e. thinking up different ideas). Over the first two weeks each group generated from 2 to 14 new ideas, with a mean of 4.08 new ideas generated. From weeks 3 to 9 relatively few new ideas were generated. As commented by participants in the diary sheets, the new ideas generated in the latter phases of the software development process were not directly related to the group's chosen idea, but rather were new ideas inspired by the idea they had chosen to develop. From figure 4.2 it is clear to see that new ideas were generated throughout the software development process, although predominantly in the first two weeks. Therefore, a requirement for CST is:

> **Requirement 1: CST should support the generation of new ideas - divergent thinking.**

Figure 4.3 shows us that the refinement of ideas mainly occurred during weeks 2 to 4, yet remained relatively steady throughout the software development process. Refined ideas built upon the new ideas generated by the group during weeks 1 and 2, showing the groups moving from a process of divergent thinking to convergent thinking. From weeks 3 to 9 the groups refined between 0 and 11 ideas each week, with a mean of 1.18 ideas being refined each week. It was during this phase of the software development process that the groups developed their chosen idea for an interaction technique, ready to be implemented. The generation of ideas tailed off towards the end of the software development process as the group moved into the phases implementation and evaluation. This process of refinement is necessary in order to develop one's ideas, ready for implementation - moving from the creative idea to the creative product. Consequently, a requirement for CST is:

Requirement 2: CST should support the refinement of ideas - convergent thinking.

These findings are similar to those observed by Tang & Leifer [1988], whom argue two key features that designers utilise when developing ideas are to: (1) try out representations of ideas (i.e. new ideas); and (2) gradually evolve those representations in distinct solutions (i.e. refined ideas). Similar to our requirements reported here, Candy [1997] argues that CST need to support the creation of new ideas and their refinement. To further understand the process of generating new and refined ideas, in the next section we consider the origin of these generated ideas - whether by an individual or the group.

4.1.2.3 Ideas generated by individuals and the entire group

An idea generated by an individual was an idea that was generated by a single member of the group. We determined the number of ideas generated by individuals by counting the number of instances of individually generated ideas as indicated by our participants on their diary sheets. Figure 4.4 presents a graph showing the average number of ideas generated by an individual for all 12 groups across their 9 week software development projects.

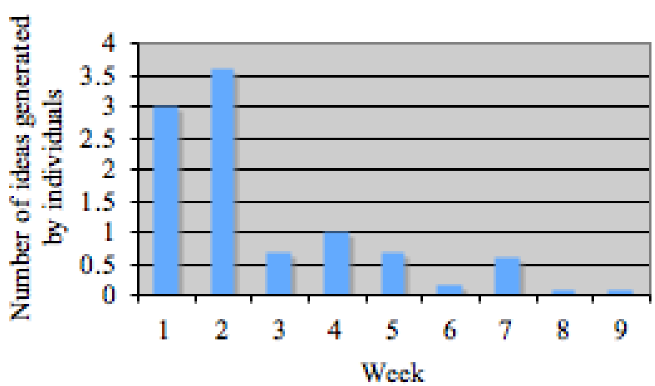


Figure 4.4: The average number of ideas generated by an individual for all 12 groups across their 9 week software development projects.

An idea generated by a group was an idea that was generated as a group effort. We determined the number of ideas generated by the group by counting the number of instance of group generated ideas as indicated by our participants on their diary sheets. Figure 4.5 presents a graph showing the average number of ideas generated by the group for all 12 groups across their 9 week software development projects.

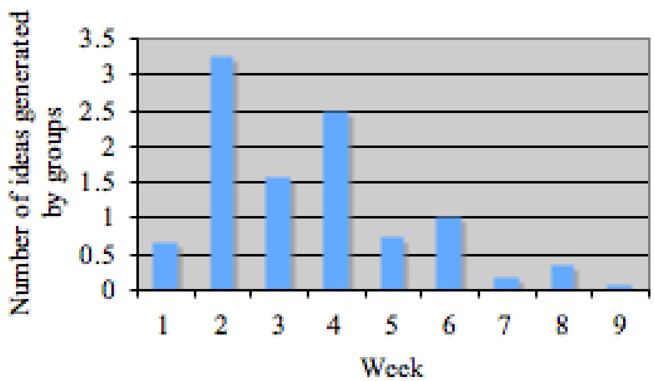


Figure 4.5: The average number of ideas generated by the group for all 12 groups across their 9 week software development projects.

Figure 4.4 shows us that individuals generated most idea during the early stages of the software development process: weeks 1 and 2. Thereafter, the generation of ideas by an individual alone tailed off dramatically. From figure 4.4 and 4.2, there seem to be a relationship between the number of idea generated by individuals and the number of new idea generated. A Pearson's correlation test (2-tailed) confirmed their to be a relationship (Pearson correlation = 0.98; p = $7.07\text{x}10^{-6}$). (A worked example of the Pearson's corelation test can be found in appendix C.) Further analysis of the data showed 68.64% of all new ideas were generated by an individual. It is clear to see that individual activities played an important part in the idea generation process, particularly with respect to generation of new ideas. Hence, a requirement for CST is:

Requirement 3: CST should support individual activities.

Idea generation was predominantly conducted by the entire group throughout the software development process, as shown in figure 4.5. This is similar to the generation of refined ideas as shown in figure 4.3. A Pearson's correlation test (2-tailed) showed their to be a relationship (Pearson correlation = 0.78; p = 0.014) between the number of idea generated by the group and the number of refined ideas generated. When the data was analysed further we discovered that 68.29% of refined ideas where generated by the group. Our data suggests that group activities play an important role in the idea generation process, particularly with regards to the refinement of ideas. Therefore, a requirements for CST is:

Requirement 4: CST should support group activities.

4.1.3 Conclusions of the diary study

The aim of the diary study was to understand the occurrence of idea generation across the software development process. From the data collected throughout the diary study we analysed the generation of design ideas - both new and refined ideas; the origin of those ideas - ideas generated by individuals and ideas generated by the group; and the relationship between the type of generated ideas and their origin.

Our analysis identified that the majority of ideas were generated in the early phases of the software development process: the design phase. Weeks 1 and 2 saw the generation of the majority of new ideas. The generation of new ideas was predominantly an individual activity, resulting in a divergence of thinking amongst the group.

Week 2 onwards saw a converging of the design ideas: a design idea was chosen to be refined, implemented and finally evaluated. This converging or refinement of the ideas was primarily carried out by the group.

Based on these findings we have identified four requirements for CST:

Requirement 1: CST should support the generation of new ideas - divergent thinking.

Requirement 2: CST should support the refinement of ideas - convergent thinking.

Requirement 3: CST should support individual activities.

Requirement 4: CST should support group activities.

4.2 Field-based observations

The diary study gave an overview of creativity across the software development process. From the diary study we observed that the early phase of the software development process (i.e. the design phase) was most active in terms of idea generation and arguably the most creative [Boden, 1994]. We conducted a number of field-based observations during the design phase of the software development process. The aim of these field-based observations was to capture rich contextual information regarding creativity in the design process, thus enabling us to elicit requirements for CST.

4.2.1 Method

The field-based study involved 12 groups of 4 to 7 students who were taking the user interface programming course. The study was designed to gather information on the process of being creative in a design meeting. Interactions between the members of the group and the artefacts they used were captured for post-analysis through the use of two digital video cameras.

4.2.1.1 Participants

The field-based observations involved the same groups who participated in the diary study (see section 4.1.1.1). All the groups volunteered to be observed during one of their design meetings and did not receive any additional course credits or other incentives.

4.2.1.2 Materials

Materials differed across the groups. No pre-defined materials were given to the participants, nor were they requested to bring any specific materials to the design meeting. The groups used the materials that they normally would in a design meeting. Such materials consisted of pens and paper, whiteboards and personal computers for creating externalisations during a design meeting; print-outs to disseminate information around the group (e.g. documents and websites); and prototype applications running on various technologies (e.g. mobile phones, Personal Digital Assistants (PDA) or laptops).

During the design meetings, audio-visual data was captured using two digital video cameras. These cameras were positioned on tripods to capture two different angles of the group in order to record the interactions between the group and the artefacts they used.

4.2.1.3 Procedure

Each group studying the user interface programming course were asked if they would volunteer to be observed during one of their design meetings for the coursework project. These observations occurred in weeks 2 to 5 of the 9 week software development life-cycle - predominantly the design phase for many of the groups. Groups made arrangements with the ethnographer during lab sessions and via e-mail. The location and time of the design meeting were left up to the group to fit in with their normal practice. Most groups had pre-defined times and rooms scheduled for their design meetings, while other groups conducted their meetings on a more ad-hoc basis.

Before a design meeting started the ethnographer set-up the digital video cameras on their tripods. The cameras were kept at the maximum distance possible and the zoom feature was used where necessary to reduce any unnecessary distraction. Varying angles were used to ensure all interactions between the members of the group and any artefacts they used were captured.

Once the cameras were set up and all members of the group were satisfied, the cameras were set to record and the design meeting began. There was no time limit for the design meeting. The meeting finished when the group decided they had covered everything they had intended. The design meetings lasted from 18 to 100 minutes, with a mean time of 35 minutes. While the design meeting was in progress the ethnographer sat at the back of the meeting room and took note of interesting events to look for in the videos. The ethnographer also periodically checked the tapes in the digital video cameras and changed them if they were nearing the end of the tape. This continued until the design meeting ended.

4.2.2 Findings

From our field-based observations we wished to refine our theoretical understanding of creativity in design. Focussing on our three high-level requirements for supporting creativity identified in chapter 2 (see section 2.3.4), we pay particular attention to the interactions with and the use of externalisations, individual and group creative activities and the occurrence and control of social influences. The findings we present here are drawn from an analysis of the video recordings from the 12 design meetings. Our analysis of the video data encoded events based a foci and interaction analysis [Jordon & Henderson, 1995]: recording time stamps, the participants of interest (e.g. the speaker), group composition (e.g. speakers and hearers), the occurrence of social influences, the phase of the creative process and any comments/notes. (An excerpt from the encoded video data can be found in appendix C.) These data were used to highlight foci within the framework of our three high-level requirements for supporting creativity. In the following sub-sections we extract and discussed example foci from the video data, eliciting further requirements for CST.

4.2.2.1 The creative process of design

In chapter 2, we reviewed and compared a number of creative process models (see section 2.2.3.1). These models describe the various phases of the creative process. Three commonly identified phases were problem framing, idea generation and idea evaluation. We frequently identified the occurrence of these phases during our field-based observations of the design meetings.

Problem framing is described as understanding the problem and identifying characteristics of a desired solution [Simon, 1973]. Understanding the problem the groups were addressing was essential. For example, one group had decided to implement a poker game using personal and shared displays. However, before they could design this system (i.e. through a process of idea generation and idea evaluation) they had to understand the process of a poker game (i.e. understanding the domain of the problem). This is illustrated in the excerpt below.

> *G8P3 (00:10:18) - "What do you mean by a dealer?"*
>
> *G8P2 (00:10:30) - [P2 steps up to the blackboard to describe the function of the dealer in a game of poker] So you have all the people around a table. Now you remember the antis, the blind bets you have to make. Well, at the moment there is no way to determine whose turn it is and who needs to put the antis down. Whereas, if you have a dealer you know that [pointing to his diagram] this person has to place the small blind and this person has to place the big blind. Now, the idea is that once that hand is finished the dealer position goes around to the next person to their left. So in the next round the small and big bets have moved on.*

Understanding the domain of the problem would subsequently provide a foundation for identifying characteristics of a desired solution. Understanding the involvement of the dealer allowed the team to consider a characteristic of their final solution, as described in the excerpt below.

> *G8P3 (00:11:25) - "So how do we keep track of this idea of left? Because in a group of people using PDA you may not have a concept of left and right."*
>
> *G8P1 (00:11:32) - "Well, we can do it by the order in which they log on."*

G8P2 (00:11:35) - "Think of that [the blackboard] as the plasma screen. You're looking at it aren't you."

G8P1 (00:11:40) - "So how do you decide [pointing at the blackboard] that this person is left and that person is right?"

G8P3 (00:11:59) - "So have it go in order of log on."

G8P2 (00:12:04) - "That is how you would have them arranged on the screen I would have thought."

From understanding the arrangement of people in a poker game and the concept of the dealer, the group realised that their system could organise players based on login and represent them on the shared display in the appropriate manner, thus allowing their final solution to have a sense of left and right. It is clear to see in this example that not understanding the problem domain would effect the generation of an appropriate solution.

Idea generation is the process of exploring and composing possible solutions to a problem [Shneiderman, 2000]. As with our diary study, we identified the occurrence of two types of idea generation: new and refined ideas.

A *new idea* is an idea that has not been previously generated to a problem (i.e. novel to the group). All the groups were given the problem of 'designing, implementing and evaluating a novel and usable interaction technique'. one group decided to design, develop and evaluate an interaction technique to navigate a ball around an electronic maze. The idea was inspired by traditionally ball and maze games where a ball is encased in a physical maze. The ball can be navigated around the maze by tilting the casing in the appropriate direction. The group designed, developed and evaluated a virtual equivalent of this real-world game. A tablet PC displayed a virtual representation of the maze and the ball. Motion sensors attached to the tablet PC detected the tilt of the tablet PC to cause the virtual ball to move, just like tilting the physical casing of a maze would cause the physical ball to move. Here we see a move from an old existing idea (i.e. a physical maze game) to a new, novel idea (i.e. a virtual maze game).

A *refined idea* is an idea that extends/improves an existing idea generated to a problem. One of the groups was designing a remote control application to control one's music through a PDA. They discussed how a remote control typically involved pressing the buttons with your finger or thumb. However, on the small screen of a PDA, small controls were interacted with through means of a stylus. The design team decided to increase the size of the onscreen PDA buttons allowing for easier interaction, especially if a user were to use their fingers or thumbs.

Idea evaluation is described as verifying that one's novel ideas are in fact appropriate to solve the problem [Osborn, 1957, Wallas, 1926]. This process involves evaluating generated ideas against the characteristics of a desired solution that were identified during problem framing. For example, one group were designing and developing a language tutor for school children. The system would present English and French words on an interactive blackboard. The children then had to pair the appropriate words. A requirement for their system was that the words should be low enough for the children to reach and interact with, as illustrated in the transcription below.

> *G4P5 (00:03:57) - "The other thing we were saying was, because kids... because the top of the blackboard is going to be quite high and kids are quite small, generally, we should have all the words at the bottom of the screen [pointing to their current sketch of the UI on which the words were randomly positioned over the paper] and the information they don't need to interact with, or only the teacher needs to interact with, exit and stuff, being right at the top."*

The characteristics for a desired solution based on the constraints of the problem provided metrics for verification. If the characteristics of a desired solution were not met, the idea would be refined or even a new idea generated to provide an alternative solution. If the problem was not understood fully the group would have to return to a phase of problem framing to understand the problem and then return to a phase of idea evaluation to effectively evaluate their ideas. This process continued until a solution to the problem was reached.

In addition to the phases of problem framing, idea generation and idea evaluation, we identified a fourth phase, namely *idea framing*. We describe idea framing as building up an understanding of a generated idea. The difference between problem framing and idea framing is in understanding the problem and ideas respectively. Csikszentimihalyi [1996] describes such a phase as an elaboration of an idea.

Idea framing is particularly important to collaborative creative tasks. When an individual generates an idea they generally have a clearer understanding of that idea than their collaborators. Hence, others in the group may need more information about the idea in order to understand it. Furthermore, members of a group can collaboratively question their understanding of the idea leading to its refinement. For example, one group were designing and developing a personal trainer assistant that could tell you if you were performing an exercise correctly by monitoring the position of your body through motion sensors. One of the members of the group had taken the lead developing a prototype application. He described his ideas for the application to others in the group so they could understand them (see figure 4.6 and the transcribed audio extract below).

Figure 4.6: An example of framing an idea.

G4P5 (00:02:12) - "So you will see an animation there [whilst pointing to the UI]. You will have some sort of data, like, hmm, I am not sure exactly how we will represent that, but that will be showing what the actual sensor should be doing. So some sort of graph or angle display for each sensor. That is basically what you are doing. So here you will have a comparison of the two [pointing to the UI]."

G4P1 (00:02:33) - "Could you overlap them?"

G4P5 (00:02:35) - "I was thinking of having a traffic light system. So, if they were way off it would be red and if you're doing its correctly its green."

G4P3 (00:02:45) - "That's a good idea."

From this example we can see that P5 was able to explain his ideas to the group and others in the group were able to question him regarding those ideas. Understanding ideas was essential to the refinement of those ideas and their effective evaluation.

In chapter 2 we identified three common phases in the creative process, namely problem framing, idea generation and idea evaluation (see section 2.2.3.1). Through our field-based observations of design meetings we have refined our understanding of the creative process having broken down idea generation into two sub-phases: new and refined idea generation. Furthermore, we identified the new phase of idea framing, which is particularly relevant to the collaborative creative process, where you need to understand ideas generated by others. Figure 4.7 models our refined understanding of the creative process of design. (The original version of figure 4.7 can be seen in figure 2.1 in chapter 2 (see section 2.2.3.2)).

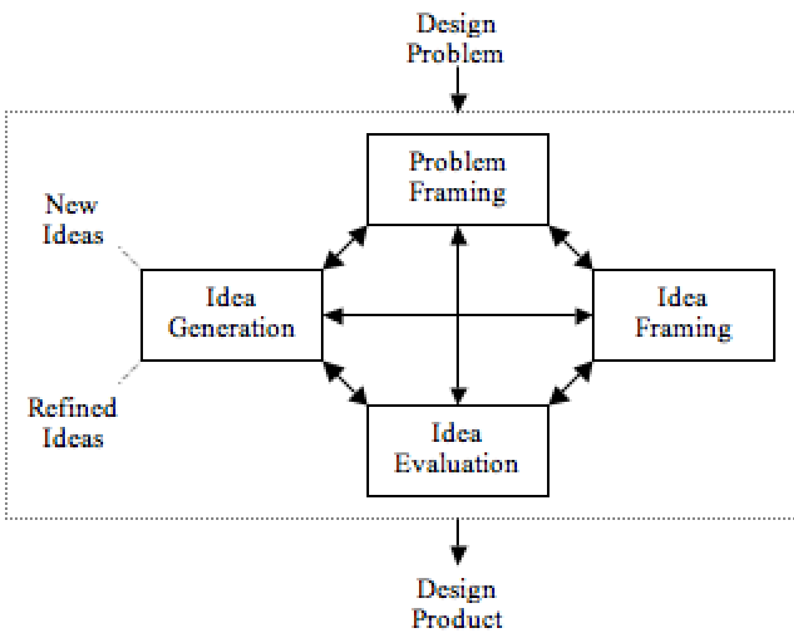


Figure 4.7: The creative process of design (version 2).

In the following sections, we build upon our understanding of the creative process identifying requirements for CST.

4.2.2.2 Types of interactions

From the analysis of the videos data, the members of the groups were seen to engage in six types of interactions with other participants and the artefacts they used: verbal communication, the creation of sketches, the creation of annotations (i.e. text dependent of a sketch), the creation of textual representations (i.e. text independent of a sketch), pointing at externalisations and gesturing with externalisations.

Verbal communication was the primary means of communication for the groups, as it is with many other collaborative activity [Baker *et al*, 2001; Baker *et al*, 2002; Gutwin & Greenberg, 2000; Schegloff, 2002]. Members of the groups verbally communicated with each other to frame the problem and frame ideas, tell others in the group about their generated ideas and evaluate their generated ideas. While verbal communication could be used in isolation, it was frequently complemented by other forms of interaction as discussed below.

Sketches provided a means of providing a permanent representation of one's verbal communications or thoughts [Schön, 1983]. Sketches were particularly useful throughout the phases of problem framing, idea generation, idea framing and idea evaluation.

During the phase of problem framing, sketches of flow diagrams were particularly useful. When designing a system it was important for the members of the group to understand the process of that system. While such a process could be verbally described, a sketch of a flow diagram allowed a permanent representation of the process being discussed to exist. For example, as discussed above, one group were trying to understand the steps involved in a poker game, which can be quite complex. The group discussed each step in turn, building up a sketch (i.e. a flow diagram) of the steps involved in the design of their poker game system.

> *G8P3 (00:00:22) - "I think we should explore the flow of play..."*
>
> *G8P1 (00:01:24) - "So what comes first? They sit down in an order..."*
>
> *G8P3 (00:01:44) - "Each person has their PDA and let us say they are all switched on. The laptop (i.e the server) is plugged into the big screen and displayed on the screen..."*
>
> *G8P1 (00:02:01) - [P1 writes the steps of the process down, as described by P3]*

Sketches were also used during the phases of idea generation and idea framing. These sketches allowed one to move from the intangible nature of verbal communication to a tangible representation. In the case of the design meetings, sketches of interface designs were common. While someone could verbally describe an interface design, others within the group would have to mental envision the described design. This could result in misunderstandings and confusion between participants. For example, the design of an in game options menu required the concept being verbalised to be repeated:

> *G3P1 (00:37:28) - "We were talking about having a button in the top-left or something. You punch it [punching his hand in the air] and then it will pause the game and bring up an options menu or something. Are we still thinking about that?""*
>
> *G3P3 (00:37:40) - "So are you saying it is not in your face the whole time you're using it, but it comes out?"*
>
> *G3P1 (00:37:49) - "So just have it, so you like, punch a button on the left-hand side [punching his hand in the air]. It stops the game."*

Even in this situation, gestures complemented the group members verbal communication. (The use of gestures for complementing verbal communication is discussed in more detail below.)

However, when someone sketched an interface design, a more concrete representation of the concept existed. For example, one group were designing and developing an interactive map system. Interface designs generated by one of the members of the group allowed others to visualise the layout of her proposed designs:

> *G2P2 (00:22:30) - "This one involves using, like buttons [pointing to the sketch], I think you would probably need some kind of touch screen to interact with it."*
>
> *G2P5 (00:22:40) - "Yeah."*
>
> *G2P2 (00:22:41) - "I can't really see how you would use a joystick to click on the buttons."*
>
> *G2P5 (00:22:46) - "Yeah."*

While the sketch helped provide a more concrete understanding of the proposed interface design, pointing to the sketch complemented the participant's (P2) verbal communication. (The use of pointing interactions is discussed in more detail below.)

Idea evaluation used sketches that had been previously created. Such a sketch provided a shared artefact, which could be viewed and referred to by the group - a process of 'seeing as' [Goldschmidt, 1991]. Referring to a sketch made the process of idea evaluation clearer to other members in the group and avoided misunderstandings. For example, a group developing a language tutor referred to a sketch to critique the layout of components on the interface.

> *G10P4 (00:02:59) - "No, I think there should just be words, because if there are many pictures, it might be too much [pointing at the picture component on the layout of the sketch]."*
>
> *G10P1 (00:03:09) - "So many pictures are not a good idea."*
>
> *G10P3 (00:03:12) - "Or, just draw the picture when they match it."*
>
> *G10P1 (00:03:15) - "Like what? In the centre?"*
>
> *G10P2 (00:03:16) - "Yeah so it comes up, as if to say, well done, here is the picture [performs a gesture to illustrate a picture appearing in the centre of the UI]"*

As discussed above, we can see sketches are essential to phases of the creative process, complementing a group's verbal communications. The creation of sketches allowed participants to externalise their thought when trying to understand a problem (e.g. creating a flow diagram to understand the complex steps involved in a poker game). The creation of sketches allowed participants to externalise their design ideas, which was more effective than verbal communication alone (e.g. creating sketches to represent a UI design). The creation of sketches also assisted idea framing, allowing features of a design to be referred to and discussed. Finally, the creation of sketches allowed participants to effectively evaluate ideas, referring to and critiquing features of a sketched design (e.g. critiquing the layout of components on a UI design). Hence, a requirement for CST is:

Requirement 5: CST should support the creation of sketches.

Annotations were used to frame information about particular features on a sketch. For example, the group who were developing the language tutor annotated the functions of particular buttons on the sketch. Sketches by their very nature are ambiguous [Buxton, 2006]. Annotations provided a permanent framing of features on a sketch, extending the intangible nature of verbal communication and adding contextual information to an otherwise ambiguous sketch. These annotations could be referred to later providing the reader with a clearer understanding of what they are looking at. Therefore, extending the functionality of sketches, a requirement for CST is:

> **Requirement 6: CST should support the annotation of sketches.**

Text was used during the phase of problem framing and during idea generation to describe attributes of a design, sketches were unable to. During the problem framing phase of the creative process text was used to note requirements. When describing an idea, text was particularly useful at describing processes or technical details. For example, one group were designing a gesture based menu system for a tablet PC. They wanted the menu to contain user-defined applications. The application should know what application to execute when a menu item was selected. The following excerpt illustrates this:

> *G11P3 (00:06:20) - "We could have a menu config screen where you add what applications you want, because our program will need to know where the application is and the title to display. So you can add your own programs to it."*
>
> *G11P4 (00:06:36) - "Yeah. So then you will have to be able to add what the different things did..."*
>
> *G11P3 (00:06:38) - [While P4 is talking, P3 writes down the requirement for their system]*

Such a requirement could not be described using a sketch, whereas text was a suitable representation to translate the group's verbal communications. Text is a useful representation that complements and extends the functionality of a sketch. Therefore, in addition to supporting the creation of sketches, a requirement for CST is:

> **Requirement 7: CST should support the creation of text.**

Pointing interactions acted as a means of referring to a specific feature on an externalisation to complement one's verbal communication - deictic reference [Baker *et al*, 2001]. Such an interaction was supported by the creation of externalisations, typically sketches. Furthermore, pointing interactions were particularly useful throughout the creative process, as illustrated by the transcripts below:

> Problem framing:
>
> *G8P2 (00:11:00) - "[P2 points to a diagram on the blackboard] If you have a dealer you know that this person has to place the small blind and this person has to place the big blind."*
>
> Idea framing:
>
> *G10P1 (00:10:09) - "[P1 points to a UI component on a sketch] What do you think it should be then. The whole lot going into the centre or individually?"*
>
> Idea generation:
>
> *G10P1 (00:02:46) - "[P1 points to the UI design] So when you click on that list you should get an explanation of that."*
>
> Idea evaluation:
>
> *G7P1 (00:16:09) - "[P7 points at a list on the mobile phone display] You wouldn't want the list at the moment with a space at the top permanently."*

Pointing to an externalisation assisted others knowing what was being discussed, preventing misunderstandings from occurring throughout the creative process and thereby supported the groups' collaborative processes [Baker *et al* 2001; Baker *et al* 2002]. Hence, a requirement for CST is:

> **Requirement 8: CST should support users' pointing interactions with externalisations.**

Gesturing allowed contextual information to be temporally added to a sketch - an intentional and illustrative reference [Baker *et al*, 2001; Bekker *et al*, 1995]. For example, the group who were developing the language tutor proposed that an English word could be dragged to the centre of the interface and the associated French word could then also be dragged to the centre to indicate a match. A member of the group illustrated this idea using their fingers to imitate the interaction (see figure 4.8).

Gestures allowed a deeper understanding to be developed of a problem, idea or the critique of an idea. As such, they directly support verbal communication and convey information [Baker *et al* 2001] essential to collaborative activities [Baker *et al*, 2001; Bekker *et al*, 1995; Tang & Leifer, 1988]. Hence, a further requirement for CST is:

> **Requirement 9: CST should support users' gesture interactions with externalisations.**

In order to support the creative process we need to provide a means for creating externalisations such as sketches, annotation and text to complement one's verbal communications. These externalisations in turn will be enhanced through pointing and gesture interactions. As argued by Tang & Leifer [1988, 248], '... this fluent expression of ideas in the workspace and the ability to interact and build on representations created by others contributes to the process of developing ideas'.

4.2.2.3 The use of externalisations

Externalisations were an important part of the design meetings. Externalisations were presented in the design meetings through notepads, paper hand-outs and prototype applications that either ran on a laptop, PDA or mobile phone. Furthermore, these externalisations could be used by individuals or shared by the group.

It was very common for some members of the group to have their own notepad. The primary use of a notepad was to make notes on what was being discussed during the meeting, thus providing a lasting record of the group's verbalisations. While not all members of the group made notes during the meeting, a common post-meeting activity was for these notes to be typed up and distributed around the group members via e-mail. In some cases, the minutes were typed during the design meeting and e-mailed around the group at the end of the meeting.

Hand-outs were another common use of paper externalisations. Hand-outs could take the form of print-outs of existing systems from websites or other sources, to lists of requirements or designs that had been produced before the meeting. These

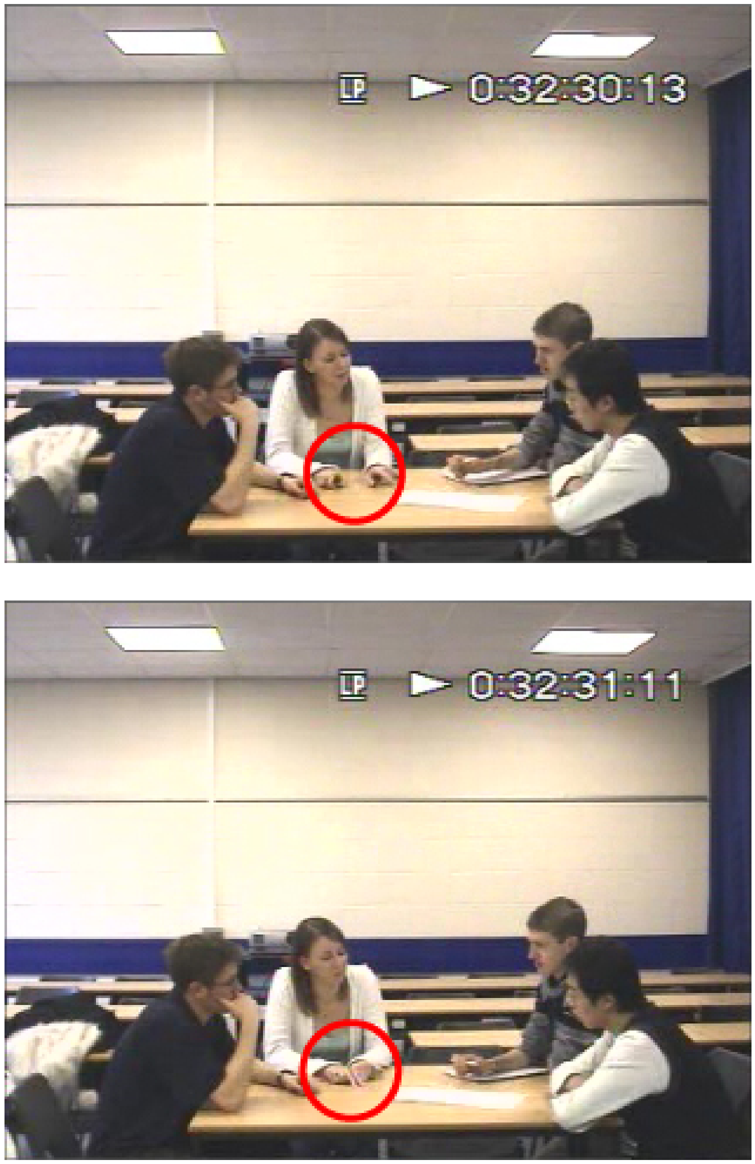


Figure 4.8: An example of gesturing to imitate user interaction.

hand-outs allowed each group member to have their own personal view of an externalisation that was publicly available to the group. As each member had their own copy of a hand-out they were able to make their own personal notes.

Paper could also be used as a shared space. Placing a piece of paper with a flow diagram or an interface design between the members of the group allowed all members to view it and refer to it (as seen in figure 4.8). It was common for group members to point to features on a sketch (as discussed above) or even refine the sketch using their own pen or pencil.

The paper used by the groups was commonly of size A4. This provided quite a small interaction space for use by the group. Often participants would have to lean in to view an externalisation or reach in to modify the externalisation in some way or point at a particular feature. When altering an externalisation, it was also common for members of the group to move the paper towards them, make a refinement/modify the sketch and then move the paper back to the centre of the table to be viewed by the group. As can be seen in figure 4.8, the position and orientation of the interface design sketched on a piece of paper on the table was biased towards the team member in the top-right corner of the table (P3). This was because P3 had recently added to the sketch.

While the use of A4 paper inherently created a small interaction space, the use of blackboards by group members made it easier to view an externalisation (see figure 4.9). Furthermore, it was easier to see what was being referred to when a member of the group was pointing to and discussing a particular feature on an externalisation. A disadvantage of the blackboard over the paper, was that the paper was placed on the table allowing group members to gather around it. The blackboard required group members to move from the table to create, refine or interact with the externalisation.

Several groups brought working prototypes to their design meetings to be discussed by the group. These prototypes were either run on a laptop, PDA or mobile phone. This allowed an understanding of the development of a group's design ideas to be realised; design decisions refined; new ideas generated; and design ideas evaluated.

The interaction space of a device used to display a prototype resulted in a number of interesting observations. One group had a prototype of their personal trainer system running on a laptop. Initially the group member with the laptop had the laptop facing him and was talking to the other group members about the prototype. Two members of the group closest to him tried to lean in to see the prototype - with difficulty. However, the other three members of the group were outside the interaction space of the laptop and were unable to view the prototype. The group member with the laptop then turned the laptop around so his colleagues could view the prototype. However, by doing so he excluded himself from the interaction space of the laptop. Figure 4.10 illustrates this.

Figure 4.9: The large interaction space of a blackboard.

Figure 4.10: The affect of a laptop's interaction space when viewing an externalisation.

The portability of a mobile phone and a PDA enable these devices to be placed in between the members of a group. However, the small interaction space created by a mobile phone or PDA meant group members had to huddle around these devices to view the display (see figure 4.11). The constrained interaction space prevented effective interaction with these devices. This was particularly noticeable with the mobile phone. Some group members gave up trying to view the prototype application as it was difficult to see anything. Such problems were mitigated by moving the mobile phone around individual members of the group. However, this resulted in the application not being viewable by all members of the group.

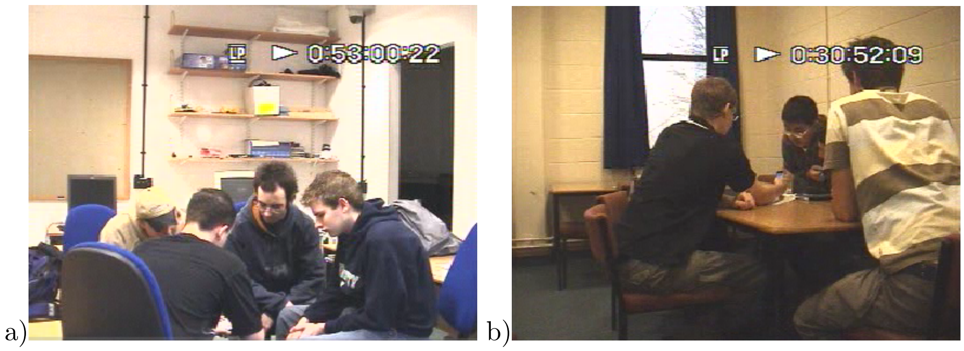


Figure 4.11: The affect of the constrained interaction space of a: (a) PDA; and (b) mobile phone.

Our observations showed paper to be the primary means for creating and disseminating externalisations - paper was used by all 12 groups during their design meetings. In the latter stages of the design process some groups developed high-fidelity prototypes to convey design ideas, moving towards the implementation phase of the software development process. In section 4.3 we examine the process of creating and disseminating externalisations using paper in more detail.

Furthermore, from our observations of the use of artefacts with varying interaction spaces we can see that large interaction spaces were suitable for group activities (e.g. the blackboard), while small interaction spaces constrained such collaborative activities (e.g. having to huddle around and interact with the small interaction space of a mobile phone or PDA). Small interaction spaces (e.g. a notepad) were more suitable and used for individual activities. Therefore, refining requirements 3 and 4, two requirements for CST are:

> **Requirement 3 (refined): CST should support individual activities using small interaction spaces.**

> **Requirement 4 (refined): CST should support group activities using large interaction spaces.**

4.2.2.4 Group compositions

During the design meetings group members engaged in individual, sub-group and group activities. Furthermore, task delegation and collaboration meant that outside the scope of the meeting room, group members engaged in individual and sub-group activities.

Working as a group was the most common group composition. Members of the group would engage in an active discussion building up an understanding of the problem, generating ideas, framing ideas and evaluating ideas. However, while in a group setting individual and sub-group activities also extended the activities of the group.

Individual activities allowed group members to work individually while an active group discussion was in progress. As already noted, group members had their own personal notepads to write their own notes and draw sketches that could then be disseminated to the group. Such an individual activity was considered private to the person who was engaged in it, and excluded other members of the group. Working individually in the group setting had the advantage of providing a degree of privacy in which to pursue one's own goals. As argued by Hilgard [1959], 'In this day of team research we often hear voices crying for the return of privacy, arguing that thinking goes on better in one head at a time'.

Whilst in a group setting, two or more members could form a sub-group and have a discussion. The other group members would remain idle and listen to what was being discussed. The reason for such a sub-group activity was due to some exchange of knowledge specific to the members of the sub-group. For example, during one design meeting one group member was questioning another who had expertise in the C♯ programming language. The other members of the group were passive hearers [Goodwin, 1981].

> *G1P1 (00:03:09) - "So have any of you used C♯? [a question to the group]."*
>
> *G1P3 (00:03:14) - "Yeah. It just has a few extra bits like enumerations and stuff. You can overwrite all the basic operators. [directs his response to P1]"*
>
> *G1P1 (00:03:22) - "So it's a bit like Visual Basic, but the syntax is like Java? [directs his response to P3]"*

G1P3 (00:03:25) - "Yeah, it's totally object-oriented. Like, you can even overwrite the greater-and-equal-to operator. [directs his response to P1]"

While not the case in our field-based observations, it may be the case that sub-groups would want to break away from the group and work independently. As argued by Hare [1982, p.175], 'with a social problem, the members of the group can use the diversity of their own backgrounds to provide leads concerning the importance of different types of data as well as to facilitate communication with persons of similar backgrounds who may be important sources of information'. Although the group did not split into two or more sub-groups in the design meetings we observed, sub-group activities did occur outside the meeting room. Therefore, in additional to requirements 3 and 4 supporting individual and group activities respectively, another requirement for CST is:

Requirement 10: CST should support sub-group activities.

It should also be emphasised that individual, sub-group and group activities were not static and independent of one another. Rather there was a dynamic shift between the various group compositions of the group.

G11P3 (00:02:23) - "It wouldn't be too hard as you would just have a config button that will bring up a new screen. You will have a list of gestures and what functions you want from a drop down menu [directed P5]"

G11P5 (00:02:29) - "Yeah, so you can see what is possible [directed P3]"

G11P1 (00:02:30) - [P1 begins to create a sketch]

G11P3 (00:02:37) - "So each application could have the same screen [directed P5]"

G11P5 (00:02:37) - "[P5 says something inaudible to P3]"

G11P1 (00:02:45) - "[Moves sketch to the centre of the table] So, Windows menu bar launches and this screen pops up... [directed at group]"

As we can see from this transcript, P3 and P5 were engaged in a sub-group activities, discussing how gestures would map to application. P1 who was a passive hearer of this discussion created a sketch to convey his ideas. This sketching process was an individual activity. When P1 had completed his sketch he moved it to the centre of the table and presented it to the group as they looked on. We can see here there was a transition from a sub-group activity, to an individual activity to a group activity. Such transitions frequently and dynamically occurred through the design meetings - the transition between loosely and tightly coupled collaboration [Baker *et al*, 2001; Gaver, 1991; Greenberg *et al*, 1999; Gutwin & Greenberg, 2000; Tang & Leifer, 1988]. Therefore, a requirement for CST is:

> **Requirement 11: CST should support the transitions between individual, sub-group and group activities.**

As well as the change in group composition being observed in the design meetings, pre- and post-collaborations were also important [Olson *et al*, 1992]. During the design meetings, individuals brought work they had produced for the meeting. This could take the form of handouts for the group, lists of requirements and designs of their proposed system. Similarly, towards the end of the design meetings work was delegated to individuals or sub-groups to be completed for the next meeting. For example, taking one design meeting as an example, the group delegated their tasks as follows: P1 - prototype development; P2 - database design; P3 - not assigned a task; P4 - refine the requirements specification based on what had been discussed during the meeting; P5 - write up the design specification based on the notes produced during the meeting; and P6 - storyboard interaction design. Here we see that the design process extended beyond the meeting room. As argued by Fischer [2005, p.129], 'Collaborative design can be distributed: (1) *spatial* (across physical distance), (2) *temporal* (across time), (3) *technological* (between persons and artefacts), and (4) *conceptual* (across different communities)'. Hence, a requirement for CST is:

> **Requirement 12: CST should support creative activities beyond the meeting room.**

4.2.2.5 The occurrence of social influences

The social influences of production blocking, evaluation apprehension and free riding have been shown to have a negative influence on creativity [Diehl & Stroebe, 1987]. During our field-based observations we observed the occurrence of such social influences, their effect on the creative process and the way some group members mitigated their effects.

Production blocking: During the design meetings ideas were verbally expressed and externalised using sketches, annotations and text. This resulted in only one idea being able to be expressed at a time. Due to the step-by-step delivery of ideas, some design ideas may have been suppressed, forgotten or rehearsed by an individual taking their attention away from the group's discussion [Warr & O'Neill, 2005a]. There were even cases when group members cut each other off mid-speech while expressing an idea so they could tell the group about their moment of inspiration.

> *G8P1 (00:27:51) - "So they will just choose all the options on the PDA. You can remember them from beforehand or you can have a variety..."*
>
> *G8P2 (00:27:54) - "But say..."*
>
> *G8P3 (00:27:55) - "No, I think we choose them on the laptop."*
>
> *G8P1 (00:27:57) - "Yeah, ok, we choose them on the laptop and then they..."*
>
> *G8P2 (00:27:59) - "The thing is though..."*

It has been recommended that the effects of production blocking can be reduced by providing synchronous forms of interaction [e.g. Diehl & Stroebe, 1987, Prante *et al*, 2002]. Some group members did have their own notepads, which could have provided a means for writing down their ideas if others were currently expressing theirs. However, the notepads were generally not used for this purpose. Instead they were used to record important points discussed by the group.

Asynchronous forms of interactions (e.g. verbal communication) constrain group members creativity in the design process [Diehl & Stroebe, 1991]. Whereas, providing synchronous forms of interaction can facilitate group members creative design process allowing them to externalise more than one idea at a time [e.g. Demhis & Valacich, 1993; Nunamaker *et al*,1991; Prante *et al*, 2002; Paulus & Yang, 2000; Valacich *et al*, 1994]. Therefore, a requirement for CST is:

Requirement 13: CST should support synchronous forms of interaction, thereby reducing the effects of production blocking.

Evaluation apprehension: In the design meetings we observed it was impossible for a member of the group to express an idea without being identified with it. There was no means for the anonymous expression of ideas as recommended by previous research as a way of reducing the effects of evaluation apprehension [e.g. Diehl & Stroebe, 1987]. However, some group members reduced the possibility of being criticised by others by working through an idea on their own. There were occasions when a member of the group sketched a design idea on a pad of paper in their own personal space out of the view of others and then moved the sketch to the centre of the table when satisfied with it, where other members of the group could see the design. Similarly, Tang & Leifer [1988], has observed the migration of externalisations from one's private space into a shared space. Figure 4.12 illustrates this.

Therefore, based on this findings, we recommend providing members of a group with privacy, thereby supporting individual work away from *prying eyes*. Hence, another requirement for CST is:

Requirement 14: CST should support individual/private interactions, thereby reducing the effects of evaluation apprehension.

Previous research has also recommended removing one's identify with an idea to reduce the effects of evaluation apprehension [e.g. Diehl & Stroebe, 1987]. If an individual can not be identified with an idea, they can not be criticised by others. Hence, a requirement for CST is:

Requirement 15: CST should support the removal of a user's identity from their ideas, thereby reducing the effects of evaluation apprehension.

Free riding: It was frequently observed that at least one member of the design team did not contribute as much as their colleagues. Some researchers [e.g. Diehl & Stroebe, 1987] have recommended making individuals accountable for their own performance, rather than being able to hide amongst the productivity of the group. Similarly, others research [e.g. Paulus & Dzindolet, 1993] have recommended providing comparison standards to increase individual performance. While such recommendations may promote the productivity of lazy group members, our observations identified the appearance of members free-riding as the result of shy personalities or

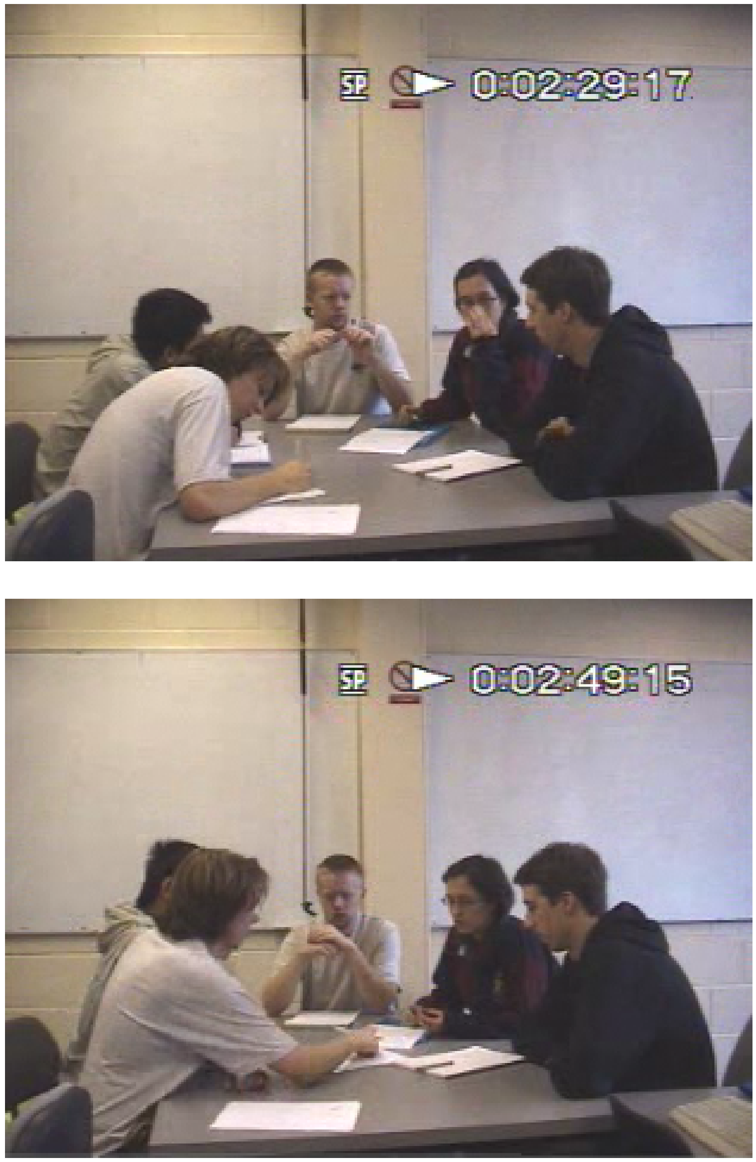


Figure 4.12: Moving an externalisation from a private to a public space.

cultural differences. For example, in one design meeting a member of the group was quite a shy person. A topic of discussion indirectly related to the meeting ‘opened up’ the shy member of the group, as he knew something about the subject matter and could contribute to that discussion. The result of this conversation increased his participation in the design meeting and caused other members of the group to ask his opinion more. Ethnicity differences were also common in the groups, with members coming from around the globe. Those from minority ethnicities were often less productive than members of the group from the same ethnicity. Those groups who encouraged and asked the opinion of the members from different ethnic backgrounds within the group increased their participation in the design meeting.

Although the effects of personality types and ethnicity/culture on collaborative creativity are outside the scope of this research (this is a body of research within itself [Arieti, 1976]), we argue from these observations that active encouragement can reduce the apparent effects of free-riding in groups. However, to remain consist with previous research [e.g. Diehl & Stroebe, 1987; Paulus & Dzindolet, 1993] a requirements for CST is:

> **Requirement 16: CST should make individuals accountable for their own productivity, thereby reducing the effects of free-riding.**

Controlling social influences is necessary for promoting creativity, as the effects of production blocking, evaluation apprehension and free riding have been shown to be detrimental to social creativity. In order to control social influences we need to provide CST that allow for synchronous forms of interaction - to control production blocking; remove identification with one's ideas and support groups members privacy - to control evaluation apprehension; and make individual's accountable for their own productivity and provide a supportive and encouraging working environment - to control free-riding.

4.2.3 Conclusions of the field-based observations

Our field-based observations aimed to acquire contextually rich information from the design process, deepening our understanding of creativity in the design phase of the software development process. We achieved this by observing 12 groups, each during one of their design meetings. From the analysis of the videos we reported our findings: a refined understanding of the creative process of design; types of interactions used in design meetings; the use of externalisations; the changing compositions of groups; and the occurrence of social influences. Building upon the requirements identified from our diary study, we were able to generate additional and refined requirements for CST.

Section 4.2.2.1 refined our understanding of the creative process of design. Building upon the three phases of the creative process identified in chapter 2 (see section 2.2.3.1) - problem framing, idea generation and idea evaluation - we refined our understanding of idea generation to include two sub-phases, namely new and refined idea generation. Furthermore, we identified the new phase of idea framing, which is particularly relevant to the collaborative creative process, where you need to understand ideas generated by others.

In section 4.2.2.2 we showed the importance of different types of interactions between members of a group and the artefacts they used during the creative process of design. The groups created externalisations, such as sketches, annotations and textual representations allowing knowledge to be framed, ideas generated, ideas framed and those generated ideas evaluated. These externalisations complemented the verbal communication of the group, providing a permanent record of what had been said during the design meeting and presented an artefact that could be referred to through pointing and gesture interactions. Hence, five requirements identified for CST were:

Requirement 5: CST should support the creation of sketches.

Requirement 6: CST should support the annotation of sketches.

Requirement 7: CST should support the creation of text.

Requirement 8: CST should support users' pointing interactions with externalisations.

Requirement 9: CST should support users' gesture interactions with externalisations.

Section 4.2.2.3 built upon section 4.2.2.2 reporting findings on the use of externalisations. We showed in this section that externalisations were important throughout the phases of the creative process. For example, hand-outs for problem framing; sketches for idea generation; and prototypes for idea evaluation. Due to the importance of paper during the design process in section 4.3 we observe the use of paper for creating and disseminating externalisations to specify requirements building upon the affordances of paper.

In section 4.2.2.4 we observed that the varying sizes of interaction spaces created by the artefact used, enabled and constrained the collaborative activities of the group. Small interaction space were particularly useful for individual activities and not collaborative activities. While large interaction spaces were suitable for group activities. Therefore, we refined requirements 3 and 4:

Requirement 3 (refined): CST should support individual activities using small interaction spaces.

Requirement 4 (refined): CST should support group activities using large interaction spaces.

During our field-based observations of the design meetings we saw the groups engage in individual, sub-group and group activities. Furthermore, we observed the various group compositions extending beyond the meeting room, where team members delegated individual and sub-group tasks. Building upon requirements 3 and 4 reported in Section 4.1, three further requirements for CST were:

Requirement 10: CST should support sub-group activities.

Requirement 11: CST should support the transitions between individual, sub-group and group activities.

Requirement 12: CST should support creative activities beyond the meeting room.

Finally, in section 4.2.2.5 we showed how the effects of production blocking, evaluation apprehension and free riding can have detrimental effects on social creativity. Hence, we identified four requirements to support the control of these social influences:

Requirement 13: CST should support synchronous forms of interaction, thereby reducing the effects of production blocking.

Requirement 14: CST should support individual/private interactions, thereby reducing the effects of evaluation apprehension.

Requirement 15: CST should support the removal of a user's identity from their ideas, thereby reducing the effects of evaluation apprehension.

Requirement 16: CST should make individuals accountable for their own productivity, thereby reducing the effects of free-riding.

4.3 Lab-based observations

During the field-based observations, we saw that the use of externalisations was essential during the creative process of design. The groups would use paper, blackboards and electronic media to facilitate their creative process, where paper was the most commonly used medium. To further understand the creation, use and dissemination of externalisations we conducted a number of controlled lab-based observations. We observed the use of paper for creating externalisations, how the tools participants were given were used (e.g. a pencil) and generally we wished to understand the process of externalising design ideas. Having shown the creative process to involve both individual and collaborative activities (see section 4.2.2.4), we were interested in observing both individuals and a pair of individuals collaborating together while externalising design ideas.

4.3.1 Method

Our lab-based observations involved 12 participants performing an individual creative task. In addition to this, 6 pairs of participants performed a collaborative creative task. Interactions amongst the participants and the artefacts they used were captured using two digital video cameras for post-analysis. A questionnaire was also given to the participants at the end of the study to complement the video data.

4.3.1.1 Participants

12 participants took part in these observations - 6 males and 6 females. The participants varied in age from 19 to 31, with a mean of 21.18 years. All participants were either undergraduate or postgraduate students from a variety of disciplines at the University of Bath. The participants were recruited via mailing lists and volunteered to participate in the lab-based observations.

4.3.1.2 Materials

On each participant's desk was a pile of plain, white A4 paper, an HB pencil, a pencil sharpener, an eraser and a ball-point pen (see figure 4.13). During the collaborative sketching task, each participant had access to their own set of materials.

To capture interactions with the artefacts and interactions between participants in the case of the collaborative creative task, two digital video cameras on tripods were used. During the individual creative task a digital video camera would record the participant's working area with the participant in view. During the collaborative

a) b)

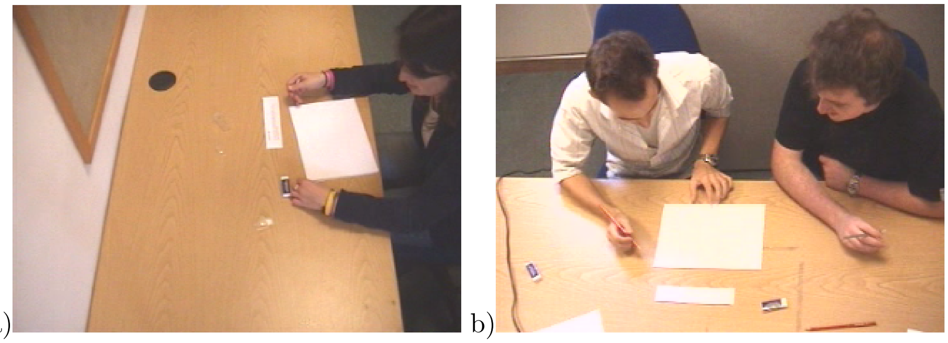


Figure 4.13: The (a) individual; and (b) collaborative lab-based observations set-up.

sketching task one digital video camera would capture the collaborative drawing area and the second digital video camera would capture a wide angle view of both participants and their interactions.

4.3.1.3 Procedure

Participants were run in pairs in a sound-proof usability lab. At the outset, participants were asked to take a seat, each at their own desk, located at opposite ends of the room from each other, facing opposite directions. Once seated, the instructions for the study were read aloud from a script by the observer.

> *This study is designed to gain an understanding of the process of idea generation, both individually and collaboratively.*
>
> *During this study you will be asked to first work alone for ten minutes, generating potential ideas to a given problem. Upon the completion of this task you will be paired up to collaborate on another task, which will involve spending a further ten minutes generating potential ideas with your partner to a given problem.*
>
> *For each of these tasks you may use the materials provided: the plain A4 paper, the pencil, the pencil sharpener, the eraser and the ball-point pen.*
>
> *If you have any questions, please ask the observer before you begin the tasks. You may not ask the observer any questions once you have begun the task.*

The observer then asked the participants if they had any questions and answered them to the best of his abilities. Once observer and the participants were satisfied, the observer gave each participant a slip of paper on which the individual creative task was written. The observer also read aloud the task.

> *You are a member of a Hollywood film production company. You have been asked to sketch some initial ideas of a scary monster for a new animated horror film.*

Once again the observer asked the participants if they had any queries and dealt with them to the best of his ability. Once the observer and the participants were satisfied, the observer informed the participants they had ten minutes to generate their ideas for the task.

Upon the completion of the ten minute time period, the observer informed the participants to stop what they were doing and remain seated. The observer then collected the paper the participants had used. Upon all the paper being collected, the observer asked the participants to sit together at a desk and rearranged the digital video cameras to get a top-down view of the area the participants would use and a wide angle view capturing the interactions between the two participants. The observer then gave each participant a slip of paper on which the collaborative creative task was written. The observer also read aloud the task.

> *You are a pair of designers working for a major car company. You have been asked to sketch some initial ideas of features for a car of the future.*

Before commencing with the collaborative task the observer asked the participants if they had any queries and answered them as best he could. When both the observer and the participants were satisfied, the observer informed the participants they had ten minutes to collaboratively generate their ideas for the task.

When the participants had completed ten minutes of collaboratively generating ideas, the observer informed the participants to stop what they were doing and remain seated. The observer then collected the paper the participants had used. The observer then concluded by handing each participant a questionnaire (see appendix C).

4.3.2 Findings

The findings we report here are drawn from a foci analysis [Jordon & Henderson, 1995] of the individuals and collaborating pairs generating ideas. Specifically, we were interested in how the paper was used to externalise ideas. (An excerpt of the foci analysis can be found in appendix C.) These data are complemented by the data from the questionnaire, which was administered to each participant at the end of the study. We present our findings, focussing on the materials used and the participants' use of these materials to understand the process of externalising generated ideas. In the following sub-sections we extract and discussed example foci from the video data, eliciting requirements for CST..

4.3.2.1 The process of externalising generated ideas

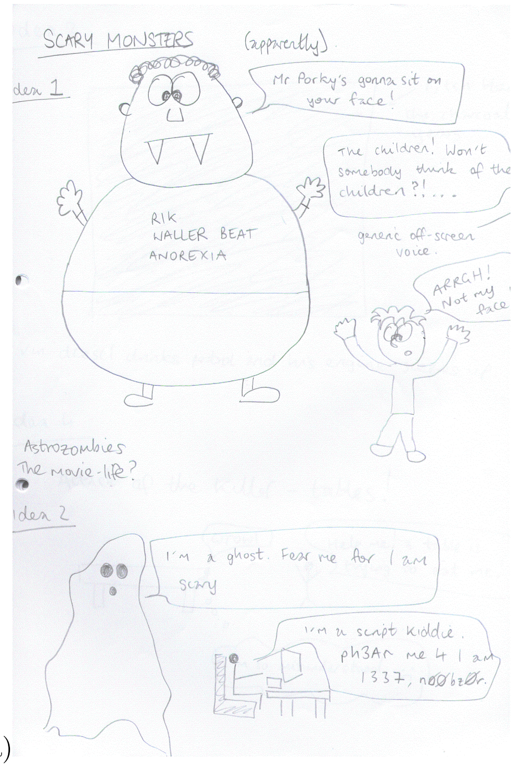
Each participant started the creative tasks with a single piece of A4 paper in front of them, a pencil in their hand, and the other material and tools (i.e. the pile of A4 paper, the pencil, sharpener, the eraser and the ball-point pen) positioned off to the side of their working area. When externalising an idea, only one tool (e.g. the pencil) was used at a time. When another tool was to be used (e.g. the eraser), the current tool would be put to one side and the new tool would then be used. Unused items were not left on the paper itself. This observation is illustrated in figure 4.13.

This process of using and switching between tools differs from many existing tools designed for creating externalisations (e.g. Adobe Photoshop and Illustrator), which use floating toolbars. These menus and toolbars provide the user with available functionalities (e.g. a pencil tool, an eraser tool, etc). However, they usually float over the solution space (i.e. the canvas). This can result in the user being obstructed when creating an externalisation, requiring them to remove the obstruction by moving the floating toolbar.

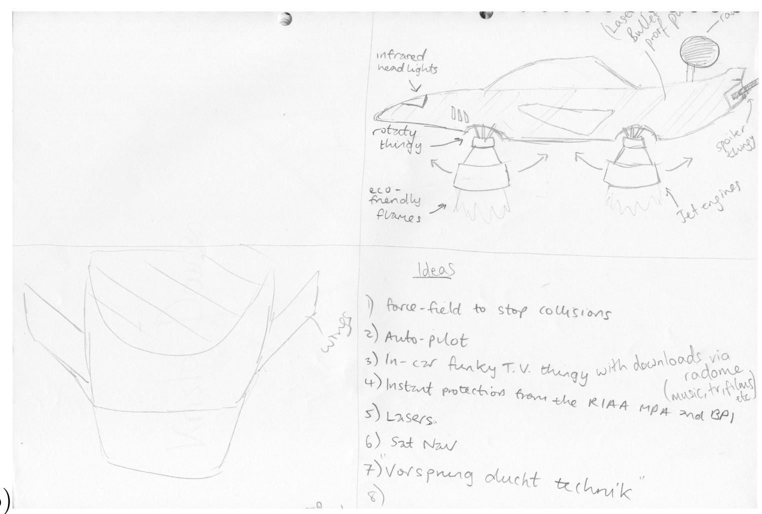
Obstructing objects could interrupt the process of externalising one's ideas. Hence, a requirement for CST is:

> **Requirement 17: CST should provide users with an unobstructed solution space.**

When sketching a generated idea, the A4 piece of paper would be either positioned portrait or landscape, depending on what the participant intended to sketch. For example, a horizontally dominant sketch (e.g. a car) would require the paper to be landscape, while a vertically dominant sketch (e.g. a tall monster) would require the paper to be portrait. Figure 4.14 illustrates this.



a)



b)

Figure 4.14: Two example externalisations from the lab-based observations: (a) a scary monster; and (b) a futuristic car.

In addition to the orientation of the paper, most participants had the paper at approximately a 45 degree angle to their body. Participants would frequently move the paper, depending on where on the paper they were externalising an idea. This could involve moving the location of the paper, or rotating the paper. Figure 4.15 provides an example of paper being rotated.

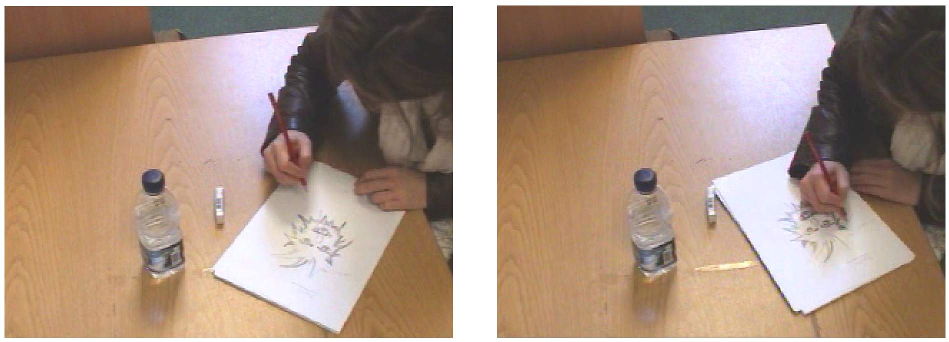


Figure 4.15: An example of rotating paper when externalising an idea.

Although not as common, another approach was for the participant to move their own body around the paper itself. This reorienting and repositioning of the paper facilitated the participants when creating and viewing externalisations. Therefore, a requirement for CST is:

> **Requirement 18: CST should allow users to change the orientation and position of an externalisation and/or the CST.**

When working individually, sketches were used to visualise one's ideas. In some cases participant's complemented their sketches with annotations and text. Figure 4.14 presents an example externalisation from one of the lab-based observations. This observation confirms our requirement for CST to provide multiple representations - sketches, annotations, text - for externalising ideas (Requirement 5, 6, 7).

The approach to sketching an idea happened in one of two ways. Participants would either sketch the entire outline of the idea and then add detail within the outline. Alternatively, participants would work on one section of a sketch at a time - draw an outline, add detail and then move onto the next section. The outline stroke were light, long pencil strokes. While detail was added using hard, short pencil strokes. Alternating the angle of the pencil also gave different visual effects, which were utilised when adding detail to a sketch. Adding detail to a sketch was a means of refining it. This observation provides supportive evidence for CST to support the refinement of ideas (Requirement 2).

The way in which the paper was used varied between participants. In the majority of cases a single idea was presented on a single sheet of paper. These ideas would be quite refined, as the participant would roughly sketch the outline of their idea and then spend time on refining the detail. Multiple ideas were also presented on a single sheet of paper if there was sufficient room. Multiple sheets of paper were also used to present different ideas or were used when the space on one sheet had been used. Furthermore, participants scaled their sketches to fill either the width or height of the paper. This description is intended to illustrate the flexibility in which externalisations were created. As such, a requirement for CST is:

> **Requirement 19: CST should not constrain the ways users externalise their ideas.**

For example, CST should not prevent users from externalising multiple ideas on a single canvas. As argued by Guindon [1990, p.341], 'The environment should not embody a method that locks designers into a strict order of activities. A strict order of activities may hinder the opportunistic insights critical in discovering the proper design decomposition... not imposing a predetermined order of activities'. Similarly, Candy & Edmonds [2000] argue that CST should provide its users with a degree of flexibility, giving the user the locus of control.

Many of our observations of individuals sketching have led us to identifying specific requirements for CST than those generated in our diary study and field-based observations. In the next section, we further specify requirements through our observations of the collaborative creative tasks.

4.3.2.2 The collaborative process of externalising generating ideas

We now describe the collaborative creative process for externalising an idea and the differences compared to the individual creative process.

During the collaborative creative process a piece of paper that was located in between the participants with no bias on the orientation of the paper towards a particular participant. This allowed for equal access to the paper. Figure 4.13b illustrates this. CST should be able to be positioned between collaborating participants, thereby creating a shared interaction space. This support is specified through requirements 4 and 18. Requirements 4 specifies that large interaction spaces are suitable for group activities, thereby providing multiple users with access to a CST. Furthermore, requirement 18 specifies that users should be able to change the position of CST, which could be done to create a shared interaction space. For example, as with the paper, moving a CST in between two participants would create a shared interaction space, allowing both users to interact with it.

During individual creative tasks, individuals internally reflect on their externalisations [Coughlan & Johnson, 2006; Goldschmidt, 1991; Schön, 1983; Schön, 1992]. Collaborative idea generation involved verbally communicating with one's collaborator. Ideas were either verbally described to the collaborator, establishing a shared understanding of an idea before it was externalised on paper. Or, an idea would be externalised immediately and then described to one's collaborator. It was also common for participants to talk to their collaborator about what they were doing while they were externalising an idea. These approaches to externalising ideas allowed for pre-, post-, and during- shared understanding of externalisations to be developed.

In addition to the act of sketching ideas, annotations, pointing and gesture interactions played a big part in the collaborative creative process and facilitating a shared understanding between participants. During an individual creative task an individual knows what they have drawn and why. However, during a collaborative creative task, each participant has only partially contributed to an idea. Annotating the sketch allowed a permanent framing of the idea to be established. For example, drawing an arrow to the door of the car and writing at the end of the arrow, 'This door opens upwards'. Pointing allowed an externalisation to be referenced, complementing one's verbal communication. For example, pointing to the car door and saying, "how does this work?" allowed the other person in the group to understand their collaborator was asking 'how does the car door works'. Finally, gesturing acted as a means of adding context to an otherwise static sketch. For example, pretending one's hand was the car door and gesturing the car door opening illustrated how the car door worked in practice. Annotations, pointing and gesturing were important techniques in establishing a shared understanding during the collaborative sketching process.

Supporting this collaborative creative process has been specified in our requirements identified during the field-based observations. Our lab-based observations have verified the need for these requirements. Re-iterating requirements 5, 6 and 7, CST should provide multiple representations - sketches, annotations and text - for externalising ideas allowing for shared understandings to be developed. These externalisations provide a permanent record of the groups verbal communications. Furthermore, these externalisations facilitate pointing and gesture interactions enhancing a group's shared understanding (Requirement 8 and 9).

Participants externalised their ideas asynchronously the majority of the time. On some rare occasions both participants would use the paper at the same time. However, when this happened the participants would only create an externalisation on the side of the paper closest to them. If a participant did start moving closer to another participant, the participant who was being moved towards would withdraw. Figure 4.16 demonstrates two participants using the paper at the same time to create an externalisation.

Figure 4.16: An example of participants simultaneously creating an externalisation.

As argued in chapters 2 (see section 2.3.3.1), synchronous forms of interactions (e.g. multiple inputs) can reduce the effect of production blocking. Building upon requirement 13 to support the control of production blocking, a further requirements for CST is:

Requirement 20: CST should support multiple inputs, thereby reducing the effects of production blocking.

4.3.3 Conclusions of the lab-based observations

The lab-based observations aimed to complement and build upon our diary study and field-based observations, providing a deeper understanding of how ideas were externalised, both individually and collaboratively. From the analysis of the videos and the questionnaires we reported how ideas were externalised during individual and collaborative creative tasks, thereby eliciting requirements for CST.

Existing CST, such as Adobe Photoshop use floating toolbars providing access to the tool's available functionalities. However, a findings from our lab-based observation was that participants kept the paper clear of unused tools. Obstructing objects (e.g. floating toolbars) could interrupt the process of externalising one's ideas. Hence, a requirement for CST was:

> **Requirement 17: CST should provide users with an unobstructed solution space.**

Paper is a very flexible tool. As observed during the individual and collaborative creative tasks, individuals and collaborating pairs could re-position and orient the paper as they wished. Individuals on occasions would even re-position themselves around the paper. Hence, a requirement for CST was:

> **Requirement 18: CST should allow users to change the orientation and position of an externalisation and/or the CST.**

Despite the similarities in the ways paper was used to externalise ideas, there were also a number of differences. Participants would use the paper to represent a single externalisation or multiple externalisations; and this ranged from the use of a single sheet of paper to multiple sheets of paper. This illustrated the flexibility provided by paper for externalising one's ideas and was a property that should be captured by CST. As such, a requirement for CST was:

> **Requirement 19: CST should not constrain the ways users externalise their ideas.**

Two important interactions for promoting a shared understanding during collaborative tasks were pointing and gesture interactions. Pointing allowed externalisations to be associated with one's verbal communications. Gesturing allowed context to be added to an otherwise static externalisation. The shared interaction space of the paper between the participants provided an accessible interactions space for pointing and gesturing interactions. This complements requirements 8 and 9 reported in the field-based observations.

Building upon requirement 13 to support the control of production blocking, our lab-based observations observed participants simultaneously creating externalisations on the paper. The synchronous interactions were a way of overcoming the effects of production blocking (i.e. turn taking). Therefore an extension of requirement 13 was:

> **Requirement 20: CST should support multiple inputs, thereby reducing the effects of production blocking.**

4.4 Summary

In this chapter we have reported three studies aimed at deepening our understanding of creativity in design, enabling us to identify requirements for CST. These studies aimed to address our second RO, eliciting a set of requirements for CST (RO2).

First, we presented a diary study which gathered information about the occurrence of idea generation across the software development process. We analysed the number of ideas generated across the software development process; the types of ideas generated - new and refined ideas; the number of ideas generated by individual and group; and the relationship between the types of ideas generated and who they were generated by.

Secondly, we focussed on the most highly creative phase of the software development process, namely the design phase. We reported our findings from our field-based observations of design meetings. From our observations we were able to build upon our theoretical understanding of the process of creativity. In addition to the phases of problem framing, idea generation and idea evaluation, we identified a phase of idea framing, which is particularly important to collaborative creativity where group members build up an understanding of the generated ideas. As with the diary study, we also documented the occurrence of the generation of new and refined ideas during the idea generation phase of the creative process. Furthermore, we were able to identify and refine requirements for CST by observing the way the groups interacted, the use of externalisations, the composition of the groups and the occurrence of social influences.

Finally, we refined our understanding of creativity in design by conducting lab-based observations. The lab-based observations allowed us to observe the occurrence of creativity in design, while in a controlled environment. In this study we observed the way participants created externalisations both individually and collaboratively, building upon the affordances of paper.

Based on our findings from these studies we identified 20 requirements for tools to support creativity in design. These requirements map to our high-level requirements for supporting creativity in design identified in chapter 2 (see section 2.3.4). A complete list of requirements for tools to support creativity in design as identified by our studies is as follows:

High-level requirement 1: Support the creation and dissemination of externalisations to support the phases of the creative process.

Requirement 1.1: CST should support the creation of sketches.

Requirement 1.2: CST should support the annotation of sketches.

Requirement 1.3: CST should support the creation of text.

Requirement 1.4: CST should support users' pointing interactions with externalisations.

Requirement 1.5: CST should support users' gesture interactions with externalisations.

Requirement 1.6: CST should support the generation of new ideas: divergent thinking.

Requirement 1.7: CST should support the refinement of ideas: convergent thinking.

Requirement 1.8: CST should not constrain the ways users externalise their ideas.

Requirement 1.9: CST should provide users with an unobstructed solution space.

Requirement 1.10: CST should allow users to change the orientation and position of an externalisation and/or the CST.

High-level requirement 2: Support the various compositions of a group using appropriately sized interaction spaces.

Requirement 2.1: CST should support individual activities using small interaction spaces.

Requirement 2.2: CST should support sub-group activities.

Requirement 2.3: CST should support group activities using large interaction spaces.

Requirement 2.4: CST should support the transitions between individual, sub-group and group activities.

Requirement 2.5: CST should support creative activities beyond the meeting room.

High-level requirement 3: Support the control of social influences.

Requirement 3.1: CST should support synchronous forms of interaction, thereby reducing the effects of production blocking.

Requirement 3.2: CST should support multiple inputs, thereby reducing the effects of production blocking.

Requirement 3.3: CST should support the removal of a user's identity from their ideas, thereby reducing the effects of evaluation apprehension.

Requirement 3.4: CST should support individual/private interactions, thereby reducing the effects of evaluation apprehension.

Requirement 3.5: CST should make individuals accountable for their own productivity, thereby reducing the effects of free-riding.

With this set of requirements established, we wish to see how they apply to existing CST. Such a review of existing CST based on our requirements allows us to: verify those requirements already supported by existing CST; refine our requirements based on our findings from the evaluation of existing CST; and critique CST where they have not met our requirements. In the following chapter we review and critique a number of CST and report an evaluation of one such CST: the Envisionment and Discovery Collaboratory (EDC).

Chapter 5

Creativity in Design: A Tools Perspective

In chapter 4 we conducted a diary study and a number of field-based and lab-based observations, to build up a detailed understanding of how to support creativity in design and identify requirements for CST. This chapter aims to address our third RO allowing us to reflect upon and refine our requirements for CST (RO3). We achieve this by first reviewing and critiquing a number of existing CST, which include the EDC, Caretta and the i-LAND environment. We then focus on one of these tools - the EDC - applying our requirements for CST as a framework (i.e. a set of heuristics) for evaluation.

In section 5.1 we consider how to support creativity from a tools perspective, reviewing and critiquing the EDC, Caretta and the i-LAND environment.

Section 5.2 provides a high-level overview of the EDC evaluation.

Section 5.3 specifies the evaluation methodology, including information on the participants, a detailed description of the EDC and other equipment used, and the procedure of the evaluation.

In section 5.4 we report the findings from the evaluation. Our findings are presented in three sub-sections based upon our three high-level requirements for supporting creativity: the support and use of externalisations to support the creative process, the support of group compositions and the control of social influences.

Finally, section 5.5 summarises the evaluation, presenting and reflecting upon our requirements for CST accumulating our findings from chapters 4 and 5.

5.1 A review of existing creativity support tools

Many design environments have been designed and developed over the years [e.g. Alborzi *et al*, 2000; Arias *et al*, 2000; Buur & Bødker, 2000; Fischer, 1999a; Gross & Yi-Luen Do, 1996; Klemmer *et al*, 2001; Landay & Myers, 1995; Lin *et al*, 2002; Nunamaker *et al*, 1991; Stefik *et al*, 1987; Streitz *et al*, 1999; Sugimoto *et al*, 2004; Twidale *et al*, 1993], yet relatively few of them have explicitly focussed on supporting creativity [e.g. Arias *et al*, 2000; Fischer, 1999a; Nunamaker *et al*, 1991; Streitz *et al*, 1999; Sugimoto *et al*, 2004]. In this section we focus on a review and critique of three tools that have been explicitly designed to support creativity - the EDC [Arias *et al*, 2000], Caretta [Sugimoto *et al*, 2004] and the i-LAND environment [Streitz *et al*, 1999]. Each of these CST supports creativity in design differently. The EDC supports the design process as a group activity; Caretta supports personal and shared spaces throughout the design process; and i-LAND supports individual, sub-group and group design activities.

The EDC is a computerised tool for supporting social creativity. The main goal of the EDC is to 'support social creativity by creating shared understandings among various stakeholders, contextualising information to the task at hand, and creating objects-to-think-with in collaborative design activities' [Fischer, 1999a, p.100]. More specifically, Fischer [1999b, p.119] argues the EDC was designed to support stakeholders in '(1) creating and capturing knowledge in the context of collaborative design activities; (2) sustaining the timeliness and utility of evolving information; (3) articulating their own knowledge in a form that other people can understand; (4) enhance existing knowledge with new knowledge; and (5) creating tools that help stakeholders think, and help analyse their constructions and artefacts'. While the EDC can be applied to many collaborative activities, its test bed domains have been urban design and decision-making.

The current implementation of the EDC (see figure 5.1) comprises a projected image on a table that can be manipulated via physical objects (i.e. Radio-frequency identification (RFID) tagged wooden blocks on a grid structure embedded in the table) and an ultrasonic sketching tool, allowing boundary objects (e.g. sketches) to be created and evolve, thereby facilitating shared understandings between the users of the EDC.

Caretta is a similar environment to the EDC, with the exception that it extends the shared interaction space to account for personal space. Caretta allows stakeholders to discuss and negotiate around the shared space by manipulating physical and virtual objects, while providing the opportunity to examine ideas in their own personal spaces. Like the EDC, Caretta is applicable to many collaborative tasks, but uses the activity of urban design as its test bed.

Figure 5.1: The Envisionment and Discovery Collaboratory.

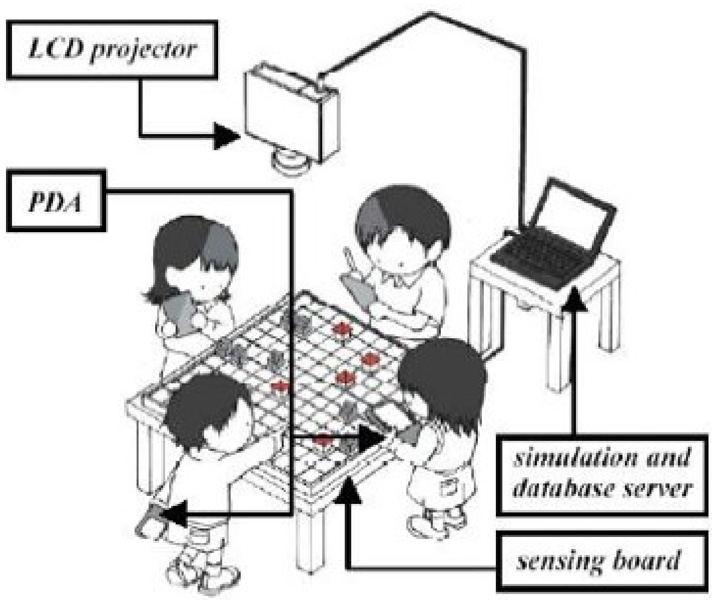


Figure 5.2: Caretta.

Caretta consists of a sensing board, a simulation and database server, an LCD projector and a number of PDA (see figure 5.2). The hardware exchanges data through a wireless network. The shared space takes the form of a sensing board that allows users to manipulate physical objects through the use of RFID tags. The personal space takes the form of a PDA, which can be synchronised with the shared space. Upon bringing the PDA in contact with the shared space, the visualisation on the PDA is updated with that of the shared space. This allows users to work in their own personal space at their own pace, while cooperatively working in the shared space and smoothly transitioning between the two.

The i-LAND environment is a vision for future work spaces supporting the cooperative work of dynamic teams with changing needs. The i-LAND environment achieves this through the integration of architectural and interaction spaces. The i-LAND environment has primarily been used for brainstorming and project management.

Figure 5.3: The i-LAND environment.

The i-LAND vision has been implemented through the use of several roomware components [Streitz *et al*, 1997; Streitz *et al*, 1999; Streitz *et al*, 2001]: DynaWall, InterTable, ConnecTable and CommChair. Each roomware component runs a software application for producing hypermedia concept maps using text and scribbles [Streitz *et al*, 1999]. The use of these different roomware components provides different interaction spaces supporting the various group compositions of a design team - individual, sub-group and the entire group compositions [Streitz *et al*, 1999].

5.1.1 A critique of existing creativity support tools

The EDC [Arias *et al*, 2000], Caretta [Sugimoto *et al*, 2004] and the i-LAND environment [Streitz *et al*, 1999] have been developed to support creativity in design. We critique these support tools is two ways. First, for the most part, these environments do not build upon the theoretical work on creativity discussed earlier in this thesis. Secondly, and not surprisingly, these support tools do not support or only partially support our three high-level requirements for supporting creativity in design based upon the theoretical work on creativity.

The EDC, Caretta and the i-LAND environment have been developed largely on the basis of practical experience. The EDC was developed following observations of architects and city planners engaging in urban design activities [Arias *et al*, 2000]. Caretta was developed following several studies that showed effective collaboration requires the support of both individual and group activities [e.g. Gutwin & Greenberg, 1998]. The i-LAND environment, similar to Caretta, was developed based on observations and empirical evidence showing that when groups engage in a balanced proportion of individual, sub-group and group activities, collaboration is most effective [Streitz *et al*, 1997].

However, there has been a recognition of the need for theory in the development of such systems [e.g. Candy & Edmonds, 2002; Kiesler *et al*, 2004]. While acknowledging the importance of practical experience, these environments which aim to support creativity in the design process have not built upon the wealth of theoretical work on creativity, as discussed in chapter 2 (see section 2.2) [e.g. Amabile, 1983; Boden, 1994; Diehl & Stroebe, 1987; Guilford, 1950; Lamm & Trommsdorff, 1973; Mullen *et al*, 1991]. Despite this criticism, it should be acknowledged that through the use of such CST, much valuable research has informed our understanding of creativity and its future support: particularly with regards to the EDC [e.g. Fischer, 2004; Fischer *et al*, 2004; Fischer *et al*, 2005].

A second criticism of these CST is their support of various representations. In early versions of the EDC, physical blocks were used to 'stamp' (i.e. change the colour of) a square in a grid, which had some representational meaning. For example, using the industry block would change a square to blue, identifying the land as industrial. In addition to identifying land types, blocks could also be used to draw bus routes in the grid squares. Similarly, Caretta had the same functionality, except on a PDA the stylus was used to manipulate the squares on the grid. The problem with this grid structure for creating externalisations is that it is very constraining - users are constrained to work within the structure of the grid. In later developments of the EDC a ultrasonic sketch pen was introduced to allow for the creation of free-hand representations. This provided more flexibility. A further criticism of the EDC and Caretta is that the environments focussed the users very much on the task of urban planning - creating land types and bus routes. This would constrain the user from creating other representations to the problem that may have been relevant (e.g. annotations). A final criticism of the EDC and Caretta is that they do not allow for multiple representations of externalisations to be created, as argued by van der Lugt [2002]. For example, it is not possible for textual representation to be created, complementing or extending the externalisations created through the RFID blocks and the ultrasonic sketch tool.

The i-LAND environment uses a software application called BEACH [Streitz *et al*, 1999] that builds upon their DOLPHIN environment [Mark *et al*, 1995]. Through the use of hypermedia, groups are able to create networks of ideas. Ideas form nodes that may be linked to other nodes. These nodes may consist of freehand drawings, text and links. These representations are used to create concept maps. Mark *et al* [1995] showed that the creativity of groups using hypermedia to create networks of ideas was greater than groups who created hierarchical structures of ideas. While this builds upon the GDSS research, its application to design is questionable. Concept maps provide a high-level overview of ideas and their relationship to other ideas. Whereas, in design, ideas are not limited to concept maps, but also involve the creation of design artefacts that embody design ideas [Fischer, 1999b].

A third criticism is the support of various group compositions and the transition between these compositions. The EDC supports users' creativity through a single interactive tabletop. This constrains the support of the various group compositions of a design team, as the group are forced to work as a full-group, without support for individual creative activities. (This is not to say individual creative activities does not happen when using the EDC.) However, various studies [e.g. Gutwin & Greenberg, 1999; Streitz *et al*, 1997] have shown that effective collaboration requires at least support of individual and group activities.

Caretta expands upon the EDC approach, providing a personal interaction space for each member of the design team through means of a PDA. However, a problem with Caretta is inherent in its development. Caretta supports only the transition from the shared space to personal space, not vice versa. Hence, an individual may go about developing an idea in her personal space, but if she wants to present the idea to other group members, she must either re-do the work in the shared space - if she can remember how - or present her idea on the PDA. The first solution is both ineffective and time consuming, while the second is impractical due to the size of the interaction space defined by the PDA [Kostakos *et al*, 2006]. While support is provided for individual and group activities, the transition between these activities is not supported by the software.

The i-LAND environment, expands further upon the EDC and Caretta supporting three different group compositions - individual activities (i.e. CommChair), sub-group activities (i.e. ConnecTable) and group activities (i.e. DynaWall and InteracTable). The i-LAND environment was built with the vision of technologies being integrated into our existing architectural environment [Streitz *et al*, 1999] - walls, tables and chairs, for example. However, the very act of integrating technologies into the existing architecture has created barriers between the interaction spaces. For example, a stakeholder working in the CommChair cannot be within the same interaction space as either the ConnecTable or the InteracTable. Thus, particular combinations of architectural spaces and technologies impose barriers between different interaction spaces. The hardware potentially inhibits the transition between the various group compositions. Caretta overcomes this problem by integrating personal and shared interaction spaces in the same architectural space. Rather than technologies being integrated into existing artefacts with established physical properties, the technologies themselves are physical objects with their own set of physical properties. Due to the mobility of the PDA, the personal interaction space can be moved in and out of the architectural and interaction space of the sensing board, thereby supporting the physical transition between the various compositions of the group.

A further criticism is the dissemination of data across these group compositions. Caretta, supports the creation of private and public externalisations, created using the PDA and tabletop respectively. The i-LAND environment further provides support for social externalisations that are created by sub-groups. Caretta allows users to synchronise the public view of the tabletop on their PDA, providing a private externalisations of a public artefact that may then be modified. The same does not happen vice versa. Therefore, public information can be made private, but private information can not be made public, unless the user intentionally recreates it on the tabletop. Using the i-LAND environment information could be accessed through the various roomware components. However, were these devices suitable for displaying private, social and public externalisations? Furthermore, was the dissemination of externalisations suitable across various levels of publication?

A final criticism of these CST are their control of social influences. The EDC with its tabletop only provides a single point of interaction. Therefore, the EDC is a complementary tool to one's verbal communication [Fischer & Ostwald, 2005]. This set-up does not remove the turn-taking effect (i.e. production blocking) by introducing technologies that could be used synchronously, as recommended by previous research [e.g. Prante *et al*, 2002; Valacich *et al*, 1994]. Furthermore, as groups using the EDC are forced to work in a whole group composition the entire time, the effects of evaluation apprehension are not controlled, as externalisations created using the EDC are always visible to the group, therefore identifying the user. However, groups using the EDC tend to be relatively small (e.g. approximately four users). As these users have to work in a group composition, it is relatively difficult for them to free-ride as their productivity is apparent to the group.

Unlike the EDC, Caretta provides an individual space for personal work, with the i-LAND environment providing additional support for sub-groups. This support of individual work mitigates the effects of production blocking. Using the available technologies each user can synchronously externalise their ideas. Furthermore, the support for individual activities is provided through private interaction spaces. This in turn reduces the effects of evaluation apprehension. Although, using Caretta to publicly disseminate an idea, an individual would have to identify themselves with their idea (i.e. the user would have to recreate the externalisation using the tabletop). However, through providing an personal workspace, an individuals' productivity is not made visible to the group, allowing potential free-riding.

These CST focus on particular aspects of supporting creativity - the EDC supports the creation and representation of boundary objects for disseminating knowledge, facilitating shared understandings; Caretta supports individual and group creative activity allowing for the effective support of collaboration within the group; whereas the i-LAND environment, extends the support of Caretta to support sub-group activities also. Yet, these environments do not build upon some of the theoretical work on creativity discussed earlier in this chapter. Therefore, by combining the lessons learned from the theoretical work conducted on creativity and the practical lessons learned from the environments described above, we can hope to better understand and support creativity in design.

5.2 The Envisionment and Discovery Collaboratory evaluation overview

The main aim of the EDC was to support social creativity by creating shared understanding among various stakeholders, contextualising information to the task at hand, and creating objects-to-think-with in collaborative design activities [Fischer, 1999a]. Through the use of video analysis and a questionnaire we aimed to evaluate the EDC with respect to our three high-level requirements for supporting creativity (see chapter 2, section 2.3.4) and their subsequent low-level requirements (see chapter 4, section 4.4). Drawing lessons from this evaluation of the EDC, we wished to identify the strengths and weakness of the EDC, suggesting improvements to the EDC and other CST, as well as allowing us to reflect upon and refine our requirements for CST.

5.3 Method

The evaluation involved seven groups of four participants, collaborating to decide on the future development of land-use and the development of new bus routes, including bus stops, for the Gunbarrel area of Boulder, Colorado. Interactions with the EDC and amongst the participants were captured for post-analysis through the use of two digital video cameras and Camtasia screen capture software. A questionnaire was also given to the participants after completing the evaluation, gathering data regarding the design of the EDC and the support it provided in facilitating creativity.

5.3.1 Participants

28 participants took part in the evaluation, forming 7 groups of 4. 16 of the participants were male and the other 12 were female. The participants varied in age from 20 to 57, with a mean of 33.25 years. All participants were from the Boulder area of Colorado, consisting of undergraduate students, postgraduate students, university staff and public sector workers. The participants were recruited from mailing lists, posters and word of mouth, volunteering themselves for the evaluation.

5.3.2 Equipment

The set up of the EDC can be seen in figure 5.1. The EDC is a square table, with a projected graphical image on the surface of the table, an embedded grid structure for detecting physical objects using RFID tags, and an eBeam ultrasonic sketching tool. The input from the physical objects and the eBeam device are fed back to a standard desktop PC, which outputs the resultant graphical image via a projector onto the table surface.

The projected graphical image displays a map, a tool menu and a sketch menu, which can be manipulated via the physical objects and the eBeam sketch tool. The tool menu, which was controlled via the Admin block (see below), allowed the user to select from three options: view a satellite image of the Gunbarrel area of Boulder (aerial option); view a road map of the area (map option); and a Hide option which toggled through the options of land use colouring being shown or hidden. The sketch menu, which was controlled via the ultrasonic pen, allowed the users to sketch on the map. When a new sketch was created, the user had the option to: minimise the sketch; bring the sketch to the top - if multiple sketches were present; and close the sketch. There was also a colour palette projected on the table, which allowed the users to choose a line colour and a fill colour using the ultrasonic pen. In addition to this, there was an erase option, which could be selected using the ultrasonic pen, which then allowed the users to select lines and filled shapes with the ultrasonic pen to erase them. The embedded grid structure in the table was used to detect the position of eight physical objects. Each object had a different function as noted below:

1. *Admin:* This was a selection block to be used on the tool menu. This block was used to change between the aerial, map and hide options.

2. *Single-family residential (Yellow):* This block placed a yellow square in the cell in which it was positioned on the map, indicating low-density housing, e.g. detached housing.

3. *Multi-family residential (Orange):* This block placed an orange square in the cell in which it was positioned on the map, indicating high-density housing, e.g. apartments.

4. *Agricultural (Brown):* This block placed a brown square in the cell in which it was positioned on the map, indicating farm land.

5. *Light industrial (Blue):* This block placed a blue square in the cell in which it was positioned on the map, indicating warehouses and small factories.

6. *Commercial (Red):* This block placed a red square in the cell in which it was positioned on the map, indicating shops and offices.

7. *Open Space/Parks (Green):* This block placed a green square in the cell in which it was positioned on the map, indicating open land suitable for walking, playing and relaxing.

8. *Remove:* This block removed a land-use type (blocks 2-7) and reset it to neutral, by placing the block on the cell containing a land-use type to be removed.

During the evaluation, audio-visual data was captured by two digital video cameras, one camera capturing a view looking down on the EDC, observing the users' interactions with the EDC; and the other camera capturing a wide view of the EDC and the participants, capturing data which may have been missed by the other camera. In addition to the two digital video cameras, Camtasia software captured the screen images on the PC running the EDC.

A notebook computer was also used to play a set of audio instructions to the participants before the evaluation started.

5.3.3 Procedure

Participants were run in randomly assigned groups of four. First the participants were asked to take a seat around the EDC while the pre-recorded instructions were played. (Participants could be seated or stand during the evaluative task.) Pre-recorded instructions were used to minimise the evaluator's contact with the participants. The pre-recordings gave an overview of the evaluation; an introduction to the EDC and its functionality; a practice task; and a description of the evaluation task. After each audio file the evaluator asked the participants if they had any questions and tried to answer them to the best of his ability. It was emphasised to the participants that we were evaluating the EDC and not its users. Creativity was never mentioned, as Amabile [1983] argues that participants' performance changes if they are aware that they are being assessed on creativity.

The functionality of the EDC was described to the participants via an audio recording. While the audio recording was playing, the evaluator demonstrated the described functionality in time with the recording, so the participants were provided with an audio-visual demonstration of the available functionality. A list of the available functionality as described in the audio recording was available on the wall next to the EDC and could be referred to by the participants at any time during the evaluation (see appendix D).

To make sure the participants were aware of the available functionality of the EDC, all participants engaged in a practice session. The evaluator read aloud the tasks one at a time from a script (see appendix D). When the participants completed the current task, the evaluator moved on to the next task, until all practice tasks were complete. The evaluator did not have to intervene during this process. If one person was confused about a particular task, the other participants in the group helped to clarify it.

After the participants had completed the practice tasks, the evaluator randomly handed each participant a slip of paper describing a persona, which they were asked to read in private. The EDC is a domain-oriented design environment, intended for real users to collaborate together on real world problems. We did not have access to real users to collaborate on a transportation and development task, and surrogate users lack motivation to engage in such a task as it is not a personally meaningful activity [Fischer *et al*, 2005]. Therefore, personas were used to inform semi-authentic users. The use of these personas increases the users' motivation as it makes the task more meaningful. Furthermore, personas allowed conflict to be built into the problem causing breakdowns, which Fischer [1999b] argues can lead to moments of creativity. Cross [2002] observed that creative design arises when there is a conflict to be resolved between designers high-level goals of the problem and the criteria of the desired solution. Additionally, while the participants were not "real" users, they all lived in Boulder, Colorado and the surrounding area. The issue of the future development of the Gunbarrell area of Boulder was a real issue the participants were aware of.

Before the evaluation task was played to the participants, the evaluator loaded the EDC image file as a starting point for the evaluation. The image file contained a pre-defined map with land-use types marked up, and sketches of an existing bus route and bus stops for the Gunbarrel area of Boulder displayed.

Once all participants had read their persona, the evaluator played the evaluation task description:

> *You are a group consisting of two residents, one developer and one city planner. You have come together to discuss the future development of the Gunbarrel area in Boulder.*
>
> *Resident (R1) - You live in the south-west area of Gunbarrel. A reason for you moving to this area was its location near the countryside. However, the area in which you live is a new residential development. As yet the local bus route does not serve your area, which makes getting into Boulder and to your place of work in the north-west difficult. You would like to see the bus route extended to your area to meet your transportation needs.*
>
> *Resident (R2) - You live in the north-east area of Gunbarrel. You enjoy taking your dog for a daily walk in the local farm land. However, for a long time now you have been unhappy with the position of the bus-stop outside your house. This causes your dog to bark when people are waiting for the bus and are getting off the bus, causing disruption to yourself and your neighbours. You would like to see the bus stop moved for a more peaceful life.*
>
> *Developer - Due to an increasing demand for residential, industrial and commercial property, you are looking to buy as much land as possible to meet the growing demands: any open space and agricultural land has*

the potential for development. You wish these new developments to tie into the existing infrastructure and have good transportation links into Boulder.

City Planner - You wish to have developments to increase the economy in Boulder. You realise the current bus route is old and inadequate, but areas which are not served by the current bus route do not have a high enough demand, therefore costs cannot be justified. You want the bus route or routes to serve the most highly populated areas for maximum profit. You also wish to position bus stops along the bus route or routes to best serve the Gunbarrel community.

The tasks for the group are as follows:

1. *Discuss and come up with ideas for the future development for the Gunbarrel area of Boulder: both land-type and transportation. You have an upper limit of 30 minutes for this task, unless the group finishes sooner and are happy.*

2. *Discuss the ideas generated in task one between the group and come up with a final solution for the future development of Boulder. You have an upper limit of ten minutes for this task, unless the group finishes sooner and are happy.*

A description of the evaluation task and personas as described in the audio recording was available on the wall next to the EDC and could be referred to by the participants at any time during the evaluation.

Once all questions had been dealt with by the evaluator, the cameras were set to record and the evaluation task began. The evaluator sat at a distance from the EDC, to remind the participants after 30 minutes that they had ten minutes left and should work towards a final solution if they had not already begun to do so. After 40 minutes the evaluator informed the participants that their time was up and asked them to draw to a conclusion. To conclude, the participants were asked to complete a questionnaire (see appendix D) to complement the video data captured.

5.4 Findings

The findings that we report here are based on an analysis of the video footage and post-evaluation questionnaires. This evaluation aimed to identify strengths and weakness of the EDC, suggesting improvements to the EDC and other CST, as well as allowing us to reflect upon and refine our requirements for CST. We present our findings using our three high-level requirements for supporting creativity elicited in chapter 2 (see section 2.3.4) as a framework (i.e. a set of evaluation heuristics).

> **High-level requirement 1: Support the creation and dissemination of externalisations to support the phases of the creative process.**
>
> **High-level requirement 2: Support the various compositions of a group using appropriately sized interaction spaces.**
>
> **High-level requirement 3: Support the control of social influences.**
>
>> **High-level requirement 3.1: Support the control of production blocking by providing synchronous forms of interaction.**
>>
>> **High-level requirement 3.2: Support the control of evaluation apprehension by anonymising one's externalisations.**
>>
>> **High-level requirement 3.3: Support the control of free-riding by making individuals accountable for their own performance.**

It was not the purpose of this evaluation to determine whether the EDC was 'better' than other tools supporting creativity in design (e.g. traditional design tools such as paper and pencils), nor was it plausible to do so. Nunamaker *et al* [1991, p.59], argue, 'As electronic meeting systems (EMS) and non-EMS groups can differ in so many ways (e.g. production blocking, media richness), this research will typically not involve a comparison between EMS and non-EMS groups, as there are too many potential differences (i.e. confounding variables) to draw conclusions'. Furthermore, information technologies have the ability to change the nature of group work making it dangerous to generalise outcomes and conclusions with group working without information technologies [Huber, 1990]. The same is true for comparisons between many CST. For example, there are a number of differences between the way the EDC, Caretta and the i-LAND environment were designed to support creativity, resulting in difficulties drawing conclusions as to whether one tool is 'better' than the others. For similar reasons, it has been recommended that qualitative investigations are conducted to explore a tools' support of creativity [e.g. Nunamaker *et al*, 1991; Shneiderman *et al*, 2006], as we have done here.

We could have evaluated the EDC using existing groupware heuristics [e.g. Baker *et al*, 2001; Baker *et al*, 2002]. However, just as Neilsen's [1993] heuristics are not applicable to groupware systems [Baker *et al*, 2002], groupware heuristics are not completely applicable to CST. However, it should be acknowledged that there is some overlap between Baker *et al*'s [2001; 2002] groupware heuristics and our own derived from our requirements reported in chapter 4 (see section 4.4). Appendix D reports the results of a heuristic evaluation of EDC using heuristics derived from our requirements for CST.

Our analysis of the video data encoded events based on foci and interaction analysis [Jordon & Henderson, 1995]. From the video data we recorded time stamps, the participants of interest (e.g. speaking), the interaction class (i.e. verbal communication), the interaction type (e.g. gesturing), group composition, the phase of the creative process, the occurrence of social influences and any comments/notes. (An excerpt from the encoded video data can be found in appendix D.) The lessons learned from this evaluation allowed us to identify strengths and weakness of the EDC, suggesting improvements to the EDC and other CST, as well as allowing us to reflect upon and refine our requirements for CST.

5.4.1 Supporting the creation and dissemination of externalisations

The EDC was designed to 'support social creativity by creating shared understanding among various stakeholders, contextualising information to the task at hand, and creating objects-to-think-with in collaborative design activities' [Fischer, 1999a]. Fischer [1999b] has argued that the creation and use of boundary objects (i.e. an externalisation created by one or more members of a group) [Bowker & Star, 1999] communicates and facilitates shared understanding between CoP, as described in chapter 2 (see section 2.3.1). This design goal partially maps to our first high-level requirement for supporting creativity in design - support the creation and dissemination of externalisations to support the phases of the creative process. Hence, in this sub-section we examine the support for and use of EDC artefacts (i.e. pre-defined externalisations presented by the EDC) and boundary objects (i.e. externalisations created by users of the EDC to communicate and facilitate a shared understanding) throughout the phases of the creative process.

Table 5.1 presents the mean (and SD) proportions for all seven groups for four types of interactions observed between participants and the EDC - verbal communication, the creation of boundary objects, interaction with EDC artefacts and the interaction with boundary objects - for each phase of the creative process. This data is not intended to make any precise statistical claims, but provide evidence for general trends complementing our qualitative data.

Table 5.1: Mean (and SD) % of interaction types across the phases of the creative process for all seven groups.

	% Verbal comm.	% Interaction with EDC artefacts	% Creation of boundary objects	% Interaction with boundary objects
Problem framing	62.18 (5.64)	34.97 (5.28)	1.15 (1.31)	1.70 (1.20)
Idea generation	39.65 (2.90)	27.62 (7.18)	21.19 (8.56)	5.61 (3.59)
New ideas	*36.62 (4.01)*	*28.89 (9.62)*	*28.74 (9.63)*	*1.67 (1.32)*
Refined ideas	*43.82 (4.60)*	*26.12 (7.31)*	*10.18 (7.42)*	*11.29 (9.41)*
Combined ideas	*55.56 (9.62)*	*0.00 (0.00)*	*0.00 (0.00)*	*44.44 (9.62)*
Idea framing	59.60 (2.36)	27.21 (6.65)	0.00 (0.00)	13.19 (6.58)
Idea evaluation	62.43 (8.21)	27.54 (4.49)	0.00 (0.00)	10.03 (6.99)

The support and use of externalisations differed across the phases of the creative process. We shall now consider each phase of the creative process in turn.

5.4.1.1 Problem framing

In the problem framing phase of the creative process, verbal communication was the primary form of interaction (62.18% of interactions) for externalising knowledge, while interacting with externalisations on the EDC was a major contributor of interactions (34.97%) acting as a secondary form of communication. Interactions with externalisations complemented the verbal interactions between participants, providing shared external representations grounded in the EDC. For example, a common occurrence across all the groups was the residents' informing the others in the group where they lived. This was achieved by pointing to their house on the map and verbally communicating to the group, "I live here". Baker *et al* [2001] refer to these pointing interactions as deictic references, which are used to support people's conversation and convey meaning. Without the EDC's provision of such an externalisation, this simple communication would have been considerably more complicated and prone to misunderstanding.

Only 1.15% of interactions during problem framing were due to the creation of boundary objects. For example, one participant used the sketch tool to show others "her area" on the map using her own notation. This raised the question: why did participants not generally create boundary objects to develop shared understandings during problem framing? In the example noted, while one participant claimed that such information was "valuable", the group decided to remove the boundary object to avoid confusion as it did not fit into the existing notation, which they were working with (i.e. open spaces denoted as green areas, commercial spaces denoted as red areas, etc). It may be the case that the pre-defined notation used by the EDC (i.e. EDC artefacts) constrained stakeholders' expressions of boundary objects. There is a possible conflict here with *Requirement 1.8*: CST should not constrain the ways the users externalise their ideas. In the questionnaire, participants commented that 'the EDC is rigid in its functionality; no room for altering methods to fit learning needs' and 'it felt like we really had to work around some of the aspects to get what we wanted'. Moving away from pre-defined notations would allow stakeholders to develop their own notations suitable for the group and the problem at hand. However, it should be acknowledged that pre-defined notations provided a certain amount of support for users (e.g. a framework to work within). There is a trade-off between the rigidness and flexibility provided by a CST. As argued by Ereback & Höök [1994, p.92], 'either a limited and structured but more powerful dialogue is imposed, or a free but possibly more inefficient dialogue is allowed'.

Interactions with boundary objects saw their lowest occurrence of use during the problem framing phase of the creative process (1.70% of interactions). As well as boundary objects not being created during the problem framing phase of the creative process, another possible explanation for the reduced interactions with boundary objects compared to EDC artefacts was that participants focussed more on framing the context of the problem. It was very common for participants to ask questions such as, 'what is this land type again?' Allowing participants to create such artefacts may have increased their shared understanding of the context of the problem, reducing the need for phases of problem framing when interacting with EDC artefacts. Hence, there is a trade-off here between system-defined contexts (i.e. EDC artefacts) and user-defined contexts (i.e. boundary objects).

Across all the groups, participants interacted with externalisations (e.g. pointing and gesture interactions) to extend their communication with the group beyond verbal communication. When participants interacted with externalisations (e.g. informing others of the current bus route), they typically continued the physical interaction after they had stopped their verbal communication to the group. While this gave others within the group the opportunity to express themselves verbally, the interaction with externalisations acted as a secondary communication medium. Participants also frequently interacted with externalisations before beginning their verbal communication, informing the group of something they wished to talk about. As argued by Tang & Leifer [1988], such pointing interactions and gestures can help mediate conversational turn-taking. Figure 5.4 and the associated transcript below illustrate this.

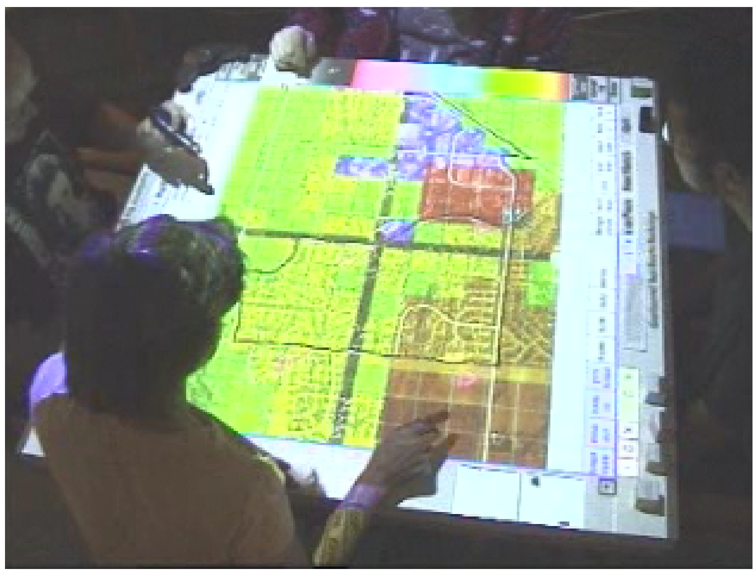


Figure 5.4: An example of pointing to extend one's verbal communication.

G1P3 (00:11:17) - "... we could put more commercial or industrial here [pointing with the ultrasonic sketch tool]"

G1P2 (00:11:19) - [points at the agricultural land]

G1P3 (00:11:23) - "Did you want to say something? [directed at P2]"

G1P2 (00:11:24) - "[P2 stops pointing at the agricultural land] Well... [P2 momentary points at the agricultural land again] I was just wondering about the agricultural land."

This use of interactions with externalisations allowed participants to extend their communication with the group, transitioning smoothly from a secondary to the more prominent primary, verbal form of communication. Here pointing and gesture interaction support what Baker *et al* [2001] refer to as consequential communication. This finding meets two of our requirements for CST - *Requirement 1.4*: CST should support users' pointing interactions with externalisations; and *Requirement 1.5*: CST should support users' gesture interactions with externalisations.

Through the use of externalisations in problem framing, a more concrete understanding was developed amongst participants. In the questionnaire, participants commented that the EDC allowed people's different perspectives to be expressed, which in turn facilitated shared understanding. As time progressed, stronger shared understandings developed, increasing the number of ideas generated and the productivity of the group, as predicted by Fischer & Ostwald [2005]. The use of externalisations went beyond being a complement to verbal communication to being a necessity in creating a shared understanding of the problem that eventually led to the development of potential solutions.

5.4.1.2 Idea generation

The idea generation phase of the creative process saw much more of an equal distribution of interaction types. Verbal communication accounted for 39.65% of interactions, while interactions with EDC artefacts accounted for 27.62%. The creation of boundary objects saw its highest frequency (21.19%) throughout the creative process, while 5.77% of interactions were with boundary objects.

In the phase of idea generation, when participants verbally expressed an idea they also acted out their idea or, in the case of an already existing idea, emphasised their idea by interacting with the boundary object. Interacting with these boundary objects added context, facilitating greater shared understandings. These illustrations provide visual meaning to one's verbal communications [Baker *et al*, 2001]. For example, if a participant added a bus route, the participant would then interact with the bus route to depict the route the bus would follow. Such interactions provide a new level of information to other members of the group. However, when these interactions stopped, the context was lost. This sometimes led to participants asking idea framing questions later in the design activity regarding the context of these lost interactions. Only two annotations were created to capture contextual information, complementing a user's sketch - two bus routes were labelled route A and route B. However, due to the EDC presenting a map of the Gunbarrel area of Boulder, it was hard for these annotations to be seen and read. Furthermore, these annotations cluttered the solution space, for example, being created on an area which could also have been suitable for a development. This resulted in annotations generally not being used to capture contextual information. There is a clear conflict here with one of our requirements for CST - *Requirement 1.2*: CST should support the annotation of sketches.

The way in which ideas were generated fell into three sub-phases: new ideas, refined ideas and combined ideas.

New ideas: When a participant wanted to express a new idea she typically did so by first interacting with the EDC to act out her idea (i.e. gesturing). For a bus route, for example, this involved drawing an imaginary line with her finger. For describing a possible residential development it involved delineating the intended area with her finger or hand. This form of interaction acted as a *dry run* - conveying information while not changing the EDC's solution space. Others within the group would then give their agreement to drawing the idea, usually using the EDC sketch tool. This led to a shared understanding of the idea, which allowed the group to establish a deeper understanding around the boundary object (i.e. idea framing), or to evaluate the idea in context (i.e. idea evaluation). However, some ideas were never verbally communicated and boundary objects were just created. For example, a group was discussing the roads in a particular area of the map (i.e. problem framing). Suddenly, one participant grabbed the EDC sketch tool and drew a potential bus route without prior discussion with the rest of the group. This was considered more of a *wet run*. In either case, the dry or wet run of idea generation, the interaction with externalisations or creation of a boundary object was essential to the dissemination of the idea, leading to the group iterating through phases of problem framing, idea generation, idea framing and idea evaluation. This finding meets *Requirement 1.6*: CST should support the generation of new ideas: divergent thinking. In particular, this support was provided as two of our other requirements were satisfied - *Requirement 1.1*: CST should support the creation of sketches; and *Requirement 1.5*: CST should support users' gesture interactions with externalisations.

Refined ideas: In contrast to the process of creating new ideas, the refinement of ideas involved much more verbal communication (43.82%). Instead of manipulating the boundary object representing the idea, participants typically talked around the existing boundary objects, verbally expressing their ideas and interacting with the existing boundary objects, acting out their refinement of the idea. Extending our analysis of the data for each group we calculated the number of boundary objects created for new and refined ideas ((the number of boundary objects created/the number of ideas expressed to the group) * 100). We found that boundary objects were created for only 24.73% of refined ideas, whereas boundary objects were created for 75.27% of new ideas. While refinement was a more verbal process, the creation of boundary objects was often used post-hoc to summarise and confirm the refinement. Hence, the EDC did meet *Requirement 1.7*: CST should support the refinement of ideas: convergent thinking.

From our analysis of the video data a third type of idea generation was identified in addition to new and refined idea generation, namely *combined idea generation*. A combined idea was the generation of a design solution from two or more existing design solutions. Figure 5.5 illustrates how this new sub-phase fits in our model of the creative process of design. (Version 1 of figure 5.5 can be seen in figure 2.1 in chapter 2 (see section 2.2.3.2). Version 2 of figure 5.5 can be seen in figure 4.7 in chapter 4 (see section 4.2.2.1).)

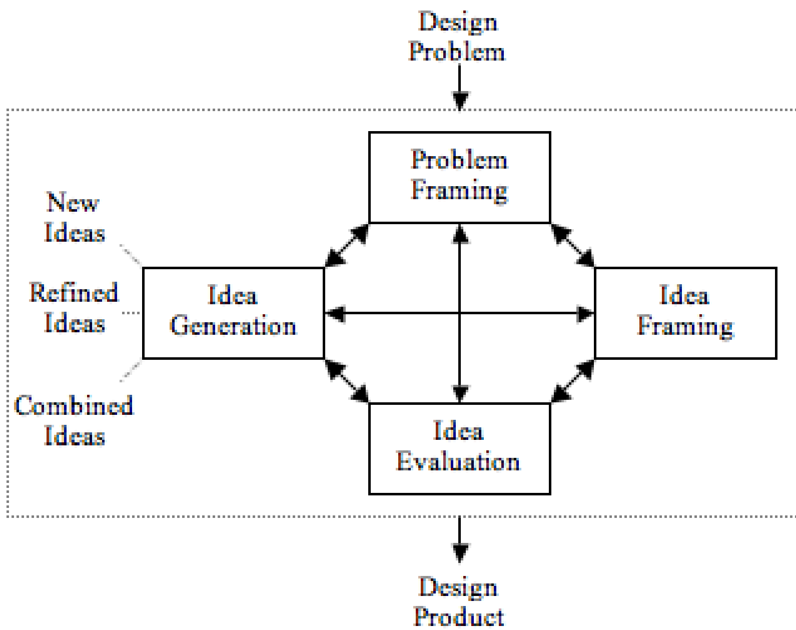


Figure 5.5: The creative process of design (version 3).

Combined ideas: The combination of ideas was rarely observed. In fact, only four ideas were combined across all seven groups. As is reflected in table 5.1, combining ideas did not require the creation of a boundary object as they already existed in the EDC as representations of previously generated ideas. Participants simply interacted with the existing boundary objects (44.44% of interactions) and verbally communicated (55.56% of interactions) with the group about their ideas. Although rare, our evaluation of the EDC has identified a new form of idea generation. Therefore, a requirement for CST is:

> **Requirement 1.11: CST should support the combination of previously generated ideas.**

The generation of ideas involved a great deal of trial and error. Participants noted in the questionnaire that the EDC allowed participants to make rapid changes without committing to them and to collaborate around these ideas. This led to many boundary objects being created, evaluated and then abandoned so that other ideas could be tried and tested. However, when participants went back to previous ideas, boundary objects had to be re-drawn. The EDC did provide functionality for layers of sketches (i.e. a provision for multiple sketches to be drawn). However, if used, these layers were used for various components of a solution, rather than the generation of multiple solutions. There is a partial conflict here with *Requirement 1.6*: CST should support the generation of new ideas: divergent thinking. While the EDC does support the generation of new ideas, divergent thinking is not truly supported if previously generated ideas are lost. Hence, a further requirement for CST is:

> **Requirement 1.12: CST should support the storage and protection of generated ideas.**

This requirement is similar to Baker *et al*'s [2001] heuristic to 'provide protection'. Baker *et al* [2001, p.131] argues, 'People can inadvertently interfere with work that others are doing now, or alter or destroy work that others have done. People should be protected from these situations'. We are particularly interested in protecting generated ideas. Requirement 1.12 can help achieve this.

Idea generation was facilitated by the EDC through the ultrasonic sketch tool and the RFID blocks. 78.14% of boundary objects created during idea generation were created using the sketch tool, while the other 21.86% were created using the RFID blocks. Participants described the sketch tool in the questionnaire as 'crucial' for the development of ideas. The sketch tool gained favour with participants due to its flexibility. The sketch tool gave the participants the ability to manipulate boundary objects as they wished, whereas the RFID blocks were constrained to a grid structure and pre-defined colors. Hence, the virtual representations of boundary objects were constrained by the physical objects that manipulated them. There is a conflict here with one of our requirements for CST - *Requirements 1.8*: CST should not constrain the way users externalise their ideas. The problem of constraining the creation and manipulation of externalisations is illustrated in the following example. One participant - a developer - who was dominant throughout the design activity preferred the RFID blocks due to their imposing nature. Sketches could be minimised and easily erased, whereas the RFID blocks acted on a single layer that was always visible. This constrained others in the group, reducing their abilities to express their ideas, but appealed to this participant, giving her greater control over the development of the final solution, thus constraining the group's creative process.

During the idea generation phase of the creative process, boundary objects facilitated the exploration of ideas between members of the group [Goldschmidt, 1991; Schön, 1983; Schön, 1992; Suwa & Tversky, 2002; Tohidi *et al*, 2006a]. The creation of boundary objects had its most dominant role in this phase of the creative process, allowing ideas to be shaped ready for idea framing and their subsequent evaluation.

5.4.1.3 Idea framing

Idea framing predominantly involved verbal communication between the members of the group (59.60%), as well as high frequencies of interactions with EDC artefacts (27.21%) and boundary objects (13.19%). It should be noted that interactions with boundary objects were most common during the idea framing phase of the creative process. Interactions with externalisations were essential to framing an idea, complementing one's verbal communication. We can see that the EDC met two of our requirements to facilitate idea framing - *Requirement 1.4*: CST should support users' pointing interactions with externalisations; and *Requirement 1.5*: CST should support users' gesture interactions with externalisations.

For example, a common idea to be framed was the new bus route. This was achieved by describing the bus route, while pointing to the externalisation of the bus route. As well as describing the bus route itself, the idea framing phase was particularly useful at conveying information about the thought process behind the generation of the idea. Idea framing allowed information to be perceived that would not have otherwise been available to the group.

Idea framing could occur before or after an idea was externalised. As noted above, ideas could be generated and externalised using gestures (i.e. a dry run of an idea). In order for these ideas to be framed participants had to duplicate the appropriate gestures, whether to question or frame the idea. This type of interaction was common when interacting with EDC artefacts. For example, a member of the group could gesture her hand over an area of open space to be developed and explain a potential development for that area. Idea framing provided a degree of information, which allowed a decision to be made whether to externalise an idea or not. Other group members may have critiqued the idea resulting in the idea not being externalised, or asked the originator of the idea to externalise it, "OK, draw it".

Idea framing could also occur after an idea was externalised. This resulted in interactions with boundary objects. Taking the example of an externalised bus route, participants would frequently point to the bus route and ask, "which direction does the bus go?". This would result in other members of the group framing information by gesturing the direction of the bus over the bus route boundary object.

Pointing and gesture interactions complemented one's verbal communication, allowing concrete understandings of generated ideas to be developed [Baker *et al*, 2001]. This framing of ideas would subsequently lead to various iterations through the creative process. Ideas may have resulted in the problem being redefined, the refinement of ideas, or even the generation of new ideas as alternative solutions, or with a greater understanding an idea could be more effectively evaluated.

5.4.1.4 Idea evaluation

The idea evaluation phase of the creative process involved verbal communication as its primary form of interaction (62.43% of interactions). This was once again frequently complemented through the use of interactions with externalisations acting as a secondary form of communication (27.54%). Whilst interactions with boundary objects accounted for 10.03% of interactions.

Idea evaluation focussed around the boundary objects created during the idea generation phase of the creative process and the context (i.e. EDC artefacts) in which they were situated. The idea evaluation phase was heavily reliant on interactions with externalisations identifying to others in the group what a participant was critiquing. The ease of reference provided by the externalisations facilitated the evaluation of ideas. For example, a participant followed a bus route with his finger, assessing the positioning of bus stops along the route based on the location of junctions along the route. Without the boundary object (i.e. the bus route representation) and the situation of the boundary object in its context (i.e. the EDC's representation of the map of the Gunbarrel area), this idea evaluation activity would have been much less effective and efficient. We can see that the EDC met two of our requirements, which were essential to supporting idea evaluation - *Requirement 1.4*: CST should support users' pointing interactions with externalisations; and *Requirement 1.5*: CST should support users' gesture interactions with externalisations.

Participants evaluated boundary objects against surrounding EDC artefacts, rather than directly comparing alternative ideas represented as boundary objects for the same purpose in the same context. For example, they would compare one or more proposed bus routes independently against other features of the map, but would not directly compare two or more potential bus routes. This is one reason for the high occurrence of interactions with EDC artefacts compared to boundary objects. This way of evaluating boundary objects was a result of the EDC constraining the solution space to a single instantiation. As we saw with the removal and recreation of ideas in the idea generation phase, the idea evaluation phase also involved considerable trial and error. A stakeholder presented an idea that was evaluated, leading to another stakeholder presenting an idea that was then evaluated. If participants wished to go back to considering a previous idea, it required the removal of the boundary object representing the current idea and the recreation of the previous idea. This process continued until agreement was reached within the group. Multiple instantiations of the solution space could have facilitated the comparison of ideas [Terry & Mynatt, 2002; Terry *et al*, 2004], reducing the need for boundary objects to be removed and recreated - the exploration of ideas, rather than trial and error. Hence, a further requirement for CST is:

> **Requirement 1.13: CST should support the comparison of generated ideas.**

Similar to the problem framing phase of the creative process, the creation of boundary objects was not observed in the idea evaluation phase. Participants evaluated ideas by interacting with existing boundary objects representing the ideas and surrounding EDC artefacts that may be related (e.g. evaluating the position of the bus stop based on surrounding developments). Once again, these interactions had the benefit of adding contextual information to the boundary object. Again however, when the interactions stopped, the context was also lost, often leading to later repetition of this information. As mentioned above, CST need to provide ways of capturing such information to be referred to throughout the creative process (e.g. annotations).

Through idea evaluation, shared understandings were further developed and refined, iterating through phases of problem framing and idea framing. In addition, this shared understanding and evaluation process promoted the creation, refinement and dissemination of ideas through the idea generation phase. The use of externalisations facilitated the iteration inherent in the creative process by providing a shared resource that bridged the various phases of problem framing, idea generation, idea framing and idea evaluation.

5.4.2 Supporting group compositions

Analysis of the video data showed the groups using the EDC to engage in group, sub-group and individual activities. During group activities the whole group would collaborate around the EDC, verbally communicating with one another and interacting with the EDC. Sub-group activities involved sub-groups verbally communicating amongst themselves, while the other group members merely acted as passive hearers [Gutwin, 1981]. On some occasions the group would split (i.e. forming two sub-groups), although this collaboration was between the sub-groups and did not involve the EDC. On rare occasions a group member would work individually, interacting with the EDC while the other groups members watched idly or formed a sub-group and engaged in conversation.

The EDC comprised of a public interaction space (i.e. the EDC table), which supported the composition of the entire group. Hence, the EDC met *Requirement 2.3*: CST should support group activities using large interaction spaces. However, support for individual and sub-group work was lacking. This finding is confirmed by the observations of group members not being able to contribute when another individual or sub-group were using the EDC. The questionnaire data provided further evidence showing participants to strongly agree that the EDC supported group activities (agreement: mean = 4.39; SD = 0.57); yet did not support sub-group activities (agreement: mean = 2.56; SD = 1.00) or individual activities (agreement: mean = 2.68; SD = 1.12). The low assessment of support for sub-group and individual work may be explained by the EDC's provision of only a public interaction space, whereas social and private interaction spaces are more supportive of sub-group and individual work [Kostakos *et al*, 2006; O'Neill *et al*, 2004]. We can see that the EDC failed to meet two our requirements for CST - *Requirement 2.1*: CST should support individual activities using small interaction spaces; and *Requirement 2.2*: CST should support sub-group activities. We argue that this was a failing of the EDC. As argued by Gutwin & Greenberg [1999] and Streitz *et al* [1997], effective collaboration requires at least support of individual and group activities, and such support can be provided through small and large interaction spaces [Kostakos *et al*, 2006; O'Neill *et al*, 2004].

While our requirements specify that group and individual activities can be supported using large and small interaction spaces respectively (Requirement 2.1 and Requirement 2.3), they do not inform us of the interaction space required to support sub-group activities (Requirement 2.2). As already mentioned, Kostakos *et al* [2006] and O'Neill *et al* [2004] argue social interaction spaces can support sub-group activities. Streitz *et al* [1999] have demonstrated such support for sub-groups through the use of their ConnecTable. The ConnecTable provides an interaction space that is suitable for more than one person, but not the entire group, thereby facilitating a sense of social inclusion. Hence, a refinement to Requirement 2.2 is:

> **Requirement 2.2 (refined): CST should support sub-group activities using interaction spaces that create a sense of social inclusion.**

The EDC did not support the transition between various group compositions. Bellotti *et al* [1991] argues that shared spaces are useful for focussed collaboration. However, enforcing users to work using a shared space hampers the smooth flow to other, less close forms of shared work such as individual and sub-group activities. A group's compositions dynamically change throughout collaborative activities [Warr & O'Neill, 2006a]. Streitz *et al* [1997] have provided empirical evidence for the need to support the dynamic change of group composition, showing groups using technologies supporting individual and group activities achieving better results than groups working as a full-group for most of the time. This transitioning between the different group compositions has been confirmed in our own research (see chapter 4, section 4.2.2.4) and others [e.g. Baker *et al*, 2001; Greenberg *et al*, 1999; Gutwin & Greenberg, 2000; Streitz *et al*, 1997; Tang & Leifer, 1988; Warr & O'Neill, 2006a]. This support is stated in one of our requirements for CST - *Requirement 2.4*: CST should support the transitions between individual, sub-group and group activities.

The EDC did not support design activities beyond the meeting room, as the EDC only provided a static interactive tabletop. Therefore, the EDC did not meet *Requirement 2.5*: CST should support creative activities beyond the meeting room. However, although not part of our evaluation, the EDC has demonstrated the support of collaborative activities beyond the meeting room through the use of PDA [Giaccardi *et al*, 2005].

5.4.3 Supporting the control of social influences

Production blocking, evaluation apprehension and free riding are the three major explanations for real groups performing poorer than nominal groups [e.g. Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973; Mullen *et al*, 1991]. While it is difficult to identify the occurrence of such social-psychological mechanisms, we can identify their effects and the use of technology that reduced or promoted their influence.

Production blocking: Analysis of the video data showed a mean of 14% of participants' verbal communication were actively blocked by other participants (i.e. they were cut off mid-speech). While this may not seem too high a statistic, it does not account for those participants who were blocked from externalising their ideas and thoughts (i.e. those people who did not cut other people off mid-speech). The questionnaire data revealed that participants moderately perceived they were able to contribute an idea without obstruction (agreement: mean = 3.43, SD = 0.96). However, the EDC could have put further mechanisms in place to reduce the impact of production blocking on creativity. As recommended by previous research in creativity and CSCW [e.g. Diehl & Stroebe, 1987; Prante *et al*, 2002], production blocking can be reduced through the use of single display groupware and synchronous groupware systems to prevent production blocking in real time collaboration. The EDC comprises a tabletop display that provides a single point of interaction for the group. This single interaction space constrains the group to work in a shared space. Providing multiple interaction spaces, as shown by the Caretta system [Sugimoto *et al*, 2004] and the i-LAND environment [Streitz *et al*, 1999] allows users to generate ideas in an alternate interaction space, while not being constrained by others. This support is emphasised by *Requirement 3.1*: CST should support synchronous forms of interactions, thereby reducing the effects of production blacking.

In addition to the number of interaction spaces created by the technologies allowing multiple points of entry to the system, the devices themselves can provide multiple points of entry by providing simultaneous inputs. The EDC used a single tabletop display, one ultra-sonic sketch tool and one RFID block per available functionality. This resulted in a form of technological production blocking. If a participant had an idea she wanted to express using the EDC, she was constrained by the available features of the EDC and whether other participants were currently expressing ideas. Providing multiple input devices and simultaneous forms of input would allow for more points of entry to the solution space, thereby reducing the effects of production blocking [Prante *et al*, 2002]. As stated in *Requirement 3.2*: CST should support multiple inputs, thereby reducing the effects of production blocking.

Evaluation apprehension: The questionnaire data gathered showed participants believed they were able to contribute ideas without fear of criticism (agreement: mean = 3.79; SD = 1.03); that is, there was little apparent evaluation apprehension. An analysis of the qualitative feedback suggested participants did not fear criticism from others because of the positive, supportive environment in which the participants were working. Participants mentioned that the ability for them to contribute ideas without fear of criticism was a result of the people, not the EDC - 'only because this was a friendly group, the EDC was not a factor here'. However, while evaluation apprehension was not an issue during the observed design activity, it may have been under different circumstances (e.g. a different group of people, a different task, etc).

The EDC's tabletop provided a public interaction space, allowing all the group members to see the ideas generated. Such a set-up conflicts with recommendations from researchers in the field of CSCW [e.g. Demhis & Valacich, 1993; Diehl & Stroebe, 1987; Prante *et al*, 2002; Valacich *et al*, 1994], where it is recommended that individual input is anonymised, thereby preventing evaluation apprehension. This was also one of our requirements for CST - *Requirement 3.3*: CST should support the removal of a user's identity from their ideas, thereby reducing the effects of evaluation apprehension.

Furthermore, in chapter 4 we found that providing user's with privacy can mitigate the effects of evaluation apprehension (see section 4.2.2.5) - *Requirement 3.4*: CST should support individual/private interactions, thereby reducing the effects of evaluation apprehension. This can be achieved by providing private or social interaction spaces [O'Neill *et al*, 2004] for individual and sub-group activities. The Caretta system [Sugimoto *et al*, 2004] and the i-LAND environment [Streitz *et al*, 1999], satisfied this requirement allowing user's to generate idea in their own personal space, without intrusion from others. A group member may always associate themselves with a particular idea if they wish. This was not possible using the EDC as idea had to be externalised in the presence of others.

Free-riding: One or two group members in each group seemed to free-ride from the analysis of our video data. Figure 5.6 shows the percentage of group members' verbal contributions for the four personas (Resident 1 = R1; Resident 2 = R2; City Planner = CP; Developer = Dev), for all seven groups, where the baseline verbal contribution for a group of 4 was 25%.

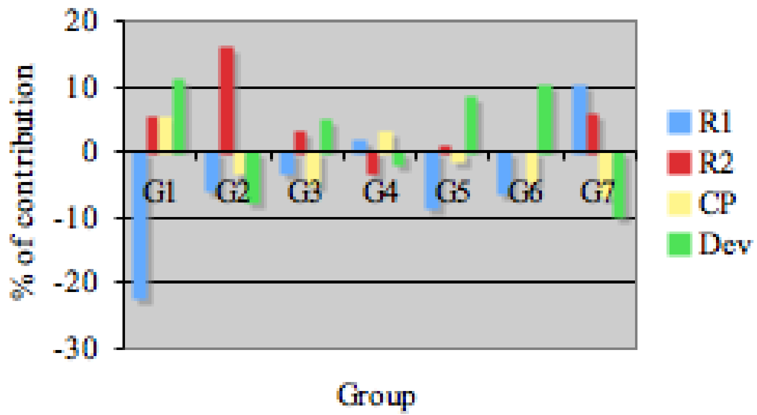


Figure 5.6: The percentage of verbal communication for each persona for all seven groups.

We can see from the graph that at least one person contributed less than other members in the group, while other members of the group made up the difference. An extreme case of free-riding can be seen in group one, where resident 1 made a very small contribution during the design activity. Whereas, resident 2 in group 2 made a large contribution to the design activity. Group members in group 4 had the most equal contributions. Overall, resident 2 and the developers seem to be the most active contributors across all seven groups, while resident 1 and the city planner contributed less to the discussion during the design activity. However, this is not to say that although one's contribution was limited it was not worthwhile. Furthermore, while some participants may not have been verbally contributing to the discussion, they may have been individually reflecting upon the problem and generating potential solutions [e.g. Coughlan & Johnson, 2006].

The questionnaire data showed that participants moderately thought everyone in the group contributed equally (agreement: mean = 3.25; SD = 1.00) and everyone considered themselves an active contributor (agreement: mean = 4.00; SD = 0.94). This seems to suggest a conflict in the results. Analysis of the qualitative data found that participants were concerned with their personal agendas and therefore considered themselves actively contributing towards the design activity when the discussion affected them. This may have left other group members with the opinion that others' did not contribute towards other areas of the problem. However, while it may be true that some group members are lazy and relied on others, it may be the case that some group members were either internally dealing with the problem or sub-problem, or were fearful of engaging in the group activities - a form of evaluation apprehension.

Due to the public interaction space provided by the EDC, the groups were forced to tackle the problem as a collective working within a shared space. Such a technological set-up would not have helped with the social pressures associated with the group setting, nor supported a group member needing to work on the problem or part of the problem on their own. Through the availability of different technologies, individuals could remove themselves from the group when needed to work individually or withdraw themselves from possible social pressures. This support is emphasised in *Requirement 2.1*: CST should support individual activities using small interaction spaces. Furthermore, this finding suggests a refinement to *Requirement 3.4*:

> **Requirement 3.4: CST should support individual/private interactions, thereby reducing the effects of evaluation apprehension and free-riding.**

Furthermore, where free riding is caused by lazy group members, it has been suggested that CST could be used to motivate users, by presenting indicators of an individuals' performance, rather than the output of the group being collated [e.g. Paulus & Dzindolet, 1993; Shepherd *et al*, 1995]. The EDC did not provide such support. Therefore, one of our requirements was not met - *Requirement 3.5*: CST should make individuals accountable for their own productivity, thereby reducing the effects of free-riding.

However, it should also be acknowledged that free riding can also be attributed to a personality trait [Guilford, 1950; Gough, 1979], (see chapter 4, section 4.2.2.5), that needs to be identified before a group or design team is formed.

5.5 Summary

In this chapter we first reviewed and critiqued a number of CST - the EDC, Caretta and the i-LAND environment. This led us to reporting an in-depth evaluation of the EDC. First, we presented an overview of the evaluation and its purpose, leading into a description of the evaluation methodology. We described the evaluation in terms of the participants, a detailed description of the EDC and the procedure of how the evaluation was conducted. The data captured during the evaluation through videos and questionnaires were then reported and discussed in the findings section, using our three high-level requirements for supporting creativity as a framework. Drawing lessons from this evaluation of the EDC, we wished to identify strengths and weakness of the EDC, suggesting improvements to the EDC and other CST, as well as allowing us to reflect upon and refine our requirements for CST.

A major finding from the review and critique of the EDC, Caretta and the i-LAND environment was that each of these tools only supported one of our high-level requirements. The EDC focussed on the support of externalisations (i.e. boundary objects) promoting shared understanding between stakeholders, although these externalisations were specific to urban planning. This support related to *High-level requirement 1*: support the creation and dissemination of externalisations to support the phases of the creative process. While Caretta and the i-LAND environment focussed on supporting individual and social creative activities, criticisms were raised over the technological support for this, particularly the transition between the various group compositions. This support related to *High-level requirement 2*: support the various compositions of a group using appropriately sized interaction spaces. None of the tools intentionally supported *High-level requirement 3*: support the control of social influences. To further understand the support provided by existing CST and reflect further upon our requirements for CST we conducted an in-depth evaluation with the EDC. In the following sub-sections we present and reflect upon our final set of requirements for CST grouped according to our high-level requirements for supporting creativity in design elicited in chapter 2 (see section 2.3.4).

5.5.1 High-level requirements 1: Supporting the externalisation of knowledge

So far throughout this thesis we have seen the importance of creating sketches during the creative process of design [e.g. Goldschmidt, 1991; Schön, 1983; Schön, 1992; Suwa & Tversky, 2002; Tohidi *et al*, 2006b]. Sketches complement one's verbal communication allowing problems to be framed, ideas externalised, refined, framed and evaluated. During the EDC evaluation we saw that the process of sketching allowed participants to externalise their ideas, subsequently framing and evaluating them. Participants did not create sketches during the problem framing phase of the creative process. However, from our data we argue that this was due to a constraint of the EDC (see section 5.4.1.1). Without support for sketching, the *language of design* is inhibited. Therefore, we argue for:

Requirement 1.1: CST should support the creation of sketches.

Annotations are intended to complement sketches, adding additional meaning to an otherwise ambiguous sketch. During the EDC evaluation annotations were used on one occasion to indicate two separate bus routes. We argue that the lack of use of annotations was due to the difficulty in distinguishing the annotation from the surrounding EDC artefacts (e.g. the map of the Gunbarrel area of Boulder) (see section 5.4.1.2). This resulted in participants having to clarify what certain parts of externalisations were during phases of problem framing (see section 5.4.1.1) and idea framing (5.4.1.3) throughout the design activity. Annotations reduce the ambiguity of a sketch providing additional meaning throughout the design activity. Hence, we argue for:

Requirement 1.2: CST should support the annotation of sketches.

Text is particular useful at externalising information for which sketches are inappropriate. During the EDC evaluation textual externalisations were not created. Similar to the problem with annotations using the EDC, it would be difficult to distinguish text from the surrounding EDC artefacts. Furthermore, creating text externalisations using the EDC would consume the solution space making it difficult to create other externalisations. It may also have been the case that the design task given to the participants was not oriented towards the creation of textual externalisations, requiring more graphical externalisations such as sketches. Although textual externalisations were not created, our data does not argue against the need to support their creation. Referring back to chapter 4 (see section 4.2.2.3), we observed that textual externalisations were useful at noting requirements, processes and technical details. Therefore, we still argue for:

Requirement 1.3: CST should support the creation of text.

Pointing to externalisations allows one to communicate with a design [Bekker *et al*, 1995], adding additional meaning to their verbal communications, thereby avoiding misunderstandings [Baker *et al*, 2001; Bekker *et al*, 1995; Tang & Leifer, 1988]. During the EDC evaluation participants frequently pointed to features of an externalisation in order to frame the problem, illustrate new ideas or refinements to ideas, frame ideas and evaluate those externalised ideas (see section 5.4.1). The utility of pointing interactions was essential throughout the phases of the creative process. Hence, we argue for:

Requirement 1.4: CST should support users' pointing interactions with externalisations.

Similar to pointing interactions, gestures allowed one to communicate with a design [Bekker *et al*, 1995], adding additional meaning to their verbal communications, thereby avoiding misunderstandings [Baker *et al*, 2001; Bekker *et al*, 1995; Tang & Leifer, 1988]. During the EDC evaluation gestures were used to illustrate ideas before they were externalised, frame information and evaluate ideas (see section 5.4.1). Furthermore, gestures allowed a dynamic context to be added to an otherwise static externalisation [Tang & Leifer, 1988]. The kinetic movement of a gesture allowed information to be visualised that was lacking from verbal communications or even pointing interactions. Gestures are an integral part of face-to-face design activities supporting the various phases of the creative process. Therefore, we argue for:

> **Requirement 1.5: CST should support users' gesture interactions with externalisations.**

Through the creation of sketches, annotations and text, new ideas can be permanently externalised. Furthermore, pointing and gesture interactions complementing one's verbal communication can allow new ideas to be temporary externalised. During the EDC evaluation participants would generally first illustrate their new ideas through pointing and gesture interactions complementing their verbal communications. The idea would then be externalised using the ultra-sonic sketch tool or RFID blocks. These externalised ideas were then discussed and interacted with through pointing and gesture interactions allowing ideas to the framed, critiqued and improved (see section 5.4.1.2). The generation of new ideas allowed different ideas to be explored (i.e. divergent thinking). Hence, we argue for:

> **Requirement 1.6: CST should support the generation of new ideas - divergent thinking.**

Similar to the creation of new ideas, through the creation of sketches, annotations and text, refined ideas can be permanently externalised. Furthermore, pointing and gesture interactions complementing one's verbal communication can allow refined ideas to be temporary externalised. During the EDC evaluation participants would generally illustrate possible refinements to an idea through pointing and gesture interactions complementing their verbal communications. Once the group agreed upon the refinement of an idea, the externalised idea could be modified to reflect the refinement using the ultra-sonic sketch tool or RFID blocks. These externalised ideas were then further discussed and interacted with through pointing and gesture interactions (see section 5.4.1.2). The generation of refined ideas allowed ideas to converge towards a final solution (i.e. convergent thinking). Therefore, we argue for:

Requirement 1.7: CST should support the refinement of ideas - convergent thinking.

In chapter 4 we observed the diverse and flexible ways in which paper was used to externalise ideas (see section 4.3.2.1). We therefore argued that CST should not constrain the way users externalise their ideas. This is similar to an argument made by Candy & Edmonds [2000] that CST should provide its users with a degree of flexibility, giving the user the locus of control. During the EDC evaluation participants saw the flexibility provided by the ultra-sonic sketch tool for externalising ideas as 'crucial'. Whereas, the RFID blocks that were constrained to a grid structure were rarely used due to their 'rigidness'. Participants wished to create externalisations the way they wished and not be constrained by the CST. Hence, we argue for:

Requirement 1.8: CST should not constrain the ways users externalise their ideas.

In chapter 4 we argued that the solution space that externalisations were created on should be unobstructed (see section 4.3.2.1). The EDC did provide an unobstructed solution space with tool bars made available to the sides. However, during the EDC evaluation it was observed that different externalisations could interfere with each other. For example, when annotations were externalised, they consumed space that could have been used for land developments. Hence, annotations obstructed the creation of other externalisations. In the case of the EDC, this would also have been true of textual externalisations. Therefore, CST need to provide a solution space unobstructed by tools and other externalisations. Hence, we argue for:

Requirement 1.9: CST should provide users with an unobstructed solution space.

In chapter 4 we observed that users reoriented and repositioned paper when creating and viewing externalisations (see section 4.3.2.1). This was also achieved on occasions by moving oneself in relation to the externalisation. The EDC was a static CST. Participants therefore oriented and positioned themselves around the EDC when creating, interacting and viewing externalisations. Simply being able to move around the EDC tabletop facilitated the participants' interactions with the EDC (e.g. creating externalisations and, pointing and gesturing with these externalisations). Therefore, we argue for:

Requirement 1.10: CST should allow users to change the orientation and position of an externalisation and/or the CST.

In addition to the generation of new and refined ideas, during the evaluation of the EDC we saw the occurrence of a third type of idea generation, namely combined idea generation (see section 5.4.1.2). Combined idea generation involved combining two or more existing design solutions. Thus, CST should support the combination of previously externalised ideas. Hence, a new requirement for CST is:

Requirement 1.11: CST should support the combination of previously generated ideas.

While the EDC supported the creation and refinement of externalisations, it did so in a trail-and-error fashion. As such, some externalised ideas were removed to make room for new ideas. This partially conflicted with *Requirement 1.6*: CST should support the generation of new ideas: divergent thinking. Divergent thinking was not effectively supported as previously generated ideas were lost. Baker *et al* [2001] argue that people should be protected from these kinds of situations. Therefore, we argue for a further requirement for CST:

Requirement 1.12: CST should support the storage and protection of generated ideas.

During the EDC evaluation ideas were removed to make way for new ideas. This meant participants evaluated boundary objects against surrounding EDC artefacts rather than directly comparing alternative ideas. This led to the removal and recreation of boundary objects. It was therefore recommended to support multiple instantiations of the solution space facilitating the exploration of alternative solutions [Terry & Mynatt, 2002; Terry *et al*, 2004]. Hence, we argue for a further requirement for CST:

Requirement 1.13: CST should support the comparison of generated ideas.

5.5.2 High-level requirement 2: Supporting individual and social creative activities

It has been argued that in order to effectively support collaboration, support needs to be provided for individual and collaborative activities [Gutwin & Greenberg, 1999; Streitz *et al*, 1997]. Individual activities in particular allow one to remove oneself from the group and personally reflect upon the design activity. Such individual reflection was not possible when using the EDC. The public interaction space of the EDC tabletop meant that the group had to work as a group the entire time. The participants agreed that the EDC did not support their individual activities (see section 5.4.2). It has been argued that smaller interaction spaces can be used to support individual activities [Kostakos *et al*, 2006; O'Neill *et al*, 2004]. Such support is provided by Caretta [Sugimoto *et al*, 2004] and the i-LAND environment [Streitz *et al*, 1999]. Caretta provides a PDA and the i-LAND environment provides a CommChair (i.e. a device with a small interaction space mounted on a chair), thereby supporting individual activities. Therefore, we argue for:

> **Requirement 2.1: CST should support individual activities using small interaction spaces.**

Of course, collaboration is not a matter simply of working either individually or as a whole group. Group members may also engage in sub-group activities [Gutwin, 1981]. During the EDC evaluation group members would engage in sub-group activities where other members of the group were passive hearers. Furthermore, on some occasions the group would split into more than one sub-group. However, the participants from the EDC evaluation were in agreement that the EDC did not effectively support sub-group activities. Kostakos *et al* [2006] and O'Neill *et al* [2004] argue that such activities can be supported by providing social interaction spaces. Streitz *et al* [1999] have practically illustrated support for sub-groups through the use of their ConnecTable. The ConnecTable provides an interaction space that is suitable for more than one person, but not the entire group, thereby facilitating a sense of social inclusion. Hence, we argue for:

> **Requirement 2.2: CST should support sub-group activities using interaction spaces that create a sense of social inclusion.**

When working on collaborative activities it is a necessity to support whole group activities. Kostakos *et al* [2006] and O'Neill *et al* [2004] argue that such activities can be supported by providing public interaction spaces. The EDC provides a public interaction space to the group through the EDC tabletop. The EDC tabletop allowed the group to create, interact, view and discuss externalisations together.

The participants in the EDC evaluation strongly agreed that the EDC tabletop supported their group activities. Similarly, Caretta and the i-LAND environment provide group members with public interaction spaces supporting group activities. Like the EDC, Caretta provides its users with an interactive tabletop. The i-LAND environment provided two public interaction spaces through their InteracTable and DynaWall. Therefore, we argue for:

> **Requirement 2.3: CST should support group activities using large interaction spaces.**

As well as groups engaging in individual, sub-group and group activities, group members also dynamically shift between these activities [Baker *et al*, 2001; Gutwin & Greenberg, 2000; Streitz *et al*, 1997; Tang & Leifer, 1988; Warr & O'Neill, 2006a]. The EDC did not support the transition between various group compositions as it provided only a public interaction space. As argued by Bellotti *et al* [1991], enforcing users to work using a shared space hampers the smooth flow to other, less close forms of shared work such as individual and sub-group activities. The i-LAND environment did support individual, sub-group and group activities. However earlier in the chapter (see section 5.1.1), we argued that the i-LAND environment did not support the transition between these various group compositions as the technologies supporting the various group compositions were embedded in physical artefacts, thereby constraining the capacity for seamless transitions from one interaction space to another. Caretta overcame this problem as the mobility of the PDA allowed its users to move into the public interaction space of the interactive tabletop, smoothly transitioning between individual and collaborative activities. The need to support the transitions between various group compositions has been argued in our own (see chapter 4, section 4.2.2.4) and others' research [e.g. Baker *et al*, 2001; Greenberg *et al*, 1999; Gutwin & Greenberg, 2000; Streitz *et al*, 1997; Tang & Leifer, 1988; Warr & O'Neill, 2006a]. Hence, we argue for:

> **Requirement 2.4: CST should support the transitions between individual, sub-group and group activities.**

In chapter 4, we showed that design activities also occur beyond the meeting room (see section 4.2.2.4). Olson *et al* [1992] have argued the importance of supporting design activities beyond the meeting room. Design tasks are delegated to individuals and sub-groups. The outputs from these delegated tasks are then presented during the next design meeting. The EDC did not support design activities beyond the meeting room, as it provided only a fixed interactive tabletop. Similarly, Caretta and the i-LAND environment did not support design activities beyond the meeting room. However, due to the mobility of the PDA in the Caretta environment, individual activities could potentially occur outside the meeting room. Although not part of our evaluation, the EDC has demonstrated such distributed support through the use of PDA [Giaccardi *et al*, 2005]. Therefore, in order to support design activities beyond the meeting room, we argue for:

> **Requirement 2.5: CST should support creative activities beyond the meeting room.**

5.5.3 High-level requirement 3: Supporting the control of social influences

In order to support social creativity, it has been argued that social influences detrimental to creativity need to be controlled [e.g. Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973]. It has been argued that the effects of production blocking can be reduced by providing synchronous forms of interactions [e.g. Diehl & Stroebe, 1987; Prante *et al*, 2002]. For example, providing users with individual interaction spaces to simultaneously externalise ideas would reduce the effects of production blocking. During the EDC evaluation participants had to work in an asynchronous fashion. The EDC only provided a single interaction space through the interactive tabletop. Therefore, if one person was externalising an idea, other group members would have to wait to externalise their ideas. This resulted in a degree of production blocking. Caretta and the i-LAND environment overcame this problem by providing interaction spaces for individual and sub-group activities. Therefore, if one interaction space was being used, others would be available, thereby allowing synchronous forms of interaction. Hence, we argue for:

> **Requirement 3.1: CST should support synchronous forms of interaction, thereby reducing the effects of production blocking.**

A further measure to mitigate the effects of production blocking is to support multiple inputs [e.g. Prante *et al*, 2002]. The EDC provided its users with one ultra-sonic sketch tool and one RFID block per available functionality. This resulted in a form of technological production blocking (see section 5.4.3). However, it should be acknowledged that one of the reasons for integrating the ultra-sonic sketch tool into the EDC was due to its ability to support multiple inputs. However, this functionality was not available when the evaluation was conducted. Furthermore, the RFID blocks could be used simultaneously, however, there was only a single block per functionality, meaning that if an RFID block was in use, its functionality would not be available to another user. To remove these constraints and mitigate the effects of production blocking we argue for:

> **Requirement 3.2: CST should support multiple inputs, thereby reducing the effects of production blocking.**

Removing a user's identify from an externalised idea can reduce the effects of evaluation apprehension [Diehl & Stroebe, 1987]. Users of the EDC were unable to contribute an idea using the EDC without being associated with it. The public interaction space provided by the EDC's tabletop meant that all ideas were externalised in the presence of others. The participants in our evaluation did not believe they feared criticism from others, due to the 'friendly groups'. However, during a real design task or with groups consisting of different people, the EDC's public interaction space may lead to evaluation apprehension as argued in previous research [e.g. Collaros & Anderson, 1969; Diehl & Stroebe, 1987; Jablin *et al*, 1977]. Therefore, we argue for:

> **Requirement 3.3: CST should support the removal of a user's identity from their ideas, thereby reducing the effects of evaluation apprehension.**

In chapter 4, we observed participants from our field-based observations externalising ideas in their own personal space and then moving their externalised ideas into the shared space of the group once they were satisfied with their ideas (see section 4.2.2.5). This was argued to reduce fear of criticism from others, as an individual would be able to work through an idea till satisfied, before sharing it with the rest of the group. This action was not possible using the EDC as it provided only a public interaction space through the interactive tabletop. While the effects of evaluation apprehension were not acknowledged by our participants during the EDC evaluation, under different circumstances fear of criticism may have been an issue. In addition to individual/private interaction spaces supporting the mitigation of evaluation apprehension, from our observations in chapter 5, we further argue that individual/private interaction spaces could allow participants to work individually on a problem or part of a problem, thereby reducing social pressures from others in the group, which could otherwise result in free-riding (see section 5.4.3). Therefore, providing individual/private interaction spaces could potential reduced the effects of free-riding. Hence, we argue for:

Requirement 3.4: CST should support individual/private interactions, thereby reducing the effects of evaluation apprehension and free-riding.

Free-riding can have a negative effect on social creativity when individuals can hide amongst the productivity of the group and are not accountable for their own productivity [e.g. Diehl & Stroebe, 1987]. Participants using the EDC during our evaluation were constrained to work as a group the entire time, due to the public interaction space provided by the EDC's tabletop. Our data showed that during the EDC evaluation some participants did free-ride (see section 5.4.3). We argue that this was because individuals were not accountable for their own productivity. Hence, we argue for:

Requirement 3.5: CST should make individuals accountable for their own productivity, thereby reducing the effects of free-riding.

In the following chapter we use our requirements for CST that have been developed and refined throughout this thesis, presenting the design, development and evaluation of our own CST: PSPD.

Chapter 6

Public Social Private Design (PSPD)

The premise of this thesis was to understand and support creativity in design. In chapter 2 we built up a theoretical understanding of creativity and an understanding of how to support creativity in design. Through an experiment reported in chapter 3, a diary study and set of ethnographic and lab-based observations reported in chapter 4 and an evaluation of an existing CST reported in chapter 5, we have refined our understanding of creativity, as well as eliciting a set of requirements for CST. In this chapter building upon the accumulation of our previous work, we present the design, development and evaluation our own CST: PSPD.

Section 6.1 introduces the design and development of PSPD. We describe PSPD in terms of its underlying framework, its hardware and its software. Furthermore, we illustrate how these components of PSPD support creativity in design.

In section 6.2, we report an initial evaluation of PSPD. Replicating and extending our lab-based study reported in chapter 4 (see section 4.3), we observe the use of the PSPD software running on a PDA and tablet PC, supporting users during individual and collaborative creative design tasks. This initial evaluation highlighted design problems and issues that fed back into the design and development of PSPD.

Section 6.3 builds upon the initial evaluation of PSPD, which identified the potential unsuitability of the PDA for creating externalisations. We report an experiment to determine the effects of screen size on sketching. During this experiment participants were asked to sketch images that contained both graphical and textual representations using a PDA and tablet PC sized interface. We measured the time and errors produced when sketching an image to determine the suitability and use of PDA in the PSPD environment.

Section 6.4 evaluates the use of PSPD to support creativity in design. Three groups of interaction designers were observed collaborating on a creative design task, using PSPD as a CST. We observed the interactions amongst the designers and their interactions with PSPD, thus analysing PSPD's support for our requirements for CST.

Finally, section 6.5 summarises the chapter, drawing out lessons learned on how to support creativity in design. In particular we summarise our findings from the evaluation of PSPD providing evidence to support or reject the proposal of our requirements for CST.

6.1 The design and development of Public Social Private Design

PSPD was designed to support creativity in the early stages of the design process (i.e. the early formation of ideas - rough designs, not polished designs) [Warr & O'Neill, 2006a; Warr & O'Neill, 2006c]. As argued by many researchers [e.g. Gaver, 1991; Greene, 2002; Jones & Greene, 2000; Olson *et al*, 1992; Tang & Leifer, 1988; van der Lugt, 2002], CSCW tools that support the early stages of design can improve and facilitate a more efficient design process. To provide such support, PSPD built upon our requirements for CST developed and refined throughout this thesis. We now describe the design and development of PSPD in terms of its underlying conceptual framework, hardware and software, and how these components support creativity in design. (We do not focus on implementation details in the main body of the thesis. A technical walkthrough can be found in appendix E).

6.1.1 Framework

Throughout chapters 2-5 we have seen the need for CST to support individual, subgroup and group compositions. In chapter 2 we saw the development of creativity research move from studying individual creativity [e.g. Wallas, 1926; Guilford, 1950; Boden, 1994], to the study of group creativity [e.g. Csikszentmihalyi, 1996; Fischer, 2004]. Furthermore, this research has progressed to viewing the relationship between individual and group creativity, not as an *or* relationship, but rather an *and* relationship [e.g. Edmonds *et al*, 1999; Fischer *et al*, 2005]. In chapter 3 we refuted the claim that creative activities such as idea generation should be conducted by nominal groups alone [e.g. Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973], having shown that through the control of social influences real groups can be as creative as nominal groups [Warr & O'Neill, 2005b; Warr & O'Neill, 2006b]. In chapter 4 our ethnographic observations of design activities identified the various group compositions of the groups - individual, sub-group and the group - and the seamless transitions between these compositions. Finally, in chapter 5 we showed how CST can support and constrain the composition of the group, through the interaction spaces they provide. A challenge we are faced with when designing and developing a future CST is, *how can we support the various group compositions of a design team and the transition between these compositions, while controlling social influences on creativity?* We partially address this challenge through an underlying framework for PSPD.

6.1.1.1 A framework for pervasive system design

Kostakos *et al* [2006] present a framework for the design and analysis of pervasive computing systems. This design framework considers the architectural space which one is designing for, the interaction spaces of the technologies to be used and the type of information or services to be presented by the technologies. Orthogonal to these concerns is a spectrum of publicness. The framework indicates the suitability of technologies with differing interaction spaces for presenting certain information spaces in a given architectural space (i.e. the solid lines) and potential conflicts (i.e. the dotted lines). Figure 6.1 presents the framework.

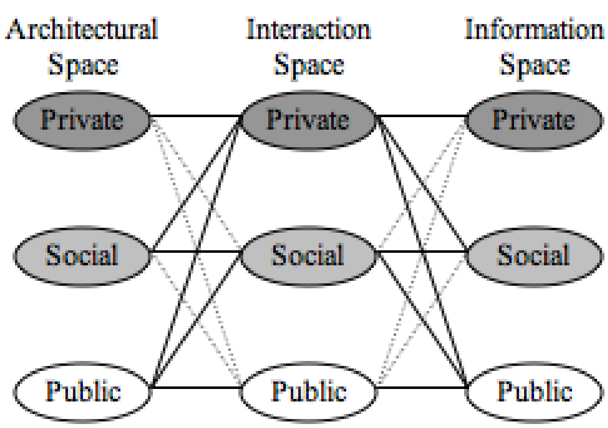


Figure 6.1: A framework for the design and analysis of pervasive systems.

The architectural space is the physical space which the system is designed for. An example of a private architectural space could be one's bedroom. A space in which a person is alone and in control of. Private spaces promote a sense of security and privacy. A public architectural space is one that is open to everyone. An example of a public space could be a town square. A social architectural space is neither private or public. Social architectural spaces are controllable by a specific person or persons. An example of a social architectural space could be a secured office space, where access to that space is only permitted to persons with the appropriate assess card.

An interaction space is the volume created by a device or artefact within which human activity is effectively supported by that device or artefact [Kostakos *et al*, 2006, O'Neill *et al*, 1999]. A private interaction space is only usable by one person, where others are excluded. An example could be one's mobile phone screen - a private visual interaction space; or a set of headphones - a private auditory interaction space. A social interaction space includes a given sub-set of users. For example, placing an order at a drive-thru using an automated system would create a social interaction space to those in the car, while people outside the car would be excluded. A public interaction space is one that is freely accessible. For instance, large advertisement boards in New York's Times Square or London's Piccadilly Circus create public interaction spaces.

The information space is specific information, associated activities or services provided by the system. Private information might be one's bank statement. This information is specific to one person and controllable by them alone. The social information space could include information belonging to a specific group of persons. For example, a business document that is shared between a certain team within the company. Information or services in the public space are available to anyone. This may include information such as train timetables and TV listings.

When designing or analysing a pervasive system the lines in the framework highlight the suitability or potential conflict in the design of the pervasive system. For example, it is not suitable to display private information through a public interaction space. This is indicated by the dotted line between the public ellipse under the interaction space column and the private ellipse in the information space column. However, it is suitable for a private interaction space to display private information. This is indicated by the solid line between the private ellipse under the interaction space column and the private ellipse in the information space column.

6.1.1.2 A framework for creativity support tools

While the design and analytical uses of the pervasive systems design framework are reported in the urban context [Kostakos *et al*, 2006], it may also be applied in the context of groupware systems, such as CST. For example, if we wished to support the various group compositions of a design team, public maps to the notion of the group, social maps to the notion of the sub-group and private maps to the notion of the individual. In the case of PSPD, the design meeting room was considered a public space (i.e. a group space). Through the adoption of various technologies we can create public, social and private interaction spaces, which in turn can support public, social and private information. The framework itself then suggests the appropriate interaction spaces for the creation and dissemination of public, social and private information. Figure 6.2 presents a simplification of the pervasive system design framework [Kostakos *et al*, 2006], for supporting creative activities in design.

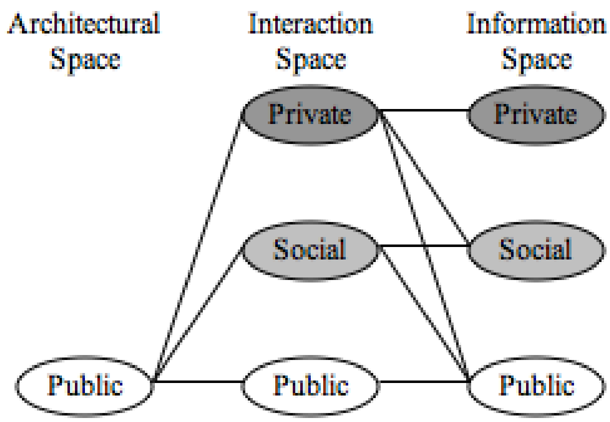


Figure 6.2: A framework for supporting creativity in design.

Through the implementation of this framework we can support a number of our requirements for CST: *Requirement 2.1* - CST should support individual activities using small interaction spaces; *Requirement 2.2* - CST should support sub-group activities using interaction spaces that create a sense of social inclusion; *Requirement 2.3* - CST should support group activities using large interaction spaces; and *Requirement 2.4* - CST should support the transitions between individual, sub-group and group activities. In this version of PSPD we only consider the domain of the meeting room. Therefore, *Requirement 2.5* was not supported - CST should support creative activities beyond the meeting room. However, due to the mobility of the PDA and the tablet PC, PSPD does have the potential to support creativity beyond the meeting room [Warr, 2006].

We next describe the instantiation of the PSPD framework, considering the PSPD hardware and software.

6.1.2 Hardware

Building upon recommendations reported in previous research [e.g. Greenberg *et al*, 1998; Gutwin & Greenberg, 1998; Luff & Heath, 1998] and extending upon the ideas embodied in existing CST [e.g. Stefik *et al*, 1987; Streitz *et al*, 1999, Sugimoto *et al*, 2004], PSPD supports group, sub-group and individual activities (High-level Requirement 2), through the use of public, social and private interaction spaces respectively (see figure 6.3).

Figure 6.3: The Public Social Private Design hardware.

An *interactive tabletop* (consisting of a plasma screen with a Smartboard overlay, powered by a PC) provides a public interaction space, allowing all group members to engage, collaborate with each other, and interact with the technology. The tabletop was particular useful for participants being able to gather around the device, allowing the creation of and interaction with externalisations. Hence, *Requirement 2.3* was supported: CST should support group activities using large interaction spaces.

A set of *tablet PC* provides a number of social interaction spaces, allowing sub-groups to form, collaborate with each other and interact with the technology. This more constrained interaction space supports only small sub-groups comfortably, providing a feeling of social inclusion for its users and exclusion for others. Furthermore, the mobility of the tablet PC allowed them to be moved in and out of the public and private interaction spaces. Hence, *Requirement 2.2* was supported: CST should support sub-group activities using interaction spaces that create a sense of social inclusion.

A set of *PDA* provides a number of private interaction spaces, allowing members of a group to work individually. The very constrained interaction space provides a private design environment for an individual user. Furthermore, the mobility of the PDA allowed them to be moved in and out of the public and social interaction spaces. Hence, *Requirement 2.1* was supported: CST should support individual activities using small interaction spaces.

The interactive tabletop and the tablet PC were particular suitable for collaborative activities as they allowed users to gather around the devices, similar to a piece of paper or artefact on a meeting room table. This set-up allowed easy accessed to externalisations, thereby supporting pointing and gesture interactions. Hence, PSPD supported *Requirement 1.4* - CST should support users' pointing interactions with externalisations; and *Requirement 1.5*: CST should support users' gesture interactions with externalisations.

The mobility of the tablet PC and the PDA allowed users to orient and position the devices as they wished. While the interactive tabletop was a static device, users could freely move around the table. These design decisions were made in order to support *Requirement 1.10* - CST should allow users to change the orientation and position of an externalisation and/or the CST. Furthermore, the mobility of the tablet PC and the PDA allowed devices to be moved between the various interaction spaces supporting group, sub-group and individual activities, thereby supporting *Requirement 2.4*: CST should support the transitions between individual, sub-group and group activities.

The use of multiple devices allowed externalisations on different devices to be compared, supporting the exploring of multiple solutions. Hence, *Requirement 1.13* was supported: CST should support the comparison of generated ideas.

The choice of technologies also meant each device had a stylus which supported interaction with the device, reflecting the metaphor of pen and paper - common tools in the traditional design process. Furthermore, each device communicated with a central server through a wireless network, which allowed externalisations to be disseminated between devices (discussed below in more detail).

As well as supporting design activities in group, sub-group and individual compositions, PSPD also facilitated the control of social influences (High-level Requirement 3).

Controlling *production blocking*: It was originally intended for users to be able to simultaneously interact with a device (i.e. multiple inputs using either the tabletop or tablet PC). However, in the current version of PSPD, only single input is possible. Therefore, *Requirement 3.2* was not supported - CST should support multiple inputs, thereby reducing the effects of production blocking. Despite this shortcoming, group members could simultaneously use the PDA, tablet PC and tabletop to create and disseminate externalisations. For example, if the group were discussing an idea around the tabletop and an individual member had an idea they wished to share with the group, they could externalise that idea using a PDA or tablet PC. Thus, the creative activities of the group and individual members were not obstructed. Hence, *Requirement 3.1* was supported: CST should support synchronous forms of interaction, thereby reducing the effects of production blocking.

Controlling *evaluation apprehension*: The social and private interaction spaces allowed members of the design team to work independently of other group members, providing a sense of privacy, therefore mitigating fear of criticism. Information could then be distributed to other group members whenever the originator felt comfortable and willing. Hence, *Requirement 3.4* was supported: CST should support individual/private interactions, thereby reducing the effects of evaluation apprehension and free-riding. Furthermore, all externalisations were anonymised, as recommended by previous research [e.g. Diehl & Stroebe, 1987; Prante *et al*, 2002]. Therefore, *Requirement 3.3* was supported: CST should support the removal of a user's identity from their ideas, thereby reducing the effects of evaluation apprehension. For example, an individual could use a PDA to externalise and work through their ideas. Due to the constrained interaction space, other group members would be excluded from this private activity. Individuals could then disseminate an externalisation either socially or publicly, making it available to a sub-set of the group or the entire group respectively. As no identification was associated with an externalisation, participants could make anonymous contributions or even identify themselves with their ideas if they wished.

Controlling *free riding*: The support of multiple group compositions meant that group members were not merely working in a group and were therefore responsible for their own productivity during individual and sub-group activities. The interaction spaces provided by PSPD allowed users to remove themselves from the group, while continuing to be productive by engaging in a sub-group or individual activities (i.e. moments of individual reflection). Hence, *Requirement 3.4* was supported: CST should support individual/private interactions, thereby reducing the effects of evaluation apprehension and free-riding; and *Requirement 3.5* was supported: CST should make individuals accountable for their own productivity, thereby reducing the effects of free-riding. For example, group members could use the PDA for moments of individual reflection, or work in a sub-group using a tablet PC. This meant they did not have to fight for 'air time' [Nunamaker *et al*, 1991]. Furthermore, as PSPD supported individual, sub-group and group compositions through various technologies, tasks could be delegated, which meant individuals would not be able to hide within the group activities and would be responsible for specific tasks.

6.1.3 Software

PSPD was designed to support the creation, manipulation and dissemination of externalisations. These externalisations could then be used to facilitate the creative activities of a design team (High-level Requirement 1).

The design of the software developed for PSPD drew upon our previous work observing individuals and groups throughout various design activities as reported in chapter 4 and similar research [Sedivy & Johnson, 1999; Sedivy & Johnson, 2000]. In this section we focus on providing a high-level overview of the design and development of PSPD. (A technical walkthrough of the PSPD functionalities can be found in appendix E.)

6.1.3.1 Creating externalisations

Based upon the metaphor of pen and paper, each PSPD device presented the user with a blank canvas. This design decision was made to support *Requirement 1.9*: CST should provide users with an unobstructed solution space. Using the stylus the user could draw on the canvas as they would with a pencil on paper (see figure 6.4). The PSPD software allowed new externalisations to be created and each of these externalisations could be returned to and refined. Hence, *Requirement 1.6* was supported - CST should support the generation of new ideas: divergent thinking; and *Requirement 1.7* was supported - CST should support the refinement of ideas: convergent thinking.

Vector-based free-hand sketches, annotations and text could be drawn using the stylus. These representations supported three of our requirements for CST: *Requirement 1.1* - CST should support the creation of sketches; *Requirement 1.2* - CST should support the annotation of sketches; and *Requirement 1.3* - CST should support the creation of text. As the externalisations were free-hand, they did not constrain the way the user externalised their ideas, thereby supporting *Requirement 1.8* - CST should not constrain the ways users externalise their ideas. Furthermore, selecting the annotation function from the pie menu or marked menu (described below), allowed annotations and text indicated by a coloured marker on the canvas to be created (see figure 6.5). These annotations were stored in a panel, which could be shown and hidden through the pie menu and marked menu. These marked annotations were intended to prevent the users' creative space from becoming cluttered.

Figure 6.4: An example externalisation created using Public Social Private Design.

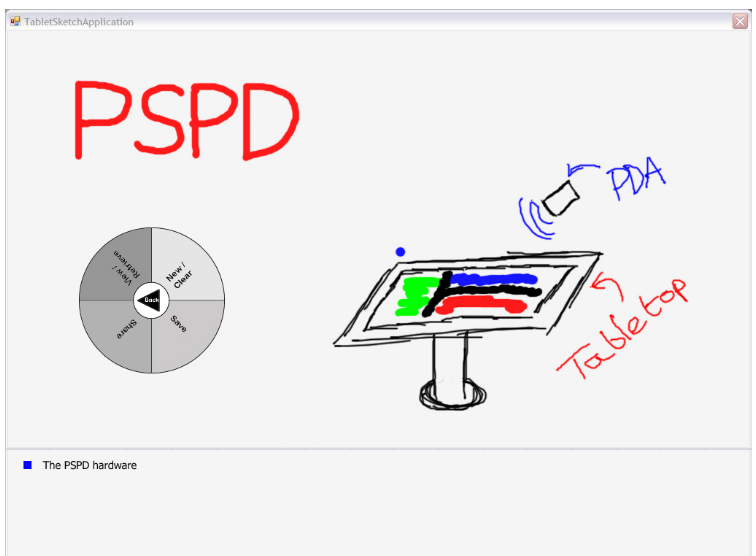
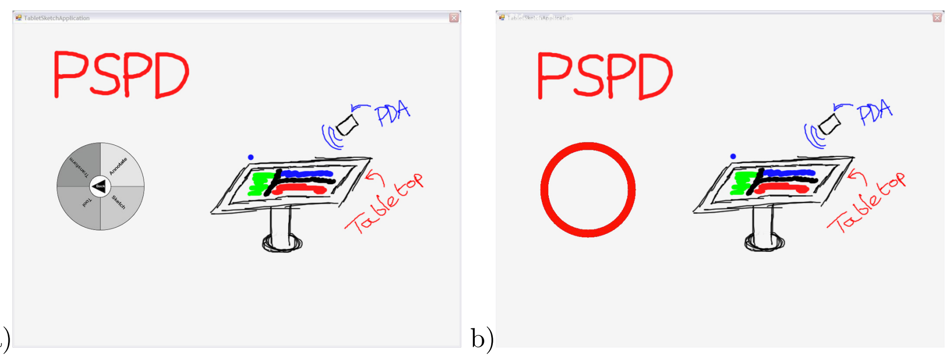


Figure 6.5: The Public Social Private Design annotations panel.

With an externalisation created, a user could then manipulate and disseminate it to other users.

6.1.3.2 Manipulating externalisations

Externalisations could be manipulated through pie menus (see figure 6.6) [Callahan *et al*, 1988] and marked menus [Kurtenbach & Buxton, 1994]. These menus allowed for a range of selection methods, supporting both novice and expert users. They were particular useful for pen-based devices as the menu appeared directly under the stylus resulting in minimal cognitive overload and stylus movement to make a selection. Furthermore, these menus were only visible when needed, thus not consuming valuable screen space, unlike floating menus and toolbars. Holding the stylus still on the canvas for 0.6 seconds accessed the pie menu. Functionality could then be accessed through the pie menu segments. Holding down the stylus for 0.3 seconds and gesturing in the appropriate direction accessed the marked menus, based on a directional stroke recognition algorithm [Kostakos & O'Neill, 2003; O'Neill *et al*, 2005]. (The cursor changed its appearance to indicate when a gesture could be performed.) The direction of the gesture mapped to the regions in the pie menu. Combinations of gestures allowed multiple menus to be navigated. The user could return to the canvas at any time by clicking outside the area of the pie menu or gesture pad.



a) b)

Figure 6.6: Public Social Private Design controls: (a) pie menu; and (b) gesture pad.

Externalisations could be manipulated in the following ways (based on our observations in chapter 4 and work conducted by Sedivy & Johnson [2000]):

> *Annotations: users could create, edit, and remove annotations. Annotations were stored in a panel, which can be viewed and hidden when selected from the pie menu.*

Externalisation options: the user could create, remove, combine, and view externalisations. Thumbnails of externalisations were stored in a panel, which could be viewed and hidden when selected from the pie menu. Selecting the thumbnail would set the canvas to that externalisation.

Dissemination: externalisations could be privately, socially or publicly disseminated (discussed below).

Pen options: the user could choose the pen color, hardness and size.

Transformations: the externalisations could be moved, rotated, scaled and zoomed.

When either the pen options or transformation options were selected a gesture pad appeared on the canvas (see figure 6.6b). With the exception of the move functionality, users could perform either clockwise or anti-clockwise gestures to manipulate their externalisations. For example, when the rotate functionality was selected and a clockwise gesture was performed, the externalisation would rotate clockwise. If the pen size functionality was selected and an anti-clockwise gesture was performed, the size of the border on the gesture pad decreased, indicating the pen size. If the move functionality was selected the canvas could be moved by moving the stylus towards the edge of the gesture pad.

When either the annotation or layer functionality was selected, a panel would appear towards the bottom of the canvas showing the user the annotations for that sketch or thumbnails of externalisations for that device respectively (see figure 6.5). Thumbnails could be compared, thereby supporting *Requirement 1.13*: CST should support the comparison of generated ideas. Selecting a thumbnail of an externalisation would set the background of the canvas to the appropriate externalisation. These externalisation could then be manipulated depending on the selected functionality. Hence supporting *Requirement 1.7*: CST should support the refinement of ideas: convergent thinking. Existing externalisations that were retrieved after being saved or shared (discussed below), formed a new instantance of an externalisation. Therefore, a record of different versions of externalisations were available, avoiding externalising being deleted. This versioning supported *Requirement 1.12*: CST should support the storage and protection of generated ideas.

6.1.3.3 Disseminating externalisations

The PSPD software allowed externalisations to be disseminated in two ways based on the PSPD framework - saved and shared. Saving an externalisation allowed it to be disseminated to the level of publicness of the device on which it was created.

Tabletop: Saved externalisations had a *public* publicness level. They were viewable and retrievable through the PDA, the tablet PC and the tabletop itself.

Tablet PC: Saved externalisations had a *social* publicness level. They were viewable and retrievable by the members of the sub-group who created them on their individual PDA or by the sub-group when using a tablet PC.

PDA: Saved externalisations had a *private* publicness level. They were viewable and retrievable only by the person who created them on her own PDA.

Through the share functionality, an externalisation could be disseminated to a greater level of publicness.

Tablet PC: *Social* externalisations could be disseminated to the *public* publicness level.

PDA: *Private* externalisations could be disseminated to either the *social* or the *public* publicness level (see figure 6.7a).

Users could be associated with private externalisations, as each member of the design team had her own personal PDA with a unique identifier (see figure 6.7b). However, when socially disseminating externalisations, the PSPD software had to ask the user(s) - via an individual's PDA or a sub-group's tablet PC - who was disseminating the externalisation (see figure 6.7c) and to whom they wished to disseminate the externalisation with (see figure 6.7b). Olson *et al* [2005] have argued the importance of giving users such control, specifying who they want to shared their information with, thereby facilitating collaborative activities. Furthermore, the PSPD software had to enquire whose externalisations to retrieve when a sub-group was using a tablet PC (see figure 6.7b).

An externalisation could not be disseminated lower than the publicness level of the device on which it was created. For example, if an externalisation had been produced on the tabletop it could not be made private, as it was created in a public interaction space. However, if an externalisation was created on the tabletop and was subsequently retrieved and modified on a PDA, the modified externalisation would be treated as a new and private externalisation. The original externalisation

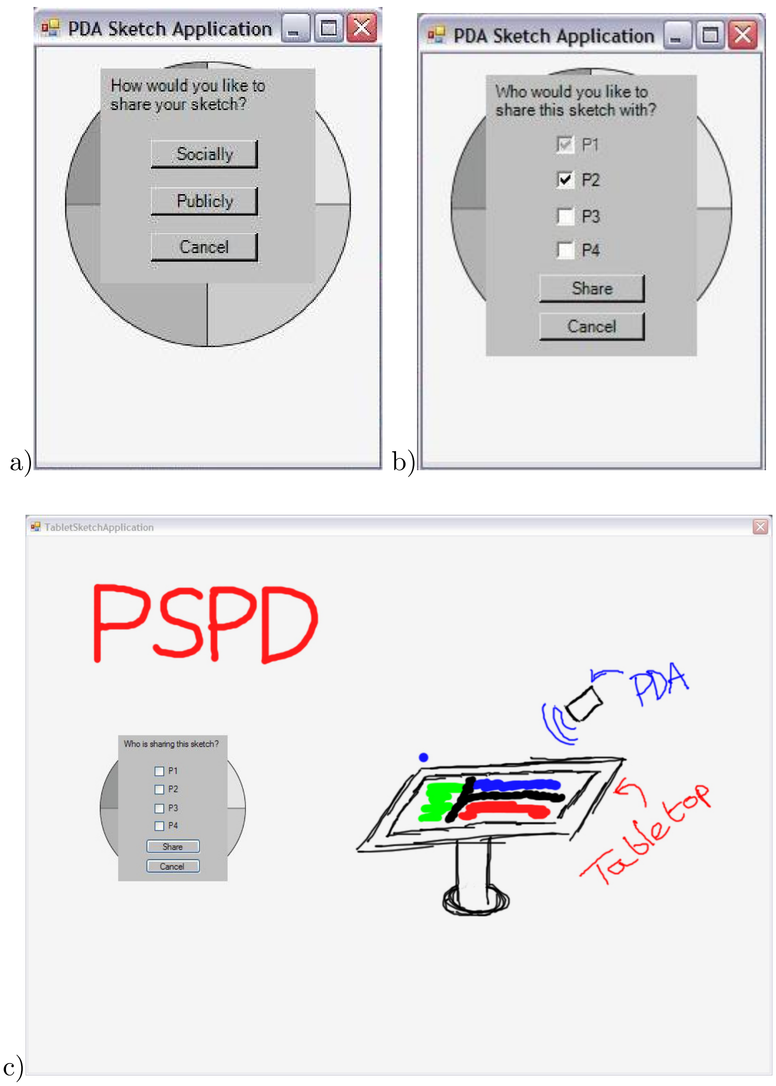


Figure 6.7: Forms to ask the user: (a) the publicness with which to disseminate an externalisation; (b) who is disseminating the externalisation; and (c) with whom they wish to disseminate the externalisation.

still existed as a public externalisation. The implementation of the PSPD framework allowed us to support *Requirement 2.4*: CST should support the transition between individual, sub-group and group activities.

6.2 An initial evaluation of Public Social Private Design

The aim of PSPD was to provide technological tools to support creativity in design. Replicating and extending our lab-based study reported in chapter 4 (see section 4.3), we replaced the traditional design tools of paper and pen with the PSPD technologies, in the case of this evaluation, a PDA and a tablet PC. Through the use of these technologies our objective was to observe individuals and pairs collaborating on individual and collaborative creative design tasks. From this initial evaluation we wished to identify design problems and issues to feed back into the design of PSPD.

6.2.1 Method

In our initial evaluation of PSPD, eight participants used either the PSPD software on the PDA or the tablet PC for an individual creative design task. In addition, four pairs of participants used the PSPD software on the PDA or the tablet PC for a collaborative creative design task. These were preliminary evaluations to understand the use of PSPD to support both individual and collaborative creative design. Participants' interactions with the PSPD hardware and software were captured for analysis through the use of two digital video cameras. A questionnaire was also given to the participants after each evaluation, assessing from a user's perspective the effectiveness of the PSPD hardware and software for individual and collaborative creative activities.

6.2.1.1 Participants

8 participants took part in the evaluation - 5 males and 3 females. The participants varied in age from 19 to 21, with a mean of 19.5 years. All participants were undergraduate students from a variety of disciplines at the University of Bath. The participants were recruited via mailing lists and volunteered to participate in the evaluation.

6.2.1.2 Equipment

On each participant's desk was either a PDA or a tablet PC. For the individual task a single stylus was provided. However, for the collaborative sketching task each participant was provided with their own stylus. Figure 6.8 illustrates the evaluation set-up for both the individual and collaborative design tasks for both the PDA and tablet PC.

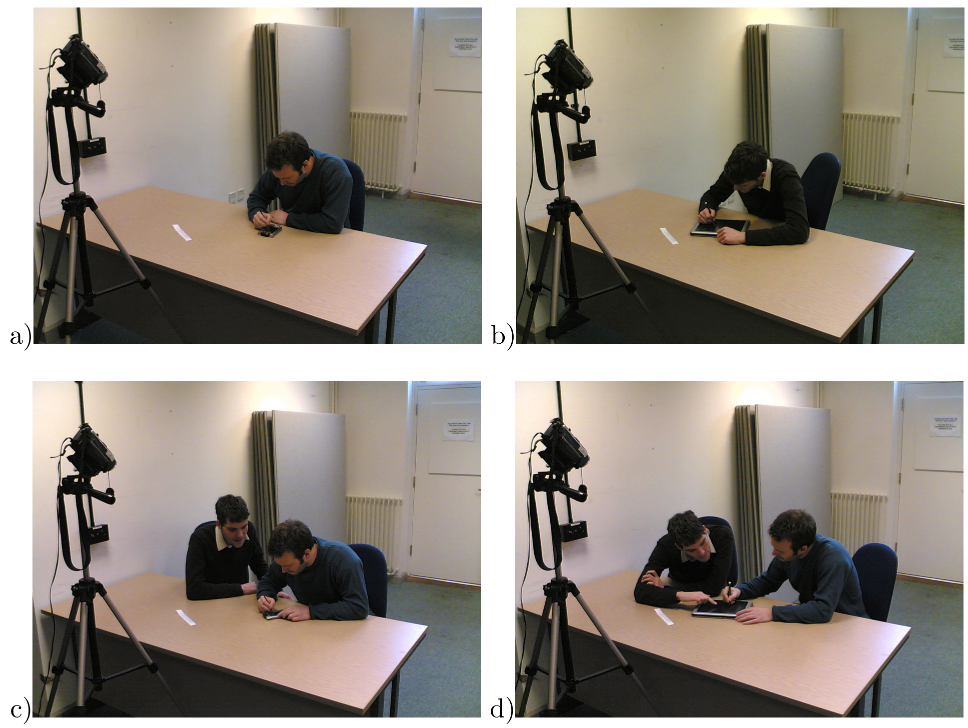


Figure 6.8: The initial evaluation of Public Social Private Design set up for: (a) the individual task with a PDA; (b) the individual task with a tablet PC; (c) the collaborative task with a PDA; and (d) the collaborative task with a tablet PC.

Both the PDA and the tablet PC ran the PSPD software for creating and manipulating externalisations. However, the externalisations could not be disseminated between devices. For this evaluation we were interested in the use of the software and hardware supporting individual and collaborative design activities. Rather than externalisations being disseminated between devices, they were merely saved locally.

Two digital video cameras on tripods were used to capture interactions with the PSPD hardware, software and between participants. During the individual sketching task a digital video camera recorded the participant's work area with the participant in view. During the collaborative sketching task one digital video camera captured the collaborative work area and the other digital video camera captured a wide angle view of both participants and their interactions.

6.2.1.3 Procedure

Participants were run in pairs in a sound-proof usability lab. Four of the participants used a PDA and the other four participants used a tablet PC. Each set of four participants worked individually on an individual creative task and paired up to collaborate on a collaborative creative task.

At the start of the evaluation one participant was asked to take a seat at a desk. The other was asked to wait in an adjacent room. Once seated the evaluator read the evaluation instructions from a script:

> *This evaluation is designed to gain an understanding of the support of creativity using our software for a CST, PSPD (either running on a PDA or a tablet PC).*
>
> *During this evaluation you will be asked to first work alone for ten minutes, externalising ideas to an individual design task. Upon the completion of this task you will be paired up to collaborate on a collaborative creative design task, which will involve spending a further ten minutes externalising ideas.*
>
> *Before the evaluation begins you will get the opportunity to familiarise yourself with the PSPD software. You will have up to two minutes for this practice session.*
>
> *If you have any questions, please ask the evaluator before you begin the evaluative tasks. You may not ask the evaluator any questions once you have begun the evaluation.*

The evaluator then asked the participant if they had any questions and answered them to the best of his abilities. Once the evaluator and the participant were satisfied, the participant was given the opportunity to practice using the PSPD software on either the PDA or tablet PC. During this time the participant could externalise anything they wished and ask the evaluator any questions they had.

When the participant was satisfied with the PSPD software and the use of the hardware they were using, the evaluator gave the participant a slip of paper on which the individual creative design task was written. The evaluator also read aloud the task:

> *You are a member of a Hollywood film production company. You have been asked to sketch some initial ideas of a scary monster for a new animated horror film.*

Once again the evaluator asked the participant if they had any queries and dealt with them to the best of his ability. Upon both the evaluator and the participant being satisfied, the evaluator informed the participant that they had ten minutes to externalise their ideas for the task.

After ten minutes the evaluator informed the participant to stop what they were doing and remain seated. The evaluator collected either the PDA or the tablet PC from the participant. The participant was then asked to take a seat in the adjacent room. The other participant who had been waiting then participated in the individual creative task using either the PDA or tablet PC, as described above.

After the second participant had completed the individual creative task, the evaluator asked the participants to take a seat at the same desk and rearranged the digital video cameras to get a top-down view of the collaborative work area and a wide angle view able to capture the interactions between the two participants and the technology. The PDA or tablet PC was then positioned on the desk between the two participants. The evaluator then gave each participant a slip of paper on which the collaborative creative design task was written. The evaluator also read aloud the task:

> *You are a pair of designers for a major car company. You have been asked to sketch some initial ideas of features for a car of the future.*

Before commencing with the collaborative creative design task the evaluator asked the participants if they had any queries and answered them as best he could. When both the evaluator and the participants were satisfied, the evaluator informed the participants that they had ten minutes to collaboratively externalise their ideas.

When the participants had completed ten minutes for the collaborative creative design task, the evaluator informed the participants to stop what they were doing and remain seated. The evaluator then stopped the digital video cameras recording and collected the PDA or tablet PC. The observer then concluded by handing each participant a questionnaire (see appendix E).

6.2.2 Findings

The findings we report here are drawn from a foci analysis [Jordon & Henderson, 1995] of the individuals and collaborating pairs generating ideas using the PSPD software running on the PDA and tablet PC. (An excerpt of the foci analysis can be found in appendix E.) Questionnaire data from each participant further complemented our video data. We report our findings, focussing on the process of being creative and the use of the PDA and the tablet PC. From these findings we wished to identify design problems and issues to be fed back into the design of PSPD.

6.2.2.1 The process of being creative using the Public Social Private Design software

A positive finding from our observations of the individual and collaborative creative design tasks was that the core process of being creative did not differ from that reported in chapter 4 describing the process of being creative using paper and pen during our lab-based observations (see section 4.3.2). For example, when externalising an idea as a sketch, when using both the PDA and the tablet PC, participants would first sketch the outline of their idea and then add detail within the outline. An outline was created using the default pen tool (a single pixel black line), the pie menu functionalities were used to change the pen colour and its size, thereby refining and adding detail to the outline sketch. Similar to when the participants used paper, our observations showed participants would scale their externalisations to fill the available space. This finding suggests that the PSPD hardware and software were not disruptive when compared to the traditional paper and pen tools.

The way participants collaborated together to generate ideas also remained the same. Verbal communication was very important to establish shared understandings between the participants. Ideas were either verbally described to the collaborator, before they were externalised; or ideas would be externalised immediately and then described in retrospect; or it was also common for participants to talk about what they were doing while externalising an idea (i.e. thinking aloud). We argue that this is a positive finding showing the flexibility in use of PSPD.

Sketching was the primary means for externalising ideas, with annotations proving useful in the collaborative task. Sketches were frequently pointed to and participants performed gestures to add context, as they did when sketching with paper. Annotations were frequently observed in our lab-based observations reported in chapter 4 (see section 4.3.2.2). PSPD extended the power of annotations by introducing marked annotations. Instead of the annotations taking up valuable screen space, the marked annotations allowed the participants to mark a particular feature on the sketch with a coloured tag, which was associated with an annotation stored in the annotations panel. This was considered an advantage over paper.

While the core process of externalising ideas remained the same, the introduction of the technologies led to some interesting observations in their use.

6.2.2.2 Externalising ideas using a PDA

The main effect the PDA had during the creative design tasks was due to its constrained interaction space. During the individual creative design task participants would be completely immersed in the interaction space of the PDA. This was desired and intended - a private interaction space from which other members would be excluded. This was evident during the collaborative sketching task. The position of the PDA was biased towards the person who was using it (see figure 6.9). It was not possible for there to be some middle ground and have both participants collaborating within the interaction space of the PDA. During the collaborative sketching task, participants had to take turns externalising their ideas when using the PDA. This resulted in the PDA being passed over to one's collaborator when they wished to externalise something. The person who was not sketching had to 'look over the person shoulder' to see what was happening. It was particularly difficult to see what was being externalised when the hand of the person who was externalising the idea often obscured the view.

Furthermore, while the private interaction space proved suitable for individual tasks, participants found the PDA difficult to use when representing ideas - "I normally draw quite big"; and "the screen is too small on the PDA". This difficulty varied according to what the user was trying to externalise. When sketching, the PDA allowed outline ideas to be sketched, but the screen size constrained details from being added. This was not a major failing since the intention for the PDA element of PSPD was to support initial sketches and expressions of ideas. These "doodles" could then be explored in greater detail using the other technologies and in collaboration with other participants.

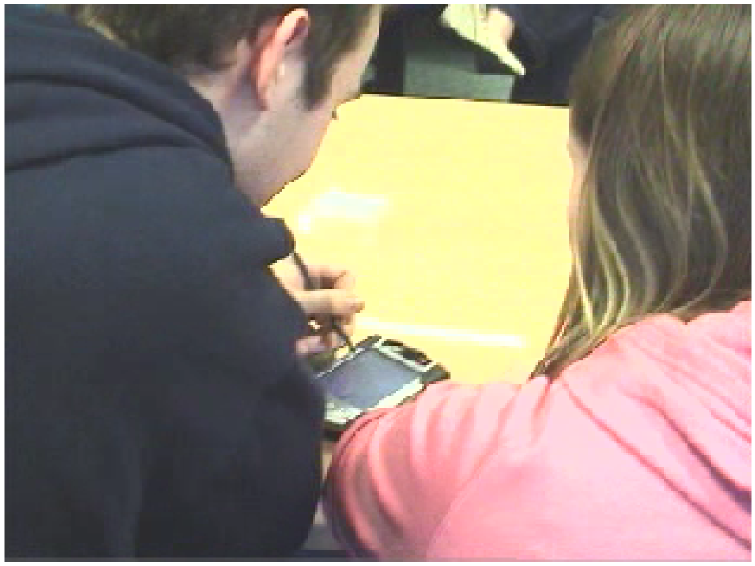


Figure 6.9: The constrained interaction space of a PDA during a collaborative task.

6.2.2.3 Externalising ideas using a tablet PC

Participants found the tablet PC provided a useful medium for sub-group collaboration with two members. During the collaborative creative design task the tablet PC was placed in between the participants, just as the paper was used in our lab-based observations (see figure 6.10).

Furthermore, unlike the PDA which had to be passed between the participants, the tablet PC's location remained static, acting as a shared space for collaboration. This allowed for both participants to easily interact with and view the tablet PC, facilitating the collaborative process.

6.2.3 Conclusions from the initial evaluation of Public Social Private Design

The results from this initial evaluation of PSPD were quite positive. The core creative process itself was the same for both the individual and collaborative creative design tasks using the PSPD technologies as it was for paper.

Figure 6.10: The social interaction space of a tablet PC during a collaborative task.

The PDA was a suitable medium for individual tasks, while collaboration was hindered by the constrained interaction space. However, this constrained interaction space, could be considered unusable by its user as it was perceived as being 'too small'. In the next section we focus on the use of the PDA in the PSPD environment.

The tablet PC itself provided a suitable interaction space, supporting the shared creation and interaction with externalisations.

In this initial evaluation of PSPD, the individual technologies were evaluated independent of one another. While the PDA, tablet PC and tabletop support individual, sub-group and group activities respectively, PSPD was intended to support the dynamic transition between these various activities. With this development complete we can evaluate PSPD understanding its effectiveness supporting creativity in design. However, before this final development of PSPD could proceed, we needed to determine the suitability of the PDA in the PSPD environment.

6.3 The effect of screen size on sketching

A major finding from the initial evaluation of PSPD was the potential unsuitability of the PDA for creating externalisations. Participants found it difficult to represent ideas when using the PDA - "I normally draw quite big", "the screen is too small on the PDA". Participants commented that while they could draw the outline sketch, they could not add detail. While this could be considered a potential usability problem, our intention for the PDA was for it to support initial sketches and expressions of ideas. These doodles could then be explored in greater detail in collaboration with other users using the other technologies. To consider the suitability and use of PDA in the PSPD environment we conducted an experiment looking at the effects of screen size on sketching. Sketching was chosen as it is a common means of externalising design ideas [Schön, 1983].

6.3.1 Method

The experiment had a repeated measures experimental design. Two independent variables were manipulated: (1) canvas size, which consisted of two levels - a small canvas to represent the PDA and a large canvas to represent the tablet PC; and (2) the complexity of the sketch, which consisted of two levels - simple and detailed sketches. The dependent variables measured were: the time taken to sketch an image; and the number of errors made while sketching. It was hypothesised that:

> *It would be quicker to sketch both (a) simple; and (b) detailed images on the small canvas compared to the large canvas (H1).*
>
> *More errors would be produced when sketching detailed images on the small canvas compared to the large canvas (H2).*

6.3.1.1 Participants

12 participants took part in this experiment - 8 male and 4 female. The participants varied in age from 22 to 40, with a mean of 30.17 years. All participants were postgraduate students from the Department of Computer Science at the University of Bath. The participants were recruited via mailing lists and volunteered to participate in the experiment.

6.3.1.2 Equipment

On each participant's desk were a 17" LCD monitor and a mouse, both connected to a standard desktop PC. There was also a 12" tablet PC with a stylus. An A4 piece of paper was stuck to the desk, presenting the experimental instructions (see figure 6.11).

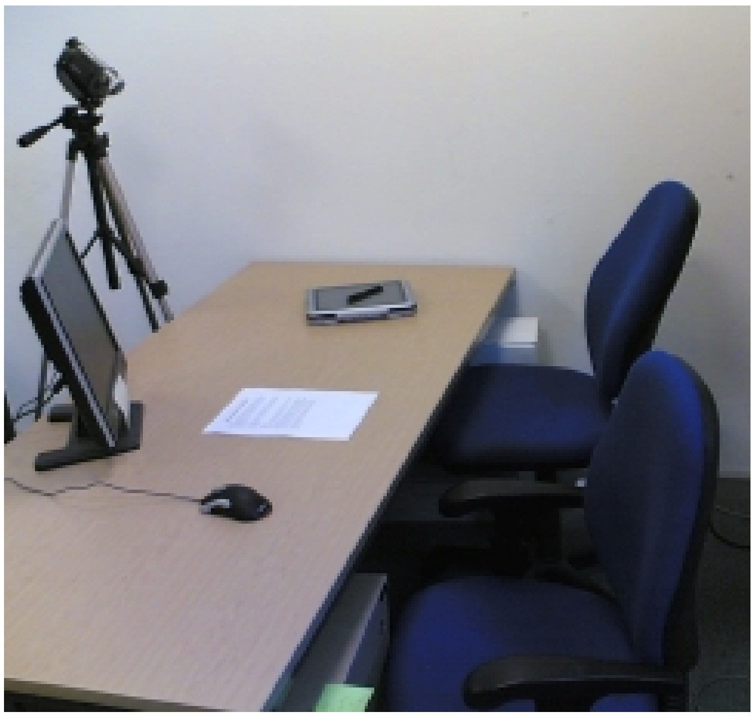
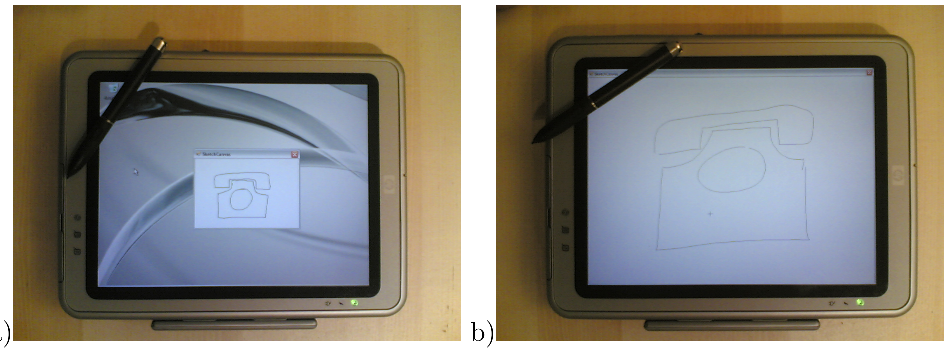


Figure 6.11: The effects of screen size on sketching experimental set-up.

The 17" LCD monitor was used to present the participants with images of what to sketch. The images were stored on the desktop PC and presented to the users through Windows Image Viewer. All images were 600x400 pixels in size. There were five simple images and five detailed images (see figure 6.12). A simple image was a sketch made up of simple geometric shapes. A detailed sketch was based on a simple sketch but contained refined details and annotations. Pilot testing ensured it took approximately the same time to draw the simple sketches and detailed sketches respectively. The experimenter used the mouse to move to the next image when required. The desktop PC was also used to play the experimental instructions to the participant via an audio file using Windows Media Player.

Figure 6.12: The simple and detailed images - left and right columns respectively.

The tablet PC ran two custom-built stand-alone applications - a small sketch application and a large sketch application (see figure 6.13). The large sketch application filled the tablet PC screen at a screen resolution of 1024x768 pixels. The small sketch application was equivalent to the size of a PDA screen measured at 320x240 pixels on an 800x600 pixel screen resolution. Other than the difference in size and resolution, the behavior of the applications was exactly the same. The tablet PC was used in all conditions to control for confounding variables due to the differences between PDA and tablet PC other than screen size.



a) b)

Figure 6.13: The (a) small; and (b) large sketching applications.

The application presented the user with a blank canvas on which to draw. Upon the user pressing down and moving the stylus across the tablet, a single pixel, black line was drawn on the canvas. When the stylus was pressed down, a time stamp was recorded. When the stylus was lifted off the tablet PC, a time stamp was also recorded. The time stamps allowed a log file containing information on how long it took to draw a line and the time between drawing lines. In addition, the current image on the canvas was captured every time the stylus was lifted off the tablet PC. The canvas could be cleared (in order to begin the next sketch) by pressing the 'esc' button on the side of the tablet PC.

In addition to the data logs on the tablet PC, a video record was captured by means of a digital video camera focussed on the participant and the tablet PC.

6.3.1.3 Procedure

Participants were run individually in a sound proof usability lab. At the outset the participant was asked to sit down and a set of pre-recorded instructions were played. Pre-recorded instructions were used to minimise the experimenter's contact with the participant, thereby minimising potential bias between participants. The audio instructions replicated the written instructions stuck to the desk in front of the participant. The instructions were as follows:

> *This experiment is designed to determine the effect of screen size - a large screen (i.e. tablet PC sized screen) and a small screen (i.e. PDA sized screen) - on sketching.*
>
> *During this experiment you will be asked to sketch a set of ten pictures as quickly and accurately as possible. Each sketch will be shown to you in turn on the display in front of you. You will sketch each of these pictures using a tablet PC and stylus. You may position and orientate the tablet PC as you wish throughout the experiment. Upon completing each sketch, please inform the experimenter you are happy, he will then reset the canvas and present you with the next image. This process will be the same for sketching using both the small and large screen sizes.*
>
> *Before starting the experiment you will get the opportunity to familiarise yourself with sketching using the tablet PC and stylus. You will have up to two minutes for each screen size.*
>
> *Before the experiment starts you may ask the experimenter any questions you may have. You may not ask the experimenter any questions during the experiment. You may only inform him you are happy with your sketch of the picture and wish to proceed to the next.*

Before the experiment proceeded the experimenter clarified what he meant by quickly and accurately. *Quickly* meant that these were simply sketches, therefore lines did not have to be perfectly straight and shapes did not have to be perfectly sized. *Accurately* meant that while this was just a sketch, the sketch had to contain all the features of the image and if an object was shown within an object (i.e. a text annotation within a shape) it had to be sketched accordingly. Once these two terms had been clarified the experimenter dealt with any queries the participant had. Once both the experimenter and the participant were satisfied, the warm-up exercise proceeded.

The participant had up to two minutes on each of the small and large sketch applications. During this time the participant could sketch whatever she wanted. This time was used by the participant to get a feel for sketching using the tablet PC and stylus.

When the warm-up time was complete, the experimenter asked the participant if she had any more questions and dealt with them to the best of his ability. When both the experimenter and the participant were satisfied, the experiment proceeded. The experimenter set the digital video camera to record, opened the first sketch application, presented the first image to be sketched, and asked the participant to begin.

Once the participant was satisfied with her sketch of the image, she informed the experimenter, who then reset the canvas and presented the participant with the next image. While the participant sketched the images, the experimenter made notes for post-analysis of any errors made.

The order of the small and large sketch applications was counterbalanced. Within each application, the five simple images were shown first and then the five detailed images. To mitigate learning effects between sketching the simple and detailed images, different orderings were used. Once the participant had sketched all ten images for one sketch application, the experimenter would open the other sketch application, and present the participant with the first of the ten images to be sketched again. The order of the images was different from the first application.

After the participant had sketched all ten images using both applications, a questionnaire was completed (see appendix E). While the participant was completing the questionnaire, the experimenter stopped the recording and saved the log files and the participant's sketches.

Upon completion of the questionnaire, the experiment concluded with an interview in which the experimenter and participant discussed any errors made during the sketching process, seeking the participant's views on what contributed to the errors.

6.3.2 Results

The dependent variables we measured in this experiment were: the time to complete a sketch; and the number of errors made whilst producing a sketch. The times were extracted from log files and represented the time from when the stylus was pressed down on the canvas to draw the first line of the sketch, to the time the stylus was lifted up after drawing the last line of the sketch. Errors were collated after the experiment in one of two categories - minor and major errors. *A minor error* was when an object (i.e. a line or set of lines) intersected another object when it should not have. For example, an annotation that should have been within a square crossed the boundary of the square. *A major error* was when an object was omitted from the sketch; or an object was completely re-positioned. For example, an annotation on a sketch was not drawn, or an annotation could not be drawn within an object and therefore had to be re-positioned to be included in the sketch. (Example statical calculations reported in this section (e.g. full data tables and the results of statistical analyses and pre-tests), can be found in appendix E.)

6.3.2.1 Timings

The mean (and SD) time to sketch a simple or a detailed image for the small and large canvas sizes is shown in table 6.1.

Table 6.1: Mean (and SD) time to sketch a simple and detailed sketch on the small and large canvases.

	Small canvas	Large canvas
Simple Sketches	18.17 (6.34)	20.99 (12.90)
Detailed Sketches	79.02 (27.74)	89.41 (40.41)

The data were analysed using a Wilcoxon test to identify the differences in time when sketching on the small and large canvases.

> No significant difference in the time to sketch simple images was found between the small and large canvas size conditions ($z = -0.828$, $p = 0.20$). Therefore, hypothesis H1(a) was not supported: it would be quicker to sketch simple images on the small canvas compared to the large canvas.

> A significant difference in the time to sketch detailed images was found between the small and large canvas sizes ($z = -2.60$, $p = 0.005$). Therefore, hypothesis H1(b) was supported: it would be quicker to sketch detailed images on the small canvas compared to the large canvas.

6.3.2.2 Error rates

The errors produced while creating a sketch were also measured. In this section we consider both minor and major errors produced, as well as the total errors.

The mean (and SD) for the number of minor, major and total errors produced while sketching detailed images using a small and large canvas are shown in table 6.2.

Table 6.2: Mean (and SD) minor, major and total errors produced when sketching detailed sketches on the small and large canvases.

	Small canvas	Large canvas
Minor	4.23	1.77
Errors	(3.23)	(2.13)
Major	1.18	0.37
Errors	(2.70)	(0.86)
Total	5.42	2.13
Errors	(4.10)	(2.38)

The data were analysed using a Wilcoxon test to identify the differences in the number of errors produced when sketching on the small and large canvases.

> Significant differences were found between the two canvas sizes for the number of minor errors produced (z = -4.12, p = 0.00003), the number of major errors produced (z = -2.77, p = 0.003) and the number of total errors produced (z = -4.93, p = 4.13x10^{-7}). Therefore hypothesis H2 was supported: more errors would be produced when sketching detailed images on the small canvas compared to the large canvas.

For completeness, table 6.3 shows the mean (and SD) for the number of minor, major and total errors produced while sketching simple images using the small and large canvas sizes.

Table 6.3: Mean (and SD) minor, major and total errors produced when sketching simple sketches on the small and large canvases.

	Small canvas	Large canvas
Minor	0.12	0.017
Errors	(0.32)	(0.13)
Major	0.067	0.05
Errors	(0.41)	(0.39)
Total	0.18	0.067
Errors	(0.54)	(0.41)

> A significant difference was found between the two canvas sizes for the number of minor errors produced (z = -2.12, p = 0.015). However, no significant differences were found between the two canvas sizes for the number of major errors produced (z = 0.27, p = 0.39) and the number of total errors produced (z = -1.48, p = 0.069).

The post-experiment questionnaire (based on a five-point Likert scale) also found that it was easier to add detail with the larger canvas (mean = 3.58; SD = 1.08) compared to the small canvas (mean = 1.58; SD = 0.67). However, there was little perceived difference when sketching a simple image - using the small canvas (mean = 3.17; SD = 0.94) and the large canvas (mean = 4.00; SD = 0.60).

6.3.3 Discussion

In this experiment we investigated the difference - in terms of time and errors - between using a small canvas (i.e. a PDA sized screen) and a large canvas (i.e. a tablet PC sized screen) for sketching simple and detailed images. The aim of this experiment was to determine the suitability and use of PDA in the PSPD environment, following a finding from the initial evaluation of PSPD that the PDA were potential unsuitability for creating externalisations, due to their size.

We have shown that the small canvas allowed detailed images to be sketched more quickly than when using the large canvas. The main reason for sketches taking longer on the large canvas was because it took longer to draw each line. The data from the data loggers showed that the time spent drawing a line was nearly twice as long for the large canvas. Participants would scale their sketch accordingly to fill the canvas area, hence taking longer on the large canvas compared to the small canvas.

The speed offered for sketching on a small canvas is often desirable in group design activities as it allows a means of rapid externalisation [e.g. Greene, 2002]. This allows members of a design team rapidly to externalise their design ideas and re-engage in the collaborative process of design.

Of course, the value of these externalisations may be lessened if they contain errors. Although there was no difference in the number of major errors between the small and large canvas when sketching simple images, the small canvas did produce more minor errors. Due to the constrained screen size, there was a higher probability of lines intersecting, giving rise to these minor errors. Overall though, there was no difference in the total errors produced for the small and large canvas when drawing simple sketches. However, when sketching detailed images, sketching using the small canvas resulted in more errors than when using the large canvas.

Our findings suggest that the small canvas, or PDA, is a suitable medium for producing rough, outline sketches. The small canvas allows ideas to be externalised rapidly, while incurring a tolerable number of errors. From here, such outline sketches may be shared and extended through other complementary technologies, such the the tablet PC, allowing for refinement and detail to be added when errors are less likely.

In the next section, we bring the PSPD technologies together and evaluate the use of the entire PSPD environment for supporting creativity in design.

6.4 An evaluation of Public Social Private Design

Building upon our understanding of creativity, the aim of PSPD was to support creativity in design. In chapter 2 we identified three high-level requirements for supporting creativity in design. In chapter 4 we expanded upon these high-level requirements eliciting requirements for CST. Our requirements for CST were reflected upon and refined when applied to the evaluation of the EDC in chapter 5. Based on these requirements we designed and developed PSPD. In the remainder of this chapter we evaluate the use of PSPD supporting three groups of interaction designers collaborating on a creative design task. We observed the interactions between the designers and their interactions with PSPD, analysing PSPD's support for our requirements to support creativity in design. The findings from this evaluation will provided evidence to support or reject the proposal of our requirements for CST.

6.4.1 Method

The evaluation involved three groups of four participants, collaborating together on an interaction design task: the design of an innovative, queue-less, pizza ordering system for use in a pizza restaurant located in the central area of the city of Bath. The groups used PSPD as a CST to assist with their creative process. Interactions with PSPD were captured through two digital video cameras built into the usability lab. The PSPD server also recorded log files of sketch creation and dissemination between the PSPD clients and the PSPD server. This included the capture of the sketches created. Interactions between the designers and their interactions with PSPD were analysed through analysis of the video data and log files. Post-evaluation methods including questionnaires, a retrospective protocol analysis of the video with the participants and a focus group were used to complement the data captured during the evaluation.

6.4.1.1 Participants

12 participants took part in the evaluation - 10 males and 2 females. The participants varied in age from 22 to 40, with a mean of 29.45 years. Participants were university post-graduates and had completed advanced interaction design courses. Participants had a range of academic (1 to 11 years, mean 3.5 years) and industrial (0 to 11 years, mean 1.5 years) experience with interaction design. All participants within each team of four knew each other and had worked with each other directly or indirectly on a variety of interaction design projects. The groups were organised based on their experience, determined through initial interviews with the participants.

6.4.1.2 Equipment

PSPD was used by each of the three groups for the interaction design task. A description of PSPD and its functionality was given earlier in this chapter. However, the version of the software used for this evaluation did not include functionality to manipulate the externalisations (i.e. move, rotate, scale and zoom; and change the pen tool colour and size). This decision was made to reduce the complexity of PSPD for this evaluation, making it easier for the participants to learn the available PSPD functionalities in the time we had available.

6.4.1.3 Procedure

From the outset of the evaluation each participant was given a colour-coded identifier tag, which they were asked to wear throughout the evaluation (this identifier was used by the participants to identify themselves when using the PSPD software). The participants were then asked to take a seat in a designated chair. (Participants could be seated or stand during the evaluation.) Pre-recorded instructions were played to the participants giving an overview of the evaluation. The instructions were pre-recorded to minimise the evaluator's contact with the participants and to ensure that each group was given the same information. After the audio file describing the evaluation had been played, the evaluator asked the participants if they had any questions and answered them to the best of his ability.

The functionality of PSPD was described to the participants via an audio recording. While the audio recording played, the evaluator visually demonstrated the functionality. A list of step-by-step instructions describing how to use PSPD was available on the wall and could be referred to by the participants at any time during the evaluation (see appendix E).

To allow the participants to become familiar with PSPD, they engaged in a practice session. Each group was given the following task:

> *You are a member of a Hollywood film production company. You have been asked to sketch some initial ideas of a scary monster for a new animated horror film.*

Participants were given ten minutes to generate ideas and were asked to utilise the different technologies and functionality of PSPD as much as possible in order to become familiar with it. The evaluator first recommended each participant generate an idea using the PDA, which should then be disseminated to another group member. These pairs were then asked to come together to form sub-groups, refine their ideas and then publicly disseminate them. The whole group then came together and discussed and refined their ideas. This allowed the participants to use all the PSPD technologies, creating, viewing and disseminating externalisations. The evaluator was on hand to answer any questions.

After they had completed the practice session, the evaluator checked again if the participants had any questions. When the participants and the evaluator were satisfied, the evaluation session began.

The evaluator played an audio recording of the evaluation activity to the participants:

> *A pair of rich venture capitalists have hired you to help them think up and design an innovative, pizza ordering system for use in a pizza restaurant (this is not an internet-based system). The design should consider both the hardware and the software. The overall goal of the system is to: cut running costs, increase sales and offer a great customer experience. Note that any solution that created queues would be unsatisfactory from a customer experience point of view.*
>
> *The system will be installed in Bath city centre near other popular restaurants, flashy bars and local attractions. The venture capitalists want the restaurant to differentiate itself from the competition. The main customers of the restaurant will be well-off students, tourists and successful young professionals. The restaurant hasn't been built yet - it's still just an idea. The venture capitalists do know that they want it to be a sit-down, not a take-away.*

The activities for the group are as follows:

Activity 1) Discuss and come up with possible solutions for a pizza ordering system that satisfy the venture capitalists requirements.

Activity 2) From the possible solutions generated during activity 1, decide on a final solution to be recommended to the venture capitalists.

These activities are not designed to produce polished designs. Rather, the venture capitalists are looking at initial ideas for the design of the hardware and software for such a proposed system.

There is no time limit for the following activities. The evaluation will stop when the group is happy that they have generated potential solutions for an innovative pizza ordering system and have decided on a final solution to recommend to the venture capitalists.

Assumptions and constraints: Money is not an object! Try to work within today's technological constraints.

Finally, draw upon your own knowledge and experiences to assist you with this task.

A copy of the above text was then attached to a wall, allowing participants to refer to it at any time. Once the evaluator had dealt with all questions by the participants, the cameras were set to record and the session began. The evaluator sat in an adjacent room, monitoring the participants' activities through screens displaying the camera feeds. The evaluator noted interesting events to raise during the retrospective protocol analysis. The three groups took between 58 and 100 minutes to complete the activity, with a mean of 76 minutes. At the end of each evaluation session the participants completed a questionnaire about PSPD (see appendix E). In addition the evaluator conducted a retrospective protocol analysis with the group using the video recording. To conclude, a focus group was conducted to gather additional information about the participants' experiences using PSPD.

6.4.2 Findings

As argued in chapter 5 (see section 5.4), it was not feasible to determine whether PSPD was 'better' than other tools supporting creativity in design (e.g. traditional design tools such as paper and pencils), nor was it plausible to do so [Nunamaker *et al*, 1991]. The evaluation of PSPD therefore drew upon qualitative techniques as recommended by previous research [e.g. Nunamaker *et al*, 1991; Shneiderman *et al*, 2006].

We could have evaluated PSPD using existing groupware heuristics [e.g. Baker *et al*, 2001; Baker *et al*, 2002]. However, as argued in chapter 5 such groupware heuristics are not applicable to CST (see section 5.4). Appendix E reports the results of a heuristic evaluation of PSPD using heuristics derived specifically from our requirements for CST.

The findings that we report here are based on an analysis of the video footage, post-evaluation questionnaires, a retrospective protocol analysis of the video with the participants and a focus group. This evaluation aimed to evaluate the use of PSPD, reflecting upon our design decisions made to support our requirements for CST. This in turn will allow us to further justify our requirements for CST. Our analysis of the video data encoded events based on foci and interaction analysis [Jordon & Henderson, 1995]. From the video data we recorded time stamps, the participants of interest (e.g. speaking), the phase of the creative process, the interaction type (e.g. verbal communication, sketching, pointing, etc), the technology being used, group composition, the occurrence of social influences and any comments/notes. (An excerpt from the encoded video data can be found in appendix E.) We present our findings using our three high-level requirements for supporting creativity elicited in chapter 2 as a framework (i.e. a set of evaluation heuristics).

> **High-level requirement 1: Support the creation and dissemination of externalisations to support the phases of the creative process.**
>
> **High-level requirement 2: Support the various compositions of a group using appropriately sized interaction spaces.**
>
> **High-level requirement 3: Support the control of social influences.**
>
> > **High-level requirement 3.1: Support the control of production blocking by providing synchronous forms of interaction.**

High-level requirement 3.2: Support the control of evaluation apprehension by anonymising one's externalisations.

High-level requirement 3.3: Support the control of free-riding by making individuals accountable for their own performance.

6.4.2.1 Supporting the creation and dissemination of externalisations

PSPD supported various externalisations allowing shared understandings to develop (i.e. problem framing), the creation of new concepts (i.e. idea generation), ideas to be framed (i.e. idea framing) and the critique and negotiation of these concepts (i.e. idea evaluation). From our analysis of the creative process documented in chapter 4 (see section 4.2.2.2), PSPD was designed to support the occurrence of six types of interaction: verbal communication, sketches, annotations, text, pointing, and gesturing. Table 6.4 presents the mean proportions of the six types of interactions observed between participants and PSPD for each of the phases of the creative process. This data is not intended to make any precise statistical claims, but provide evidence for general trends complementing our qualitative data.

We shall now consider the occurrence and use of these externalisations across the various phases of the creative process.

Problem framing

Verbal communication was the primary form of interaction (85.38% of interactions) during the problem framing phase of the creative process, while text was the only representation used to externalise information (3.86% of interactions). Participants interacted with these textual externalisations through pointing (7.80% of interactions) and gestures (2.86% of interactions) to complement their verbal communication.

During the problem framing phase of the creative process participants built up a shared understanding by discussing the problem and telling others about their past experiences and knowledge of this problem domain. For example, when discussing the problem the participants would break it down asking themselves questions such as, 'what is it to design an innovative, pizza ordering system?'; 'what does it mean by innovative?'; and 'how do you order a pizza?'. As described by Jones [1970], the problem framing phase involves breaking the problem down into pieces. When sharing experiences with one another the participants would talk about how a pizza is ordered at current pizza establishments, such as Pizza Hut and Pizza Express.

Table 6.4: Mean (and SD) % of interaction across the various phases of the creative process.

	% Verbal comm.	% Sketches created	% Annotation created	% Text created	% Pointing interactions	% Gesture interactions
Problem	85.38	0.00	0.00	3.86	7.80	2.96
framing	(6.75)	(0.00)	(0.00)	(5.85)	(3.15)	(2.94)
Idea	58.90	17.15	2.20	0.00	10.79	10.96
generation	(5.34)	(5.90)	(1.13)	(0.00)	(1.54)	(2.89)
New	79.07	5.00	1.67	0.00	1.67	12.59
ideas	(12.50)	(8.66)	(2.89)	(0.00)	(2.89)	(3.57)
Refined	57.56	18.11	2.17	0.00	11.34	10.83
ideas	(6.27)	(6.89)	(1.08)	(0.00)	(1.52)	(3.14)
Combined	50.00	0.00	0.00	0.00	25.00	25.00
ideas	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Idea	67.43	8.79	4.88	0.66	14.03	4.20
framing	(6.63)	(5.18)	(3.73)	(1.14)	(0.78)	(2.89)
Idea	81.14	0.00	0.00	0.00	13.11	5.75
evaluation	(8.03)	(0.00)	(0.00)	(0.00)	(7.76)	(1.14)

These verbal discussions lead to the participants understanding the core process of ordering a pizza and the establishment of a set of criteria for a desired solution.

Textual externalisations complemented the participants' verbal communications. Using PSPD the participants would list key features of the problem, requirements for a desired solution and the steps involved when ordering a pizza. For example, one group used PSPD to list all the steps involved when ordering a pizza so they all understood the process.

> *G1P4 (00:07:10) - "So you are going to have to get a table."*
>
> *G1P3 (00:07:13) - "[P3 uses PSPD to write down the first step in the process to ordering a pizza - Wait for table]"*
>
> *G1P3 (00:7:28) - "OK... get a table."*
>
> *G1P2 (00:7:30) - "Yeah, because you might have to wait to see the person who is assigning the tables."*
>
> *G1P3 (00:7:32) - "[P3 uses PSPD to write down the second step in the process to ordering a pizza - Seated at a table.]"*
>
> *G1P3 (00:7:40) - "OK... get seated at a table."*
>
> *G1P1 (00:7:43) - "Choose food?"*

This finding suggests PSPD met *Requirement 1.3*: CST should support the creation of text.

Sketches and annotations were not created during the problem framing phase of the creative process. This was due to their unsuitability. We argue that sketches were not suitable as they are ambiguous [Buxton, 2006]. As such, they were not suitable for listing key features of the problem, specifying requirements for a desired solution and describing the steps in a process. Sketches lacked the appropriate level of granularity to effectively specify such information. This is not to say that in a different situation (e.g. a different design task) sketches and annotations would not have been used. PSPD provides its users with a flexibility to create externalisations that suit them and the task at hand.

PSPD allowed the participants to create a shared representation of their thought process. Not only did this externalisation provide a frame of reference for the discussion (i.e. what stage of the process are we at now) [e.g. Fischer, 1999a], but it also provided a lasting representation that could be referred to by the participants throughout the design task [e.g. Hargadon & Sutton, 2000; Scrivener & Clark, 1994]. As one of the participants mentioned during the focus group, "I brought the process model back up on my PDA later in the design task in order to refer to it". *Requirement 1.12* specifies that, 'CST should support the storage and protection of generated ideas'. While this requirement is limited to the storage and protection of externalisations created during idea generation, our findings suggest that it is also beneficial to support the storage and protection of externalisations created during other phases of the creative process, such as problem framing. Hence, a refinement to *Requirement 1.12* is:

> **Requirement 1.12 (refined): CST should support the storage and protection of externalisations created throughout the creative process.**

Pointing and gesture interactions were used to further complement the participants' verbal communications, referencing the textual externalisations - deictic references and illustrative gestures [Baker *et al*, 2001]. These pointing and gesture interactions provided a secondary form of communication, making it clear what a participant was referring to, avoiding misunderstandings and confusion [e.g. Baker *et al*, 2001; Bekker *et al*, 1995; Tang & Leifer, 1988]. This finding meets two of our requirements for CST - *Requirement 1.4*: CST should support users' pointing interactions with externalisations; and *Requirement 1.5*: CST should support users' gesture interactions with externalisations.

During the problem framing phase of the creative process participants had to build up an understanding of the problem - listing key features of the problem, developing requirements and understanding processes. This understanding of the problem facilitated the generation of ideas to solve the problem. During the EDC evaluation, participants frequently return back to the problem framing phase - "what is the orange land-type again?". This was not the case in the PSPD evaluation. Why was this? During the EDC evaluation participants were provided with a pre-defined domain to work in (i.e. the Gunbarrel map of Boulder), were given pre-defined notations for the task (i.e. land-type colourings) and user roles (i.e. personas). Whereas, during the PSPD evaluation participants had to define the problem from the ground up, thereby satisfying *Requirement 1.8*: CST should not constrain the ways users externalise their ideas. We therefore argue that allowing participants to develop an understanding of the problem from the ground up facilitated the development of the groups shared understanding. This arguement has been made by previous researchers [e.g. Jones & Greene, 2000]. As acknowledged in chapter 5 (see section 5.4.1.1), there is a trade-off between system-defined contexts and user-defined contexts. In the case of problem framing, our findings suggest that user-defined contexts facilitate shared understandings of the problem.

PSPD facilitated the development of shared understandings throughout the creative process. PSPD achieved this through the creation of and interaction with textual externalisations, which complemented the participants' discussions. The use of these externalisations was a necessity to creating shared understanding of the problem and eventually the generation of design ideas.

Idea generation

During the idea generation phase of the creative process, verbal communication accounted for most interactions (58.90% of interactions). This is much less than any other phases of the creative process. Correspondingly, the creation of sketches (17.15% of interactions), the creation of annotations (1.75%) and pointing (10.79% of interactions) and gesture (10.96%) interactions were relatively high.

Ideas were primarily expressed by verbally describing an idea to the group. For example, two of the groups suggested designing a sushi style pizza restaurant. Of course, such an idea can be hard to visualise and this is where PSPD came in useful as it supported the creation of externalisations, thereby complementing the groups verbal communications. As the design task involved designing the hardware and software of a pizza ordering system - two very visual components - sketches were used to externalise the participants' ideas. An example externalisation of the sushi pizza ordering system can be seen in figure 6.14.

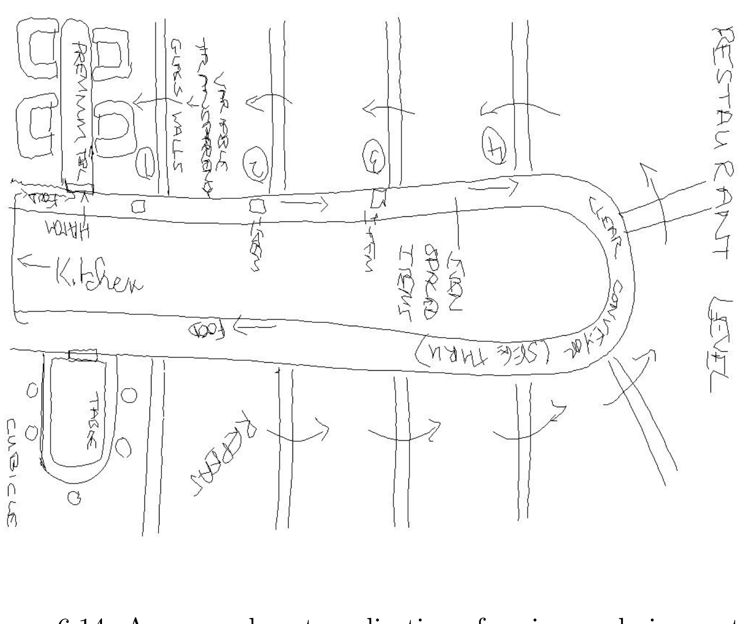


Figure 6.14: An example externalisation of a pizza ordering system.

This finding indicates the support of one of our requirements for CST - *Requirement 1.1*: CST should support the creation of sketches.

Annotations were also used to complement sketches. Annotations could take the form of text, which described a particular feature of a sketch. Furthermore, annotations could take the form of symbols. Symbols could indicate features of a sketch, or they could add dynamic meaning to an otherwise static sketch. For example, as we can see in figure 6.14, annotations indicate the conveyer belt and the kitchen to name a few examples. Symbols were used to annotate the sketch indicating where the toilets were located and the direction of movement for the conveyer belt. Hence, *Requirement 1.2* was met: CST should support the annotation of sketches. The framing of information reduced the need for participants to ask idea framing questions later in the design task. This was a problem experienced when using the EDC as discussed in chapter 5 (see section 5.4.1.2).

While the occurrence of sketches and annotations were common during the idea generation phase of the creative process, textual representations were not used. Text could not convey the visual richness that was required in this and many other design activities. After all, 'a picture says a thousand words'.

As described in chapter 5, idea generation occurred as either a 'dry or wet run' (see section 5.4.1.2). A 'dry run' was common when ideas were being created in the group composition. A participant would explain her idea to the group and then after some discussion, the idea would be externalised using PSPD. For example, one group discussed the sushi style pizza ordering system for some time before using PSPD to externalise their idea. When asked during the focus group why this was, one participant said, "an idea has to have a certain degree of refinement before it can be externalised and further explored". However, it was hard to effectively describe new ideas using this 'dry run' approach to idea generation. Using the EDC, participants could point and gesture to the EDC, which presented a framework (i.e. a map, existing land developments, etc) for the idea to be framed within. As argued by Tang & Leifer [1988, p.247], 'although gestures might not typically be thought of as a medium for storing information - because they do not leave behind any permanent record - we have evidence that information can be effectively chunked and remembered through gestures, especially if the gesture is imitated by others and labelled in text or graphics'. However, as PSPD provided a blank canvas, it was left up to the participant's imagination to visualise what her collaborators were describing to her. This resulted in a degree of confusion and misunderstanding between participants at times. Once again, we are seeing a trade-off between system-defined and user-defined contexts. During the PSPD evaluation the participants had not performed the ground work to support the generation of 'dry run' ideas, by pointing and gesturing with existing externalisations. This was a problem when generating new ideas and dealing with a blank canvas. This presents a potential problem with *Requirement 1.8*: CST should not constrain the ways users externalise their ideas.

Futhermore, as there were no initial externalisations to support one's gestures *Requirement 1.5* was impacted: CST should support users' gesture interactions with externalisations. While providing system-defined contexts may constrain the way users' externalise ideas, they do facilitate the 'dry run' style of idea generation. However, it should be acknowledged that as externalisations were created using PSPD and ideas were refined, this problem was mitigated.

Ideas were also externalised without prior discussion with the group (i.e. a wet run). This happened when an individual expressed an idea using their PDA. An individual could externalise and reflect upon an idea in her own private space, while not disturbing the other group members. This was not the case when using the EDC. If an idea was immediately externalised using the EDC's tabletop, the rest of the group could merely look on. When one participant immediately externalised an idea during the EDC evaluation, another participants said, "what are you doing?". PSPD, supported the 'wet run' approach to idea generation, while not being disruptive. For example, one participant used the PDA to externalise an idea he had, while the rest of the group were discussing the design task. At the appropriate time he was able to present his idea to the rest of the group. This finding suggests four of our requirements for CST were met - *Requirement 2.1*: CST should support individual activities using small interaction spaces; *Requirement 3.1*: CST should support synchronous forms of interaction, thereby reducing the effects of production blocking; *Requirement 3.4*: CST should support individual/private interactions, thereby reducing the effects of evaluation apprehension and free-riding; and *Requirement 3.5*: CST should make individuals accountable for their own productivity, thereby reducing the effects of free-riding.

Such externalisations could then be complemented by pointing and gesture interactions. For example, when designing the layout of a restaurant, one participant pointed to the corners of the restaurant and said to the others in the groups, "we could have the toilets here". Furthermore, when generating the idea of a sushi style pizza ordering system the participant gestured the direction of the conveyer belt's movement. Hence, two of our requirements for CST were met - *Requirement 1.4*: CST should support users' pointing interactions with externalisations; and *Requirement 1.5*: CST should support users' gesture interactions with externalisations. Annotations also allowed contextual information expressed through verbal communications and complemented by pointing and gesture interactions to be captured and stored, thus reducing unnecessary phases of idea framing later in the design activity. This met another of our requirements for CST - *Requirement 1.2*: CST should support the annotation of sketches.

Idea generation led to the generation of three types of ideas as discussed throughout this thesis: new ideas, refined ideas and combined ideas.

New ideas were predominantly verbally described (79.07% of interactions) and were complemented by gesture interactions (12.59% of interactions). For example, the sushi style pizza ordering system was verbally discussed in the group, with gestures used to illustrate the movement of the conveyer belt. It was rare for sketches to be created for new ideas (5.00% of interactions). This was very different from the users who used the EDC. When using the EDC, new ideas were frequently externalised through the creation of externalisations. This may have been because less effort was needed to externalise an idea into the framework provided by the EDC. Whereas, it took more effort to develop a new idea using PSPD, therefore more time was invested discussing the proposed ideas. This finding suggests that the system-defined contexts provided by the EDC were advantageous when externalising ideas. As argued by Fischer [2000] a challenge for social creativity is to capture a significant portion of the knowledge generated by a group. To achieve this the individual generating the idea must perceived the benefit to outweigh the effort required; and the effort required to externalise an idea must be minimal as not to interfere with getting real work done [Carroll & Rosson, 1987]. The effort required to externalise a new idea using PSPD outweighed its benefit. Therefore, ideas were verbally discussed between participant. When an idea was chosen to be explored further it was externalised. Hence, PSPD constrained the externalisation of divergent ideas in the early phases of a design activity. Through the use of PSPD we see a conflict with *Requirement 1.6*: CST need to support the creation of new externalisations - divergent thinking. However, during the latter stages of the design activity in the PSPD evaluation, multiple ideas were generated and externalised using PSPD (i.e. divergent thinking). However, these were divergent ideas that made part of the chosen solution. These divergent thinking activities usual occurred when tasks were delegated and group members engaged in individual and sub-group activities. When the group reconvened, ideas would be framed, critiqued and selected during convergent thinking activities. Hence, we see from this finding that PSPD supported divergent thinking in the latter phases of a design activity. Therefore, *Requirement 1.6* was partially supported.

Refined ideas involved much less verbal communication (57.56% of interactions) and involved the creation of sketches (18.11% of interactions) and pointing (11.34% of interactions) and gesture (10.83%) interactions. The reason for this was that once the core solution for the design activity had been established amongst the group (i.e. a shared understanding developed), participants would delegate individual and sub-group activities refining various design ideas. These activities involved less verbal communication and focussed more on the refinement of the design ideas to be presented to the group. This was quite different from using the EDC where the refinement of ideas involved much more verbal communication. The EDC only had a single solution space, meaning multiple refinements of an idea could not exist at once. This resulted in more verbal agreement between the participants using the EDC before a decision was made. Whereas, PSPD allows sketches to be copied and refined without affecting the original sketch. This allowed for the exploration and refinement of ideas. This finding suggests PSPD met *Requirement 1.7*: CST should support the refinement of ideas: convergent thinking. In particular, this support was provided as two of our other requirements were satisfied - *Requirement 1.1*: CST should support the creation of sketches; and *Requirement 1.12*: CST should support the storage and protection of generated ideas.

Combined ideas were rarely observed. In fact, only one idea generated was from the combination of two existing ideas. Combining ideas did not require the creation of a new externalisation as they already existed in PSPD as representations of previously generated ideas. Participants simply pointed (25.00% of interactions) and gestured (25.00% of interactions) at the existing externalisations and verbally communicated (50.00% of interactions) with the group about their ideas. Hence, *Requirement 1.11* was met: CST should support the combination of previously generated ideas. This support was achieved through two requirements for CST that were met - *Requirement 1.4*: CST should support users' pointing interactions with externalisations; and *Requirement 1.5*: CST should support users' gesture interactions with externalisations.

Finally, as briefly mentioned above, PSPD supported the creation of many sketches, which allowed multiple ideas and refinements of ideas to be generated. For example, one group split their final design of their restaurant into three levels - a restaurant level, a cubicle level and a table level. The group created a new sketch for each level. This was similar to the support provided by paper as reported in chapter 4 where participants used multiple sheets of paper to externalise different ideas (see section 4.3.2.1). For example, when one pair of participants were sketching their futuristic car design, they used multiple sheets of paper to represent different views of the car. Yet, PSPD extends the use of paper allowing ideas to be copied and refined without any re-drawing required. This functionality further extends existing CST, such as the EDC which limited the participants to one solution space, resulting in externalisations being removed to allow new ideas of refined ideas to be externalised; and required externalisations to be re-created when returning to a previously externalised idea. Hence, two requirements for CST were met - *Requirement 1.6*: CST should support the generation of new ideas: divergent thinking; and *Requirement 1.7*: CST should support the refinement of ideas: convergent thinking. Participants did comment that a useful extension to the sketching functionality provided by PSPD would be to allow hotspots that allowed the user to navigate between sketches - similar to that provided by DENIM [Lin *et al*, 2002] and SILK [Landay, 1995].

During the idea generation phase of the creative process, externalisations facilitated the exploration of ideas between members of the group. The creation of externalisations had its most dominant role in this phase of the creative process, allowing ideas to be shaped ready for idea framing and their subsequent evaluation.

Idea framing

Idea framing predominantly involved verbal communication between the members of the group (67.43%), as well as a high frequency of pointing interactions with externalisations (14.03%). It should be noted that interactions with externalisations were most common during the idea framing phase of the creative process. Interactions with externalisations were essential to framing an idea, complementing one's verbal communication. Idea framing rarely required the creation of sketches, since they already existed (only 8.79% of interactions). Although rare, one group also created textual externalisations (0.66% of interactions). Furthermore, this phase saw the highest occurrence of annotations being created (4.88% of interactions). Hence, PSPD met five of our requirements to facilitate idea framing - *Requirement 1.1*: CST should support the creation of sketches; *Requirement 1.2*: CST should support the annotation of sketches; *Requirement 1.3*: CST should support the creation of text; *Requirement 1.4*: CST should support users' pointing interactions with externalisations; and *Requirement 1.5*: CST should support users' gesture interactions with externalisations.

Idea framing complemented the idea generation phase of the creative process, allowing shared understandings of ideas to be established between group members. Taking the example of the sushi style pizza ordering system, a participant described to the group how a pizza coming along the conveyer would be represented through a UI on the customers table.

> *G3P1 (00:51:52) - "So this is a representation of the whole conveyer. You have items going around like that. Then you can touch on it and it'll blow up into this area - what is it."*

While participant P1 was explaining the UI design to the rest of the group, he was constantly pointing to various features on the sketch. This created a point of reference complementing his verbal communication and assisted facilitating a greater understanding between members of the group - a deictic reference [Baker *et al*, 2001].

In addition to the features of an idea being discussed, annotations were also commonly used to provide a permanent framing of information. For example, pointing to the centre of an early version of figure 6.15, a participant said, "what is this?" Another participant answered, telling him that it was the kitchen. An annotation in the form of a label was then added to permanently convey this information. Another example was when a participant gestured the motion of the conveyer belt for the sushi style pizza ordering system. Adding annotations in the form of arrows permanently reflected the direction of movement of the conveyer belt.

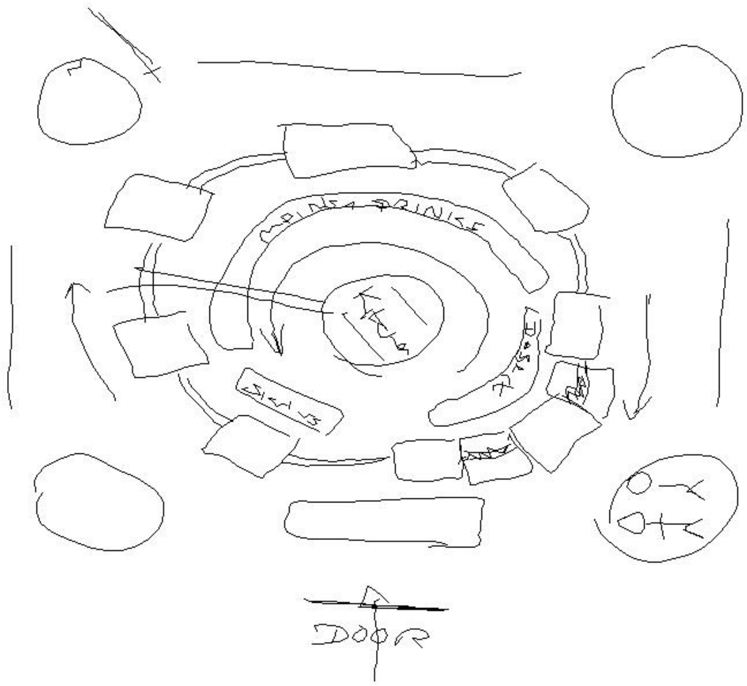


Figure 6.15: An example of idea framing using annotations.

It was rare for sketches and text to be externalised during the idea framing phase of the creative process. The creation of sketches allowed existing externalisations to be clarified. For example, one of the groups who were designing a sushi style pizza ordering system designed their restaurant as a ride. When discussing where customers would start the ride, participants added a door to their externalisation further framing the idea. Only one group created textual externalisations during the idea framing phase. These textual externalisations were used to externalise idea framing questions, such as, ‘how many people?’. Using PSPD to externalise these idea framing questions allowed the participants to reduce their cognitive load and see what issues needed to be addressed.

Pointing interactions complemented participants’ verbal communications, allowing a more concrete understanding of generated ideas to be developed. Furthermore, the contextual information conveyed through pointing and gesture interactions was permanently represented through annotations. The creation of sketches allowed idea that were already externalised to be clarified. The creation of textual externalisations facilitated the groups’ idea framing process, as idea framing questions could be externalised and stored. This phase of idea framing allowed greater understandings to be developed facilitating other phases in the creative process, such as the more effective evaluation of generated ideas.

Idea evaluation

The idea evaluation phase of the creative process involved verbal communication as its primary form of interaction (81.14% of interactions). This was frequently complemented through pointing interactions acting as a secondary form of communication (13.11%). The creation of externalisations was not observed during the idea evaluation phase of the creative process.

Idea evaluation focussed around the externalisations created during the idea generation phase of the creative process. Pointing to the various features of an externalisation identified to others in the group what a participant was critiquing. This ease of reference provided by the externalisations facilitated the evaluation of ideas. For example, one of the groups was designing an entertainment area for their restaurant. Looking at their restaurant layout and pointing to the entertainment area, one participant said, "This is getting too big". Without the externalisations presented by PSPD in such instances, this idea evaluation activity would have been much less effective and efficient. Hence, PSPD met one of our requirements for CST - *Requirement 1.4*: CST should support users' pointing interactions with externalisations.

As mentioned in chapter 5, users of the EDC evaluated their generated ideas against the surrounding environment in which their ideas were situated, rather than comparing ideas directly against each other (see section 5.4.1.4). We argued that this was because only one idea could be explored at a time. However, using PSPD multiple versions of a solution could be developed and compared against one another. While the PSPD software did not support the presentation of multiple externalisations on the same device (although thumbnails could be compared against one another), participants did compare alternative externalisations on different devices. For example, two participants working in a sub-group were able to compare ideas for table designs, where each design was on a PDA. Of course, the exploration of multiple solutions is limited to the number of devices available. However, this set-up did allow the exploration of ideas rather than a trail-and-error approach to getting the right design. Hence, another of our requirements for CST was met: *Requirement 1.13*: CST should support the comparison of generated ideas.

The idea evaluation phase of the creative process allowed the group to iterate through the various phases of the creative process - redefining the problem where necessary, generating alternative solutions, refining existing ideas and developing understandings of ideas where appropriate.

Our evaluation suggested that PSPD was successful in supporting the phases of the creative process. PSPD directly supported the production of sketches, annotations and text to externalise ideas, which in turn allowed for further interactions (i.e. pointing and gesturing at externalisations). These types of interactions encouraged and enabled shared understandings to develop, the creation of new concepts, ideas to be framed and the critique and negotiation of these concepts.

6.4.2.2 Supporting group compositions

PSPD supported the various group compositions of a design team - individual, sub-group and group compositions - and the transitions between them.

All our evaluation groups engaged in individual, sub-group and group activities. The groups initially started the evaluative activity as a group, framing the problem and sharing past and related experiences. As an understanding of the problem was developed and ideas began to be generated, some members of the groups engaged in individual activities, working through ideas to propose to the group. All groups developed the basis of an agreed idea as a group. When the general idea was established, the group would split, delegating the refinement of the ideas into individual and sub-group activities. Sub-group compositions were preferred during this stage of the design process. Individuals worked in a private interaction space when they had a particular idea of their own they wished to work through. Finally, the group would come back together to present the refined ideas they had developed and how they fitted into the final solution. During this final group composition the design was critiqued to make sure it satisfied the criteria for a solution to their assignment. Based on this finding, we can see that PSPD met four our our requirements for CST - *Requirement 2.1*: CST should support individual activities using small interaction spaces; *Requirement 2.2*: CST should support sub-group activities using interaction spaces that create a sense of social inclusion; *Requirement 2.3*: CST should support group activities using large interaction spaces; and *Requirement 2.4*: CST should support the transition between individual, sub-group and group activities.

An advantage of using the PDA and tablet PC was their mobility. Unlike other CST [e.g. Stefik *et al*, 1987; Streitz *et al*, 1999] where the technologies are built into the architecture of the meeting room and are thereby constrained by its physical properties, PSPD allowed the technologies to be merged into the same interaction space. For example, as already mentioned above, an individual was able to generate potential ideas on a PDA while being in the interaction space of the group and the tabletop, able to see and hear what was being discussed. Furthermore, participants frequently switched between interaction spaces, for example switching between working as a sub-group on a tablet PC and then sharing the public interaction space of the tabletop. This supported the transition between group, sub-group and individual activities - the transition between loosely and tightly coupled collaboration

[Gutwin & Greenberg, 2000]. This finding suggests further evidence that PSPD met *Requirement 2.4*: CST should support the transition between individual, sub-group and group activities.

While the PDA, tablet PC and interactive tabletop were each chosen for individual, sub-group and group activities respectively, their use sometimes differed from our intentions. One participant decided to use the tablet PC to create a private interaction space. Furthermore, when working individually using a PDA, participants would sometimes show their externalisations to their sub-group collaborators to get some feedback. While it has been argued small interactions spaces are not suitable for collaborative activities [Kostakos *et al*, 2006; O'Neill *et al*, 2004], the PDA was suitable to briefly present a design facilitating short bursts of collaboration before re-engaging in an individual activity. In another case, two participants used their own PDA to engage in a sub-group activity. Rather than relocate and use a tablet PC, they socially disseminated their externalisations and used the PDA to view the externalisations while talking about them to each other with their backs to each other on opposite sides of the tabletop. When asked why they did this, one participant said, "it was not worth the effort, I just wanted to see it (the sketch)". The other participant commented, "by verbalising the idea across the table, it allowed the others in the group to have an awareness of what was going on". Gaver [1991] argues that such an awareness is essential for all collaborative work.

While the PDA was intended for private use, creating a space for initial ideas to be developed [Warr & O'Neill, 2006a] and was used in this way, some participants commented that the interface was too small, both in terms of creating and retrieving externalisations that were created on the tablet PC or tabletop. For example, one participant mentioned that he tried to retrieve a process diagram that was developed by the group, however the interface on the PDA was too small to read the text. Some participants commented that the tablet PC provided a suitable sized interaction space for private activities as well as social activities. However, it was also argued that the PDA could be a more suitable device to extend beyond co-present activities in a room, allowing for distributed idea generation [e.g. Warr, 2006]. However, in this version of PSPD, the technologies were not able to be used beyond the meeting room. Therefore, PSPD did not met *Requirement 2.5*: CST should support creative activities beyond the meeting room.

The PSPD environment provided flexibility for the group to use the technologies to create a range of interaction spaces, in intended and unintended ways, to support their creative activities. Through the use of the interactive tabletop, the tablet PC and the PDA, the design teams were able to engage in group, sub-group and individual activities, as well as the transition between these activities. Furthermore, they were able to successfully adapt the use of the technologies to suit their needs as the activity progressed.

6.4.2.3 Supporting the control of social influences

PSPD supported the control of the social influences reported to inhibit creativity in real groups: production blocking, evaluation apprehension and free riding.

Production blocking: PSPD overcame the effect of production blocking by providing multiple technologies that could be used simultaneously. For example, while one group were engaged in a phase of framing the problem around the tabletop, one participant (P3) picked up his PDA and started sketching some ideas he had. While P3 was externalising his ideas on a PDA he was still in the interaction space of the group, able to see and hear what was being discussed. When the others in the team had finished their discussion, P3 asked if he could bring his ideas up and present them to the group. P3 retrieved his ideas on the tabletop and discussed them with the group. This finding suggests PSPD met *Requirement 3.1*: CST should support synchronous forms of interaction, thereby reducing the effects of production blocking.

While PSPD was suitable for generating new ideas, it was not considered entirely practical for refining ideas. If a member of a group retrieved an externalisation and then refined it while the rest of the group worked on the same externalisation, the two externalisations would be out of sync. This would require one externalisation to be updated with the refinements made in the other, consuming time and effort. Hence, it was important for participants to be aware of their collaborators activities [e.g. Gaver, 1991].

Although told it was not possible for multiple participants to interact with a single device at the same time, there were occasions when two participants tried to draw on the tabletop at the same time. Hence, PSPD did not meet *Requirement 3.2*: CST should support multiple inputs, thereby reducing the effects of production blocking. During the focus group, participants requested that PSPD be developed to support multiple inputs. This was particularly desirable for the tabletop where participants said they would want to work on an externalisation at the same time or even work at each end of the tabletop (e.g. Tang *et al*, 2006).

Evaluation apprehension: PSPD mitigated the effects of evaluation apprehension by anonymising participants' externalisations, as recommended by previous research [e.g. Paulus & Dzindolet, 1993]. Hence, PSPD met *Requirement 3.3*: CST should support the removal of a user's identity from their ideas, thereby reducing the effects of evaluation apprehension. It was left to group members to identify themselves with an externalisation, if they wished

However, it was the public, social, private architecture that was observed to reduced evaluation apprehension. When a participant worked on ideas in her private space, she would disseminate only those ideas she wished to share. As one participant commented, "I generated about seven sketches on the PDA, but only decided to disseminate two of them". Because such sketches were private, participants had no need to fear criticism from others and could disseminate the externalisations that had reached a degree of refinement and they were satisfied with. Therefore, PSPD met *Requirement 3.4*: CST should support individual/private interactions, thereby reducing the effects of evaluation apprehension and free-riding.

On a few occasions the tablet PC was used as a private interaction space by a single participant. The publicness of a device is not merely determined by the interaction space it creates but also by the architectural space in which the device is used [Kostakos *et al*, 2006]. One participant (P4) left the group at one stage to work on a system diagram. P4 went to a desk with her back facing the rest of the group while the others in the group evaluated their current ideas around the tabletop. When questioned during the retrospective protocol analysis P4 said, "I like to have my private space if I am not sure. The whole time I felt like I did not want my idea to be criticised (the system diagram). So I would like to use this first (the PDA/tablet) and then share it when I am sure". P4 chose the tablet PC over the PDA for her externalisation as the PDA was too small for her needs at that time. PSPD allowed P4 to work through her ideas in her on private space. This reduced the effects of evaluation apprehension, as well as making her accountable for her own productivity. This finding provides further evidence that PSPD met *Requirement 3.4*.

Free riding: From the questionnaire data, participants were in strong agreement that all members of the group contributed equally (4.08 on a five-point Likert scale; SD = 0.52). A reason for this was the ability for the group to assign tasks. Due to the technical set up, the group was not constrained to work as a whole group all of the time, but could delegate tasks, allowing members to be responsible for a certain aspect of the design. Rather than the design process being a universally collective activity it involved periods of individual input. Therefore, this finding suggests PSPD met *Requirement 3.5*: CST should make individuals accountable for their own productivity, thereby reducing the effects of free-riding.

PSPD provided the technologies to reduce the effects of social influences upon creativity, with the ability to move externalisations of ideas between private, social and public being seen as particularly important. This reduced the social constraints upon the creative process and hence increased the creative potential of the design teams.

6.5 Summary

In this chapter we have reported details of the design, development and evaluation of our CST: PSPD. We first described PSPD in terms of its underlying framework, hardware and software, and how these components aimed to support creativity in design. We next conducted an initial evaluation of PSPD to identify design problems and issues. This work influenced the design of an experiment to determine the suitability and use of PDA in the PSPD environment. Finally, we evaluated the PSPD environment comparing its practical use against our requirements for supporting creativity in design.

The three major components of PSPD that enabled it to support creativity were its framework, hardware and software.

The PSPD framework built upon a design and analysis framework for pervasive systems design [Kostakos *et al*, 2006]. This framework indicated the suitable use of technologies with various interaction spaces supporting public, social and private creative activities. The framework was instantiated through the PSPD hardware and software.

The PSPD hardware consisted of a tabletop (i.e. public interaction space), a set of tablet PC (i.e. social interaction space) and PDA (i.e. private interaction space), each supporting group, sub-group and individual creative activities respectively (High-level requirement 3). Furthermore, these technologies helped support the control of social influences (High-level requirement 2). Multiple devices reduced the effects of production blocking by providing synchronous forms of interaction. Private and social interaction spaces provided a degree of privacy and all externalisations were anonymised reducing the effects of evaluation apprehension. Finally, multiple devices with differing interaction spaces supported individual, sub-group and group activities, which allowed individuals to be accountable for their own productivity, hence reducing the impact of free-riding.

The PSPD software allowed users to create, manipulate and disseminate externalisations to help facilitate the creative process (High-level requirement 1). As when using pen and paper, users could create sketches, annotations and text using the PSPD software. Through pie menus and marked menus, externalisations could be manipulated (e.g. rotating the canvas, changing the pen colour, etc). Furthermore, externalisations could be disseminated between devices and viewed. The rules for disseminating and viewing sketches were based on our PSPD framework which indicated the suitability of devices with differing interaction spaces for viewing information with differing levels of publicness.

The initial evaluation of PSPD identified the strengths and weaknesses of our tool. A positive finding from this evaluation was that PSPD was used to externalise ideas in a similar way to paper. PSPD did not change the users' core creative process. This was true for both the individual and collaborative tasks. Another finding was that the PDA was suitable for individual tasks, but made collaborative tasks difficult, while the tablet PC provided a suitable interaction space for collaborative creative design. A concern that was raised from this evaluation was the potential unsuitability of the PDA for externalising ideas, as it was considered too small and constraining. This problem questioned the use of PDA in the PSPD environment.

An experiment comparing the effects of screen size on sketching investigated the suitability of PDA for use in the PSPD environment. We found that small devices such as PDA provide a private interaction space suitable for the rapid externalisation of initial design ideas, while not being suitable for adding details to an idea. Whereas, we found that with larger devices such as the tablet PC and the interactive tabletop, it took longer to externalise ideas, but these devices were suitable for adding detail to an idea. It was therefore concluded that a PDA would be suitable for the rapid externalisation of initial ideas and the tablet PC and the interactive tabletop would be suitable for the further refinement of ideas, providing an appropriate interaction space for the inclusion of other participants in the collaborative process of design.

Our final evaluation of PSPD observed its use in practice supporting the creation of and interaction with externalisations, supporting the various group compositions of the design team and controlling social influences. The following sub-sections we review and reflect upon how each of our requirements for CST was supported using PSPD. We present our review using our three high-level requirements for supporting creativity in design as a framework.

6.5.1 High-level requirements 1: Supporting the externalisation of knowledge

Many researchers have argued the importance of creating sketches to facilitate one's creative process [e.g. Goldschmidt, 1991; Schön, 1983; Schön, 1992; Suwa & Tversky, 2002; Tohidi *et al*, 2006b]. Sketching is seen as part of the *language of design* complementing a groups verbal communications through the design process [Schön, 1983], allowing ideas in the mind to be externalised, refined, framed and evaluated. During the PSPD evaluation sketches were used to externalise ideas during the idea generation phase of the creative process. The externalisation of participants' ideas led to iterations of idea framing, idea evaluation and further phases of idea generation (see section 6.4.2.1). Sketches were not created in the problem framing phase of the creative process during the PSPD evaluation. This was due to their unsuitability. We argue that sketches were unsuitable, because they are ambiguous [Buxton, 2006]. For example, a common activity in the problem framing phase of the creative process is to specify the criteria of a desired solution [Simon, 1973]. Sketches lacked the appropriate level of granularity to effectively specify such criteria. During our design activities textual externalisations were more appropriate during problem framing (see section 6.4.2.1). Such textual externalisations were appropriate for specifying information such as the criteria of a desired solution. However, if the participants were to engage in a different design activity, sketches may have been an appropriate means of externalisation. Overall, the creation of sketches facilitated the creative process of design as shown during our evaluation of PSPD. Hence, this finding supports our proposal of:

Requirement 1.1: CST should support the creation of sketches.

Annotations are intended to complement sketches. During the PSPD evaluation, annotations were frequently created to complement sketches (see section 6.4.2.1). Annotations could take the form of text, which described a particular feature of a sketch. Furthermore, annotations could take the form of symbols. Symbols could indicate features of a sketch (e.g. the location of the toilets), or they could add dynamic meaning to an otherwise static sketch (e.g. an arrow). The creation of annotations was particularly common during the idea framing phase of the creative process. The creation of annotations reduced the need for idea framing information to be repeated, reducing the ambiguity of a sketch. Therefore, this finding supports our proposal of:

Requirement 1.2: CST should support the annotation of sketches.

Text is particularly useful when externalising knowledge sketches are unable to externalise. As mentioned above, textual externalisations were created during the problem framing phase of the creative process. Text was particularly useful for listing key features of the problem, specifying requirements and describing processes (see section 6.4.2.1). During the phase of idea framing, textual externalisations were also created to externalise idea framing questions. However, textual externalisations were not created during the idea generation phase of the creative process. Sketches were more appropriate to convey the visual richness required during the design activity of the PSPD evaluation. However, it should be acknowledged that if participants had engaged in a different design activity, textual externalisations may have been created during the idea generation phase of the creative process. Hence, our evaluation of PSPD has shown the utility of textual externalisations created during various phases of the creative process. As such, our findings supports our proposal of:

Requirement 1.3: CST should support the creation of text.

Pointing to externalisations allows one to communicate with a design [Bekker *et al*, 1995]. During the PSPD evaluation participants frequently complemented their verbal communications by pointing to various externalisations throughout the creative process (see section 6.4.2.1). During the problem framing phase participants pointed to lists of key features of the problem, requirements and process models they had created. During phases of idea generation, idea framing and idea evaluation, participants referred to sketches they had created representing their ideas. Pointing to an externalisation reduced the possibility of misunderstandings occurring [Baker *et al*, 2001; Bekker *et al*, 1995; Tang & Leifer, 1988]. Hence, this finding supports our proposal of:

Requirement 1.4: CST should support users' pointing interactions with externalisations.

Gestures also allowed participants to communicate with a design [Bekker *et al*, 1995]. During the PSPD evaluation gestures were used to illustrate ideas before they were externalised, frame information and evaluate ideas (see section 6.4.2.1). Furthermore, gestures allowed a dynamic context to be added to an otherwise static externalisation [Tang & Leifer, 1988]. The kinetic movement of a gesture allowed information to be visualised that was lacking from verbal communications or even pointing interactions. Such gestures have been argued to allow richer understandings to develop and avoid the occurrence of misunderstandings between participants [Baker *et al*, 2001; Bekker *et al*, 1995; Tang & Leifer, 1988]. Therefore, this finding supports our proposal of:

Requirement 1.5: CST should support users' gesture interactions with externalisations.

Through the creation of sketches, annotations and text, new ideas can be permanently externalised. Furthermore, pointing and gesture interactions complementing one's verbal communication can allow new ideas to be temporarily externalised. During the PSPD evaluation participants would generally first illustrate their new ideas through pointing and gesture interactions complementing their verbal communications. After discussing a number of ideas, an idea was chosen to be externalised. We considered this a negative aspect of PSPD. Ideally, we would have liked to have seen externalisations of divergent ideas at the beginning of the design activity. This would have provided a permanent record of a groups idea generation process, which could have been referred back to if needed. It would have also shown PSPD to be a suitable tool for supporting the rapid externalisation of ideas, as recommended by previous research [e.g. Gaver, 1991; Greene, 2002; Jones & Greene, 2000; Olson *et al*, 1992; Tang & Leifer, 1988; van der Lugt, 2002]. However, the effort required to externalise a new idea using PSPD outweighed its benefit. Participants in the PSPD evaluation commented that their was no point creating an externalisation using PSPD until an idea had reached a certain degree of refinement. During the EDC evaluation, new ideas were externalised using the EDC, even if they did not contribute to a group's final solution. While we argued that the system-defined contexts and notations provided by the EDC constrained the creation of externalisation, our findings indicate the framework provided by the EDC (i.e. the map of the Gunbarrel area of Boulder) facilitated the rapid externalisation of new, divergent ideas (see chapter 5, section 5.4.1.2). Perhaps a refinement to PSPD would be to allow users to load pre-defined contexts. This support is similar to tools that provide templates to users (e.g. slide templates provided in PowerPoint). Based on our findings from the PSPD evaluation, future research needs to be conducted to improve the support PSPD provides for divergent thinking in the early stages of a design activity. During the latter stages of the design activity in the PSPD evaluation, individuals and sub-groups engaged in divergent thinking activities when delegated tasks. When the group reconvened they engaged in convergent thinking activities, framing, evaluating and selecting ideas to contribute towards their final solution. We considered this a positive aspect of PSPD, as a group's divergent ideas were externalised and captured as intended. Overall, we can see that PSPD partially supports our proposal of:

> **Requirement 1.6: CST should support the generation of new ideas: divergent thinking.**

Similar to the externalisation of new ideas, through the creation of sketches, annotations and text, refined ideas can be permanently externalised. Furthermore, pointing and gesture interactions complementing one's verbal communication can allow refined ideas to be temporarily externalised. Many refinements of ideas were externalised using the PSPD technologies (see section 6.4.2.1). This was quite different from the use of the EDC, where a number of refinements were discussed, critiqued and then a chosen refinement resulted in the modification of the externalisation representing the group's solution. We argue that PSPD supported the rapid refinement of existing ideas as PSPD allowed externalisations to be copied and refined without affecting the original externalisation. This allowed for the storage and protection of ideas and their refinement using PSPD. This is a feature argued for by Baker *et al* [2001] for groupware systems. Being able to externalise such refinements to ideas would allow group members to better reflect upon their design decisions [Goldschmidt, 1991; Schön, 1983]. Hence, this finding supports for our proposal of:

Requirement 1.7: CST should support the refinement of ideas: convergent thinking.

In chapter 4 we observed the various ways in which paper was used to externalise ideas (see section 4.3.2.1). We therefore argued that CST should not constrain the way users externalise their ideas. This is similar to an argument made by Candy & Edmonds [2000] that CST should provide their users with a degree of flexibility, giving the user the locus of control. The design of PSPD aimed to build upon the affordances of paper, not constraining the way users had to externalise their ideas. Just as the sketch tool for the EDC was seen as 'crucial', PSPD used a paper and pen metaphor allowing users to create freehand externalisations. As mentioned above, this allowed the creation of sketches, annotations and text suitable for the task at hand. Furthermore, PSPD did not provide a framework for participants to work within, unlike the EDC (i.e. displaying a map of the Gunbarrel area of Boulder). Therefore, externalisations could be created to support various phases of the creative process, not just idea generation. Therefore, this finding supports for our proposal of:

Requirement 1.8: CST should not constrain the ways users externalise their ideas.

In chapter 4 we argued that the solution space on which externalisations were created should be unobstructed (see section 4.3.2.1). PSPD provided its users with a blank canvas. Furthermore, no menus were permanently displayed through the interface. These design decisions were made so the PSPD software provided its users with the maximum solution space and did not present features (e.g. floating toolbars) a user would have to work around when externalising her ideas. During the EDC evaluation it was noted that annotations (and potentially textual externalisations) could also obstruct the creation of externalisations. Hence, PSPD was designed to support marked annotations - annotations and text stored in a panel, which were associated with small coloured markers presented on the externalisations. The panel could be opened and closed to view any annotations and text. (This was not a feature implemented for the version of PSPD used in the final PSPD evaluation. This was done to make it easier for the participants to learn the available PSPD functionalities. However, this feature was used in the initial evaluation of PSPD (see section 6.2).) During the PSPD evaluation participants were able to freely externalise ideas without obstruction. Hence, this finding supports for our proposal of:

Requirement 1.9: CST should provide users with an unobstructed solution space.

In chapter 4 we showed that users would orient and position paper when creating and viewing externalisations (see section 4.3.2.1). This was also achieved on occasions by moving oneself in relation to the externalisation. During the PSPD evaluation, participants would orient and position themselves around the interactive tabletop when creating, interacting and viewing externalisations. When using the PDA and tablet PC participants would change the orientation and position of devices. Simply being able to move around the PSPD tabletop and reorient and reposition the PDA and tablet PC facilitated the participants' interactions with PSPD (e.g. creating sketches, annotations and text, as well as the participants' pointing and gesture interactions with these externalisations). Hence, this finding supports for our proposal of:

> **Requirement 1.10: CST should allow users to change the orientation and position of an externalisation and/or the CST.**

In chapter 5, we identified a third type of idea generation when existing externalisations where combined (see section 5.4.1.2). This type of idea generation was rare and only happened once during the PSPD evaluation. However, our findings have shown that through the representation of ideas through various externalisations and a CST supporting pointing and gesture interactions to combine already externalised ideas, combined idea generation can be supported (see section 6.4.2.1). Hence, this finding supports for our proposal of:

> **Requirement 1.11: CST should support the combination of previously generated ideas.**

In chapter 5 we observed that ideas were frequently removed to make way for new externalisations when using the EDC (see section 5.4.1.2). When this occurred, old ideas were lost. Baker *et al* [2001] argue that people should be protected from these kinds of situations. The PSPD software supported the storage and protection of generated ideas, where new ideas could be created without affecting existing ideas and existing ideas could be modified without affecting the original externalisation. As mentioned above, this allowed refinements of ideas to be externalised and reflected upon. Furthermore, findings from our evaluation of PSPD suggested that it is not only externalisations of ideas that should be stored and protected, but externalisations from all phases of the creative process. This finding led to the refinement of and provides support for our proposal of:

Requirement 1.12: CST should support the storage and protection of externalisations created throughout the creative process.

It has been recommended that CST should support multiple instantiations of the solution space facilitating the exploration of alternative solutions [Terry & Mynatt, 2002; Terry *et al*, 2004]. During the PSPD evaluation we observed that different externalisations were compared on different devices (e.g. comparing an externalisation on a PDA with an externalisation on the interactive tabletop) and thumbnails of externalisations were also used to compare externalisations (see section 6.4.2.1). Therefore, this finding supports our proposal of:

Requirement 1.13: CST should support the comparison of generated ideas.

6.5.2 High-level requirement 2: Supporting individual and social creative activities

It has been argued that in order to effectively support collaboration, support needs to be provided for individual and collaborative activities [Gutwin & Greenberg, 1999; Streitz *et al*, 1997]. Individual activities in particular allow one to remove oneself from the group and personally reflect upon the design activity [Fischer *et al*, 2005]. Building upon previous research [e.g. Kostakos *et al*, 2006; O'Neill *et al*, 2004; Streitz *et al*, 1999; Sugimoto *et al*, 2004], PSPD provided PDA to support individual creative activities. During the PSPD evaluation this was frequently observed that the PDA were used for individual activities (see section 6.4.2.2). Individuals would use the PDA to externalise ideas synchronously with other group members. The PDA also supported individual activities when tasks were delegated. Furthermore, from our observations, on one occasion a tablet PC was used to support an individual activity. These findings show the flexibility of PSPD to support individual creative activities providing supportive evidence for our proposal of:

Requirement 2.1: CST should support individual activities using small interaction spaces.

Group collaboration can also involve a number of sub-group activities [Gutwin, 1981]. During the PSPD evaluation sub-groups would form when tasks were delegated (see section 6.4.2.2). Generally the group would split into two sub-groups. As intended, the tablet PC was used on many occasions to support sub-group activities. The tablet PC provided an interaction space that is suitable for more than one person, but not the entire group, thereby facilitating a sense of social inclusion. However, there were also occasions when PDA were used during sub-group activities. While the PDA was not suitable for use during collaborative activities (e.g. collaboratively sketching an externalisation) due to its small interaction space [Kostakos *et al*, 2006; O'Neill *et al*, 2004], the PDA was useful for presenting an externalisation to one's collaborator, thereby facilitating a discussion. Furthermore, there was an occasion when two participants sat at opposites ends of the meeting room, facing the opposite direction to one another, discussing the externalisations they were viewing. These findings provide further evidence for the flexibility PSPD provided, thereby facilitating sub-group creative activities. Hence, this finding supports our proposal of:

> **Requirement 2.2: CST should support sub-group activities using interaction spaces that create a sense of social inclusion.**

Kostakos *et al* [2006] and O'Neill *et al* [2004] argue that whole group activities can be supported by providing public interaction spaces. Like many other tools [e.g. Arias *et al*, 2000; Streitz *et al*, 1999; Sugimoto *et al*, 2004], PSPD supported group activities providing a large interaction space through an interactive tabletop. The interactive tabletop provided a shared space for group members to collaborate together (see section 6.4.2.2). Using the interactive tabletop, participants collaborative created externalisations. Participants could then point and gesture to complement their verbal communications, developing shared understandings amongst the members of the group [Baker *et al*, 2001; Bekker *et al*, 1995; Tang & Leifer, 1988]. This finding supports our proposal of:

> **Requirement 2.3: CST should support group activities using large interaction spaces.**

As well as groups engaging in individual, sub-group and group activities, group members also dynamically shift between these activities [Baker *et al*, 2001; Gutwin & Greenberg, 2000; Streitz *et al*, 1997; Tang & Leifer, 1988; Warr & O'Neill, 2006a]. PSPD supported the transition between these different group compositions in two ways. First, the mobility of the PDA and tablet PC allowed users to move seamlessly between the public, social and private interaction spaces and therefore group, sub-group and individual activities. For example, during the PSPD evaluation one participant was able to generate potential ideas on a PDA while being in the interaction space of the group and the tabletop, able to see and hear what was being discussed. Furthermore, the PSPD software supported the transition between various group compositions allowing externalisations to be disseminated to various levels of publicness. For example, using the example mentioned above, once the participant was ready to share his ideas with the group, he disseminated his externalisation from a private level to a public level, so the entire group could clearly view and interact with his externalisation on the interactive tabletop. Using the PSPD hardware and software, participants were able to transition between individual, sub-group and group activities. This finding supports our proposal of:

> **Requirement 2.4: CST should support the transition between individual, sub-group and group activities.**

Olson *et al* [1992] have argued the importance of supporting design activities beyond the meeting room. In chapter 4, we observed tasks being delegated to individuals and sub-groups, to be completed before the next design meeting (see section 4.2.2.4). PSPD did not support creative activities beyond the design meeting room. However, we have argued that due to the mobility of the PDA and the tablet PC in the PSPD environment, distributed creative activities could be supported [Warr, 2006]. While not supported by PSPD, the need to support creative activities beyond the design meeting room is essential to supporting the entire design process [Olson *et al*, 1992]. Hence, we need to move towards supporting:

> **Requirement 2.5: CST should support creative activities beyond the meeting room.**

6.5.3 High-level requirement 3: Supporting the control of social influences

It has been argued that social influences detrimental to creativity need to be controlled in order to enhance social creativity [e.g. Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973]. To reduce the effects of production blocking some researchers have recommended providing synchronous forms of interaction [e.g. Diehl & Stroebe, 1987; Prante *et al*, 2002]. PSPD facilitated synchronous forms of interaction through multiple interaction spaces that could be used simultaneously to create externalisations. As mentioned above, during the PSPD evaluation one participant externalised several ideas using his PDA, while other members of the group were discussing the process around the interactive tabletop (see section 6.4.2.3). This finding illustrates how the use of multiple interaction spaces overcomes the constraint of turn-taking, thereby reducing the effects of production blocking. This finding supports our proposal of:

Requirement 3.1: CST should support synchronous forms of interaction, thereby reducing the effects of production blocking.

Multiple inputs have been argued as another solution to reduce the effects of production blocking [e.g. Prante *et al*, 2002]. PSPD did not support multiple inputs. However, the interactive tabletop and the tablet PC do have the ability to accept multiple inputs after further development. During the PSPD evaluation, although told it was not possible, several participants tried simultaneously to create externalisations on the interactive tabletop (see section 6.4.2.3). This finding supports our proposal of:

Requirement 3.2: CST should support multiple inputs, thereby reducing the effects of production blocking.

Removing a user's identify from an externalised idea can reduce the effects of evaluation apprehension [e.g. Diehl & Stroebe, 1987]. It was not possible to contribute an idea anonymously using the interactive tabletop provided by the PSPD environment, as the creation of an externalisation would be in the presence of other group members. However, any ideas that were disseminated to the group from the private or social interaction spaces were anonymous (see section 6.4.2.3). Users could then identify themselves with an idea if they wished. During the PSPD evaluation, participants only disseminated an idea with the rest of the group if they wished to discuss it. For example, one participant only disseminated two of the seven ideas that he created on his PDA. These two ideas were the ones he wished to discuss with the group. When he disseminated his ideas with the rest of the group he said, "let me bring this up". Although the ideas were anonymised the participant associated himself with his ideas. Alternatively, the participant could have disseminated his ideas and not have associated himself with them. PSPD supported the removal of a user's identify from their ideas, thereby reducing the effects of evaluation apprehension if a user did not want to associate themselves with an idea. This finding supports our proposal of:

Requirement 3.3: CST should support the removal of a user's identity from their ideas, thereby reducing the effects of evaluation apprehension.

From the example presented in the above paragraph, we see that it was not just the anonymisation of ideas that reduced the effects of evaluation apprehension, but also the private interaction space in which the participant was able to externalise his ideas. PSPD provided PDA and tablet PC to support individual and sub-group activities. As mentioned above, the PDA and tablet PC were both used to allow an individual to externalise an idea in their own private space (see section 6.4.2.3). Once satisfied with an idea, participants were able to anonymously disseminate their externalisations. This was done to avoid criticism from others in the group. Furthermore, the private and social interaction spaces allowed individuals to engage in individual or sub-group activities. This meant that individuals and sub-groups were able to work on the problem or parts of the problem on their own, thereby reducing social pressures from others in the group which could have otherwise resulted in free-riding (see chapter 5, section 5.4.3). Therefore, providing individual/private interaction spaces could reduced the potential effects of free-riding. Therefore, these findings supports our proposal of:

> **Requirement 3.4: CST should support individual/private interactions, thereby reducing the effects of evaluation apprehension and free-riding.**

It has been shown that if participants perceive that their contributions are being assessed collectively with other group members, they will be less productive than if their efforts are being assessed individually [Diehl & Stroebe, 1987]. This has been described as free-riding. Using PSPD, individuals could become accountable for their own productivity. This was especially true when tasks were delegated. We therefore argued that this reduced the effects of free-riding (see section 6.4.2.3). For example, the delegation of tasks allowed individuals and sub-group to contribute towards to overview problem. This made individuals and sub-group accountable for part of the final solution. If tasks were not delegated some members of the group may not have been as active in the design activity and therefore perceived as free-riders. Hence, this supports our proposal of:

> **Requirement 3.5: CST should make individuals accountable for their own productivity, thereby reducing the effects of free-riding.**

The findings from the evaluation of PSPD provided evidence to support the proposal of our requirements for CST. These requirements contribute towards our understanding of how to support creativity in design. The next and final chapter concludes the thesis reflecting upon our RQ and the contribution of this research.

Chapter 7

Conclusions and Future Work

This thesis has addressed both theoretical and practical perspectives understanding and supporting creativity in design. This chapter summarises the thesis, reflects upon the outcomes of our RQ, addresses the limitations of the research reported and suggests possible avenues for future work.

Section 7.1 summarises the thesis, outlining our motivations and provides a brief overview of each chapter and their main contributions to the thesis.

Section 7.2 collects the knowledge accumulated throughout this thesis answering our two RQ: what is creativity in design?; and how can we support creativity in design?

In section 7.3, we address the limitations of this research.

Finally, section 7.4 concludes the thesis with some suggested directions for future work.

7.1 Thesis summary

This thesis has addressed the problems of understanding and supporting creativity in design. This topic was motivated by the mystery behind design, where terms such as 'creativity' have been used at times as a replacement for understanding [Fallman, 2003]. Rosson *et al* [1987] argues that if we don't understand this mystical element of creativity, how shall we know how best to support the creative process of design? This lack of understanding could arguably impact the quality of the design process itself and its resultant products [Rosson *et al*, 1987]. This problem prompted our two RQ for this thesis:

RQ1: What is creativity in design?

RQ2: How do we support creativity in design?

To answer these questions we have developed both theoretical and practical perspectives on creativity, applying a number of research methods and techniques. These methods and techniques were applied to four RO, where the accumulation of their findings contributes towards answering our RQ:

RO1: Understand the effect of group composition on creativity in design when social influences are controlled

RO2: Elicit requirements for CST

RO3: Reflect upon and refine our requirements for CST

RO4: Build upon both our theoretical and practical perspectives on creativity to design, develop and evaluate a new tool to support creativity in design

Chapter 2 set the scene for the thesis. It provided an understanding of the design process and identified the limitations of this understanding. Identifying creativity as a mystical element of the design process, we reviewed definitions, metrics and measures, and process models of creativity, thereby developing a theoretical understanding of creativity. We then identified and explored characteristics of social creativity, which allowed us to elicit three high-level requirements for supporting creativity in design.

One of the characteristics of social creativity identified in chapter 2 was the detrimental affect of social influences on creativity. Chapter 3 recapped our understanding of social influences and reported a review and critique of GDSS, which have been shown to increase of productivity of real groups over nominal groups. We then reported an experiment comparing four group compositions - nominal, nominal-real, real-nominal and real group compositions - to identify their effects on creativity - the quantity of creative ideas, the divergence of creative ideas and the quality of creative ideas - when social influences were controlled. The results of this experiment suggested that there was no difference between nominal and real group creativity when social influences were controlled. This refuted past findings that nominal groups are significantly more creative than real groups and refuted claims that creative activities should therefore be performed by nominal groups alone [e.g. Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973]. Futhermore, our results complemented and extended those presented by in GDSS research [Demhis & Valacich, 1993; Nunamaker *et al*, 1991; Valacich *et al*, 1994]. The experiment addressed RO1.

Chapter 4 built upon chapter 2 moving away from our theoretical perspective on creativity to develop a complementary practical perspective (RO2). We achieved this by observing the occurrence of creativity in a real design setting, requiring us to draw upon a number of ethnographic techniques: a diary study, field-based observations and lab-based observations. From these studies we have further developed our understanding of creativity and elicited a number of requirements for CST (CST).

Chapter 5 first presented a review and critique of three existing CST: the Envisionment and Discovery Collaboratory (EDC), Caretta and the i-LAND environment. We then presented an in-depth evaluation of the EDC. We evaluated the EDC against our requirements to support creativity identified in chapter 4. This allowed us to identify strengths and weakness of the EDC, suggesting improvements to the EDC and other CST, as well as allowing us to reflect upon and refine our requirements for CST. This addressed our third research goal (RO3).

Chapter 6 reported the design, development and evaluation of our own CST: PSPD. The design and development of PSPD built upon our requirements for CST established throughout chapters 4 and 5. The evaluation of PSPD assessed the practical use of our requirements supporting creativity in design. These findings provided evidence to support or reject the proposal of our requirements for CST. This chapter addressed our fourth and final research goal (RO4).

Overall, this thesis made two major contributions - theoretical and practical. Addressing our first RQ - what is creativity in design? - we made a theoretical contribution. This contribution came in the form of a definition of creativity in design, identified metrics and measures of creativity and an understanding of the process of being creative. These contributions were developed throughout the thesis building upon previous theoretical work and were refined throughout our practical research.

Our second RQ - how do we support creativity in design? - made a practical contribution to this thesis. This contribution was delivered in the form of a number of requirements for supporting creativity in design, which were elicited from our theoretical work and practical studies. The application of these requirements has been illustrated through the evaluation of an existing support tool (the EDC) and the design, development and evaluation of our own CST: PSPD.

In the following section we focus on the contributions of this thesis in more detail, summarising the answers to our two RQ.

7.2 Thesis outcomes

The aim of the thesis was to understand and support creativity in design. This aim was broken down into two RQ: what is creativity in design?; and how do we support creativity in design? As discussed above, each of these questions inspired a theoretical and practical contribution, respectively. While the entire thesis reflected upon these questions, our next section summarises each of these contributions in turn.

7.2.1 What is creativity in design?

Our first RQ was prompted by a lack of understanding of the process of design. Design has been described as a *process* that produces a *new or refined product* [e.g. Alexander, 1964; Coyne, 1995; Ehn, 1989; Fallman, 2003; Jones, 1970; Mayall, 1979; Rasmussen *et al*, 1994; Rittel, 1984; Schön, 1983; Simon, 1996; Vicente, 1999]. How though does this design process produce a design product? Rosson *et al* [1987] reported that designers find it difficult to articulate where their ideas come from, or even differentiate between the process of generating new or refined ideas. Fallman [2003], furthermore argues that our philosophical, theoretical and methodological underpinnings of design are relatively poor. Instead of understanding this process of design, it has been described as involving a certain 'mystical element' [Fallman, 2003]. This mystical element has been referred to using terms such as 'creativity' [e.g. Alborzi *et al*, 2002; Buur & Bødker, 2002; Fallman, 2003; Guindon, 1990; Rosson *et al*, 1987].

Therefore, to better understand design, it was our goal to better understand creativity. This understanding came in the form of a definition of creativity in design, identified metrics and measures of creativity and a process model of creativity in design.

7.2.1.1 A definition of creativity in design

In chapter 2 we reviewed three categories of creativity definitions: the creative process [e.g. Boden 1994; Koestler, 1964], the creative person [e.g. Guilford, 1950; Gough, 1979] and the creative product [e.g. Amabile, 1983].

Definitions of the creative process describe the occurrence of creativity as the exploration (i.e. recalling existing bundles of knowledge) and the transformation (i.e. forming new knowledge structures) of conceptual spaces [e.g. Boden, 1994; Koestler, 1964]. This may be either sub-conscious (i.e. an 'eureka' moment) or conscious (i.e. deliberate).

Definitions of the creative person describe an individual having some creative traits [Guilford, 1950; Gough, 1979]. The creative traits of a creative person may affect their creative abilities, where some persons may be more creative than others. However, in addition to a person's traits, a person's knowledge has also been argued to be a determining factor of how creative that person can be [Boden, 1994; Csikszentmihalyi, 1996].

Definitions of the creative product describe a product (e.g. a response or solution) produced by a creative person as having distinguishing characteristics of creativity [e.g. Amabile, 1983]. These characteristics have been defined in terms of novelty and appropriateness [e.g. Amabile, 1983; Bruner, 1962; Gilchrist, 1972; Jackson & Mersick 1965]. Novelty lies on a spectrum between something that has never been done before (i.e. historical novelty), and something that has been done before, but is new to the individual (i.e. personal novelty). A product is appropriate if it conforms to the characteristics of a desired solution. The degree of appropriateness depends on how appropriate the product is. Products that are both novel and appropriate are considered creative.

Many of these definitions have been presented as distinct from the others. However, Lawson [1980] argues that we need to examine the products, processes and persons together. While the focus of definitions of creativity has evolved over time, from the process, to the person, to the product, these are all essentially important components of creativity and design. Each individual (e.g. member of a design team), has certain creative abilities; she may explore and transform conceptual spaces, combine existing bundles of knowledge to generate new ideas (e.g. the design process); and these ideas may consist in or lead to the development of a creative product (e.g. a design product).

Therefore, in our research we unified the three categories of creativity definitions to propose a new unified definition of creativity in design [Warr & O'Neill, 2004; Warr & O'Neill, 2005a]:

> **'Creativity in design is the generation of ideas, which are a combination of two or more existing bundles of knowledge to produce a new knowledge structure. For this new generated idea to be considered creative it should be: novel - unusual or new to the mind in which it arose; and appropriate - conform to the characteristics of a desired/accepted solution. Such creative ideas may then be implemented and embodied in a creative product'.**

We saw the application of this definition throughout this thesis. In chapter 3, we saw this definition operationalised in identifying creative ideas generated by individuals. Whereas, in chapters 4, 5 and 6 we identified the core creative activity of the design process when novel and appropriate ideas were expressed to design problems.

However, is creativity merely attributed to the generation of ideas? Lamm & Trommsdorf (1973) and Mullen *et al* [1991] argue that the global phenomenon of creativity can not be measured by a single metric alone. We therefore also contributed the development of metrics and measures of creativity.

7.2.1.2 Metrics and measures of creativity

In chapter 2 we identified three metrics of creativity: quantity [Boden, 1994; Csikszentmihalyi, 1996; Guilford, 1959], divergence [de Bono, 1967; Guilford, 1959; Lawson, 1980; Runco, 2003] and quality [Amabile, 1983; Boden, 1994]. Producing a large number of creative ideas per unit time (i.e. quantity) shows fluency of thinking, which is an associated characteristic of creativity [Boden, 1994; Csikszentmihalyi, 1996; Guilford, 1959]. Producing a large number of categories of creative ideas (i.e. divergence) shows the ability to change mind set easily, which is another characteristic associated with creativity [de Bono, 1967; Guilford, 1959; Lawson, 1980; Runco, 2003]. Producing highly creative ideas - ideas that are highly novel and appropriate [Gilchrist, 1972; Guilford, 1959; Jackson & Mersick 1965] - have also been associated with creativity [Amabile, 1983; Boden, 1994].

These metrics of creativity are also reflected in the process of design. Tohidi *et al* [2006a, p.1243] quote Alistair Hamilton, VP Design of Symbol Corp saying, '... a designer that pitched only one idea would probably be fired. I'd say five is an entry point for an early formal review (distilled from 100s)'. We see that it is important for designers to produce many ideas. Designers should also be divergent thinkers [Lawson, 1980], exploring multiple solutions to design problems. Such exploration helps us get the *right design* [Tohidi *et al*, 2006a]. Furthermore, with respect to creative quality, designers are also interested in producing high quality designs, thereby getting the *design right* [Tohidi *et al*, 2006a].

Building upon these identified metrics of creativity, we developed a method for objectively measuring the quantity, divergence and quality of creative ideas produced. This method improved upon the subjectivity and unreliability of previous measurements (as discussed in chapter 2).

We argued that ideas could be identified based on sentence structuring and copyright law [Warr & O'Neill, 2006b]. Sentence structuring allows an individual's responses to be analysed for the occurrence of nouns. Nouns are particular useful at identifying ideas as they classify people, places and things. Furthermore, the identification of verbs can describe the actions or states of the nouns. Identifying the occurrence of nouns leads to a natural categorisation (i.e. a tree structure) and simplification of an individual's responses. This is similar to a method presented by Johnson *et al* [1995] for identifying task knowledge structures.

This categorisation helps with the objective and reliable identification of duplicated ideas. If an idea is generated that produces an existing branch in the tree structure or a shorter branch that is a subset of a longer existing branch, the idea is considered a duplicate.

Once the ideas produced have been identified we can determine which ideas are creative by assessing them to see if they are both novel and appropriate - as specified by our definition of creativity in design. The novelty of an idea can be determined using a retrospective protocol analysis, asking the originator of the idea whether they consider it unusual or new to them in the context of the problem (i.e. p-novelty). Such a schema as been used by Benami & Jin [2002] to determine novelty by classifying ideas based on participant responses. Appropriateness can be determined using a simple checklist that confirms that the generated idea conforms to the characteristics of a desired solution [Lawson, 1980]. Those ideas that are both novel and appropriate can then be objectively and reliably counted towards the measure of the quantity of creative ideas. These measures were applied in chapter 3.

The divergence of creative ideas can be determined by the number of tree structures produced by our schema for identifying novel and appropriate ideas [Warr & O'Neill, 2006b]. Furthermore, the method can be extended to reliably measure the number of refined creative ideas, the identification of group-think and the degree of refinement [Warr & O'Neill, 2006b]. All these measures were reported in chapter 3. This was particular useful, because divergence has not been experimentally measured before.

Finally, by measuring the degree of novelty and appropriateness for each creative idea produced, the creative quality of that idea could be determined [Guilford, 1959]. Under experimental conditions the degree of novelty can be determined by looking at the frequency of occurrence of an idea. The more frequent an idea the less novel it is, while the less frequent the idea the more novel it is. The degree of appropriateness can be determined by identifying how many users find a particular idea or product useful. The higher the number of users finding an idea or product appropriate for use, the more appropriate we consider it to be; while the lower the number of users finding an idea or product appropriate for use, the less appropriate we consider an idea to be. To determine the creative quality of an idea we collate (with an equal weighting) the degree of novelty and the degree of appropriateness. Applying a threshold value on creative quality allows us a measure of the number of 'good' ideas produced [Diehl & Stroebe, 1987]. This method was used in chapter 3 to identify the total and average creative quality of ideas produced, as well as the number of 'highly' creative ideas produced.

Understanding the metrics and measures of ideas has moved our understanding beyond the generation of a creative idea. We now understand that creativity in design is also about the generation of a large number of divergent, high quality ideas. Our final contribution deepens our understanding of the process of being creative in design.

7.2.1.3 A process model of creativity in design

In chapter 2 we reviewed a long history of research [e.g. Wallas, 1926; Osborn, 1963; Ambile, 1983; Shneiderman, 2000] that described the phases in the process of being creative through the creative process models. A common theme that emerged from each of the models reviewed was the core phases of problem framing, idea generation and idea evaluation.

Problem framing involves developing an understanding of the problem at hand, framing criteria for potential solutions. This stage may involve gathering relevant data about a problem and reviewing it.

Idea generation is when group members generate design decisions as a potential solution to the problem. This is the core creative phase of the creative process.

Idea evaluation is when group members assess design decisions as a potential solution to the problem against some criteria established during the problem framing phase of the creative process.

In chapter 4 we identified a fourth phase, namely idea framing. This phase was further observed during chapters 5 and 6. We describe idea framing as building up an understanding of a generated idea. Idea framing is particularly important during collaborative creative tasks, such as design tasks. When an individual generates an idea they generally have a clearer understanding of that idea than their collaborators. Hence, others in the group may need more information about the idea in order to understand it. Furthermore, members of a group can collaboratively question their understanding of the idea, leading to its refinement.

Furthermore, we defined three types of idea generation: new ideas - the generation of an idea that has not yet been expressed; refined ideas - the generation of an idea that extends an existing idea; and combined ideas - the generation of an idea from two or more existing ideas. The occurrence of new and refined ideas was frequently identified throughout chapters 4, 5 and 6, while the occurrence of combinations of ideas occurred on a few occasions during chapters 5 and 6.

Building upon our review of existing creative process models [e.g. Wallas, 1926; Osborn, 1963; Amabile, 1983; Shneiderman, 2000] and design process models [e.g. Alexander, 1964; Carroll *et al*, 1979; Jones, 1970; Manhorta *et al*, 1980; Rosson *et al*, 1987], this thesis has refined our understanding of the creative process of design (Version 1 can be seen in figure 2.1 in chapter 2 (see section 2.2.3.2). Version 2 can be seen in figure 4.7 in chapter 4 (see section 4.2.2.1). Version 3 can be seen in figure 5.5 in chapter 5 (see section 5.4.1.2). Figure 7.1 presents a model illustrating our understanding of the creative process of design.

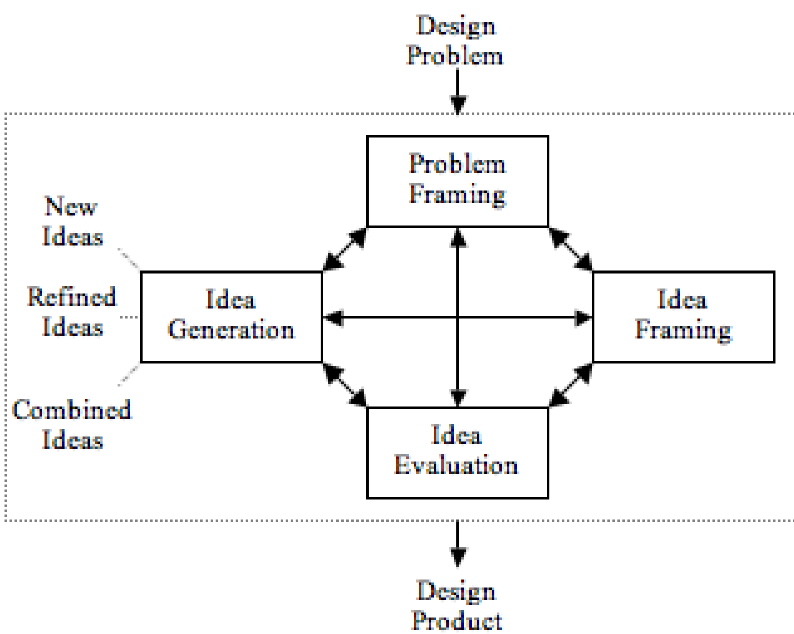


Figure 7.1: The creative process of design.

Hence, creativity in design is the generation of a large number of divergent, high quality ideas resulting from the creative process. With this refined understanding developed through answering our first RQ, we can better understand how best to support the creative process of design. In the next section we report our practical contribution in this thesis, developed in response to our second RQ.

7.2.2 How can we support creativity in design?

Rosson *et al* [1987] argue that with a better understanding of creativity, we can determine how best to support creativity. This support in turn can improve the processes and products of the design process [Rosson *et al*, 1987]. This was the inspiration for our second RQ: how can we support creativity in design?

In chapter 2, we built up an understanding of creativity. This understanding led us to identifying three characteristics of creativity in design:

> **Characteristic 1: The externalisation of knowledge and subsequent presentation of this knowledge to members of the design team.**
>
> **Characteristic 2: Individual and social creative activities.**
>
> **Characteristic 3: Social influences that inhibit the creativity of the design team.**

Further exploring these characteristics allowed us to understand how to support creativity in design. This led to the elicitation of three high-level requirements for CST:

> **High-level requirement 1: Support the creation and dissemination of externalisations to support the phases of the creative process.**
>
> **High-level requirement 2: Support the various compositions of a group using appropriately sized interaction spaces.**
>
> **High-level requirement 3: Support the control of social influences.**
>
>> **High-level requirement 3.1: Support the control of production blocking by providing synchronous forms of interaction.**
>>
>> **High-level requirement 3.2: Support the control of evaluation apprehension by anonymising one's externalisations.**

High-level requirement 3.3: Support the control of free-riding by making individuals accountable for their own performance.

These three high-level requirements provided a framework for supporting creativity and were applied throughout this thesis. In chapter 4 we utilised a number of ethnographic techniques during design activities to specify a set of requirements for CST. In chapter 5 we drew lessons from our evaluation of the EDC, identifying the strengths and weakness of the EDC, suggesting improvements to the EDC and other CST, as well as allowing us to reflect upon and refine our requirements. In chapter 6, we designed, developed and evaluated our own CST to meet our requirements.

The requirements identified throughout this thesis were the primary practical contribution. Through their application we were able to design and develop our own CST and use these requirements as a set of evaluation criteria.

7.2.2.1 A set of requirements for creativity support tools

As described above, our theoretical work led to the development of three high-level requirements for supporting creativity in design. In chapter 4 we verified and refined these requirements through a diary study, field-based observations and lab-based observations. Our diary study allowed us to capture and analyse data specific to idea generation across the software development life-cycle. Our field-based observations focussed on the creative process of collaborating groups during their design meetings. These observations allowed us to capture and analyse a wealth of contextually rich data. Finally, our lab-based observations were more controlled than the other studies reported in chapter 4, focussing on the process of generating design ideas, both individually and collaboratively. The requirements identified from our studies reported in chapter 4 were then reflected upon and refined during the evaluation of the EDC, as reported in chapter 5. Furthermore, chapter 5 led to the elicitation of some new requirements for CST. Chapter 6 further validated these requirements through an evaluation of a CST developed using these requirements - PSPD. A full list of requirements for CST and a major practical contribution of this thesis, can be found in appendix F.

While many researchers have contributed requirements for groupware systems [e.g. Grudin, 1994; Guindon, 1990; Mandviwalla & Olfman, 1994], the need for requirements specific to CST has been acknowledged [Shneiderman *et al*, 2006]. Hence, these requirements identified in this thesis were specifically aimed towards the design, development and evaluation of CST.

7.2.2.2 A set of evaluation criteria for creativity support tools

In addition to our requirements informing the design and development of CST, they can also be applied to their evaluation. This was a second practical contribution of this thesis. As described in chapter 2, the problem framing phase of the creative process leads to the identification of criteria for a desired solution (i.e. requirements). The criteria of a desired solution can then be used to evaluate design ideas and solutions generated during the idea generation phase of the creative process. In chapters 5 and 6, our requirements for CST were applied to the evaluation of an existing CST - EDC; and our own CST - PSPD.

Our requirements provided a framework for CST to be evaluated against. Similar to evaluations using heuristics [e.g. Baker *et al*, 2001; Baker *et al*, 2002; Nielsen & Molich, 1990], by analysing the use of CST we could determine if a requirement/criteron had been satisfied. A full list of heuristics for CST can be found in appendix F.

7.2.2.3 Public Social Private Design (PSPD)

The third and final practical contribution of our thesis was the design and development of our own CST: PSPD.

Building upon our requirements for CST, PSPD supported creativity in design through the creation and dissemination of externalisations (high-level requirement 1) supporting group, sub-group and individual activities (high-level requirement 2), while controlling social influences (high-level requirement 3).

To evaluate the design decisions made during the design and development of PSPD, our requirements were used as a set of evaluation criteria to confirm that our requirements had been satisfied and PSPD did indeed support creativity in design. The findings from the evaluation of PSPD also supported or rejected the proposal of our requirements for CST.

7.3 Thesis limitations

Throughout this thesis we have discussed the limitations of the specific studies we have conducted and how we have compensated for these limitations. In this section we address the wider limitations of this thesis.

Rosson *et al* [1987] argue that the support provided for the creative process of design impacts the quality of the design process itself and its resultant products. Therefore, has the support provided by PSPD improved the creative process and its resultant creative products? We would like to strive towards empirical proof (i.e. a controlled experiment) to answer this question. However, it is not ecologically valid to do so. Nunamaker *et al* [1991] argues that non-technological tools (i.e. paper and pen) should not be experimentally compared with technological support tools, as the two technologies are very different and the number of confounding variables and interaction effects are too vast. Therefore, Shneiderman *et al* [2006] have recommended exploratory evaluations of CST. In chapters 5 and 6 we conducted exploratory evaluations when evaluating the EDC and PSPD respectively. Rather than empirically proving the support of creativity, we identified and discussed qualitative data to justify our claims.

A major limitation of this thesis was not having access to 'real' design teams. If we were to have observed real design teams, working on real design tasks, in real design studios, would we have obtained the same understanding of creativity in design and the same set of requirements for CST? Of course there is no definite answer to this question, however we can argue the steps taken in order to compensate for this limitation, as described below.

While we did not have access to real design teams, we tried to form groups of participants who had characteristics of design teams. In chapter 3, the participants who formed groups for our experiment were from different backgrounds. Heterogeneity is a common characteristic of many design teams. In chapter 4, the participants who participated in the diary study and ethnographic observations, were computer science students working on a nine week software development project for a second year user interface programming course. While these groups were relevantly inexperienced, they were building up their skills as interaction designers. In chapter 5, personas were used during the evaluation of the EDC to inform semi-authentic users [Fischer *et al*, 2005]. Finally, during the final evaluation of PSPD, groups of participants with a wealth of academic and industrial experience in interaction design, and prior knowledge of their participating colleagues, were formed to make the design teams as realistic as possible.

Design tasks were also used throughout our studies to try to make our results generalisable to the domain of design. Like many design tasks, the problems we used were ill-defined and open-ended. In chapter 3 we set the 'Pervasive Scrolling Problem', asking participants to come up with ideas for interaction techniques that would allow a user or users to scroll up, down, left and right on a pervasive computing screen. In chapter 4, the design tasks used for the diary study and field-based observations were part of a user interface programming course - designing, developing and evaluating a novel and usable interaction technique. During the lab-based observations, participants were asked to come up with ideas for a scary monster and ideas for features on a futuristic car. While perhaps not entirely realistic, these tasks were very open-ended, giving the users a great degree of freedom. These tasks were also used during chapter 6 for the initial evaluation of PSPD. In chapter 5, we used a scenario to make the design task as realistic as possible for our design teams. The design task was also based on a very real issue of the redevelopment of the Gunbarrel area of Boulder, which all the participants were familiar with. Finally, in chapter 6, a modified design task from a London based interaction design consultancy was used - design of an innovative, queue-less, pizza ordering system for use in a pizza restaurant.

While we could form groups based on the characteristics of design teams and use open-ended and ill-defined design tasks, we could not replicate the design studio environment. Many of our studies were constrained to a usability lab, while our diary studies and field-based observations were the only studies performed in the users' design environment. Even then, they were constrained to holding their design meetings in lecture rooms and computer laboratories. This undoubtedly had some effect on the groups' creativity, as environmental factors have been shown to have an effect on creativity [Lasswell, 1959].

Taking an ethnographic approach to observing real design teams, working on real design tasks, in real design studios, would have provided a wealth of rich, contextual data. These data would have allowed the exploration of a number of RQ. However, it would have been infeasible to run controlled experiments providing empirical data. Furthermore, there would be an absence of theory on which to base hypotheses. Throughout this thesis we have conducted a number of controlled experiments, lab-based observations and small-scale field-based observations. Furthermore, all this work was based upon a firm theoretical foundation, allowing specific hypotheses and theories to be tested. Hence, this thesis has conducted and integrated a number of research methods and techniques, aimed towards understanding and supporting creativity in design.

7.4 Future work

The research reported in this thesis has contributed to our understanding and the support of creativity in design. From a theoretical foundation, we adopted a range of quantitative and qualitative research methods and techniques to answer our RQ. Despite addressing these questions, new questions have emerged throughout the thesis and new directions for future research has been created.

Our understanding of creativity has primarily been focussed on the domain of design from a HCI perspective. From our theoretical work and our studies we have developed a unified definition of creativity in design, identified various metrics and measures and modeled the process of being creative in design. How though do the theoretical contributions of this thesis apply to other domains? Through studying disciplines such as the arts, music composition, architecture and engineering, comparisons can be made to the work presented in this thesis. Furthermore, an analysis of creativity across these various disciplines will help us generalise our understanding of creativity.

Similarly, the requirements identified in chapters 2, 4 and 5 for supporting creativity were very much focussed on the domain of design from a HCI perspective. Observing other disciplines would allow more specific requirements for those domains to be identified. An analysis of the requirements identified across these various domains could also lead to the identification of generic requirements for supporting creativity.

In chapters 5 and 6 we used our requirements for CST as a set of evaluation heuristics for CST. Through further studies we could determine the empirical validity of these heuristics for evaluating CST. For example, we could determine the optimum number of heuristic evaluations that need to be performed in order to identify a given threshold of design issues with a CST. Such a study would be similar to that of Baker *et al* [2002] who validated the use of their heuristics [Baker *et al*, 2001; Gutwin & Greenberg, 2000] for evaluating groupware systems. It has been argued that such evaluation techniques are needed for CST [Shneiderman *et al*, 2006].

In chapter 3, we reported an experimental design observing the effect of group composition on creativity in design. The result of this experiment was that there were no significant differences between nominal and real group creativity. However, it was hypothesised, based on our theory of social creativity presented in chapter 2, that real groups would be more creative than nominal groups. Why then was this not the case? In chapter 3, it was suggested that the representation could have had an effect on creativity. Furthermore, it was also suggested that the 16 minute time frame for the experiment may not have been appropriate, causing a ceiling effect. These factors affecting creativity could be tested through further experiments, manipulating the representations used to externalise ideas and the time available for externalising ideas.

In addition to the additional studies that could be conducted, PSPD could also be further developed. PSPD failed to support two of its requirements due to technological and implementation constraints. Additional development could enable the collaborative technologies, such as the tabletop and the tablet PC to accept multiple simultaneous inputs. This would have prevented technological production blocking. Furthermore, PSPD was constrained to the lab. As identified in chapter 4, design activities transcend the design meeting room. PSPD does support the ability to extend beyond the lab due to the mobility of the PDA and the tablet PC [Warr, 2006]. However, to fully realise this potential additional implementation is required to support distributed synchronous and asynchronous interactions.

During the PSPD evaluation, an acknowledged failing of PSPD was that it did not support the rapid externalisation of divergent ideas in the early stages of a design activity. Rather, ideas were externalised when they had reached a certain degree of refinement. During our evaluation of the EDC, we found that the system-defined contexts (i.e. the map of the Gunbarrel area of Boulder) and pre-defined notations (i.e. land-type colourings) provided by the EDC facilitated the rapid externalisation of new, divergent ideas. It was therefore suggested that a further development to PSPD would be to allow users to load pre-defined contexts, thereby improving its support for the externalisation of new, divergent ideas in the early stages of a design activity.

The design and development of PSPD was constrained by today's technologies. While, our software built upon the affordances of paper, the hardware was far from what is used in a traditional design studio. However, looking towards the future this constraint could be overcome with the production of digital paper[1], providing the physical properties of paper, with the advantages of the digital realm.

While PSPD supports the creation and dissemination of externalisations it does not support their permanent presentation. A common feature in many design studios is for the walls to be covered with designs, magazine scraps and any other objects that inspire the designers. Therefore, an extension to PSPD could be to provide a presentation wall (e.g. a large interaction plasma screen)[2]. This presentation wall could store virtual objects, such as photos and articles. Due to the digital nature of this content it would be able to hold a large volume of data, be easily searched (e.g. 'give me all the designs of bikes') and allow the virtual objects to be manipulated (e.g. rotated).

Beyond the technical development of PSPD, its evaluation could also be extended. The final evaluation of PSPD was constrained to the usability lab and participants completed the design task in 58 to 100 minutes. However, as acknowledged by the participants, they believed the advantages of PSPD would be seen more in a real design setting, where the design task would transcend both space and time. With further developments completed as described above, the use of PSPD could be observed over longer periods of time.

[1] http://www.eink.com/

[2] Similar to the 'The Portfolio Wall' developed by Alias|Wavefront

Finally, while our evaluation of PSPD was focussed on a particular design activity, we believe that the lessons learned can be extended to CST for other domains involving groups, from music composition to scientific problem solving. For example, Coughlan & Johnson [2006] refer to music composition as both an individual and collaborative activity. With the PSPD software aimed at the domain of music composition, the ideas embodied in PSPD could support the individual and collaborative processes of music composition through its framework and hardware.

Addressing such future research shall contribute towards better understanding and supporting creativity. This thesis has offered a contribution towards this goal.

Appendix A

Companion to Chapter 1

Section A.1 provides a list of peer-reviewed publications that have resulted from the research reported in this thesis.

A.1 Peer-reviewed publications

Warr, A. & O'Neill, E. (2004). Getting Creative with Participatory Design. In the Proceedings of the 8th Conference on Participatory Design: Artful integration: Interweaving Media, Materials and Practices (Toronto, Canada, July 27 - 31, 2004). PDC'04. 57-61.

Warr, A. & O'Neill, E. (2005). Understanding Design as a Social Creative Process. In the Proceedings of the 5th Conference on Creativity and Cognition (London, UK, April 12 - 15, 2005). C&C'05. ACM Press, 118-127.

Warr, A. & O'Neill, E. (2005). The Effect of Operational Mechanisms on Creativity. In the Proceedings of the 10th IFIP Interaction Conference on Human-Computer Interaction (Rome, Italy, September 12 - 16, 2005) INTERACT'05, Springer-Verlag, 629-642.

Warr, A. & O'Neill, E. (2006). Public Social Private Design (PSPD). In the Extended Abstracts of the SIGCHI Conference on Human Factors in Computing Systems (Montreal, Canada, April 24 - 27, 2006). CHI'06. ACM Press, 1499-1504.

Warr, A., O'Neill, E. (2006). The Effect of Group Composition on Divergent Thinking in an Interaction Design Activity. In the Proceedings of the 6th Conference on Designing Interactive Systems: Processes, Practices, Methods and Techniques (Penn State College, USA, July 26 - 28, 2006). DIS'06. ACM Press, 122-131.

Warr, A. & O'Neill, E. (2006). Tools for Creativity: Sketching with the EDC and PSPD. In the Workshop: "Sketching" Nurturing Creativity: Commonalities in Art, Design, Engineering and Research. At the SIGCHI Conference on Human Factors in Computing Systems (Montreal, Canada, April 24 - 27, 2006). CHI'06.
Available at: http://www.kid.rcast.u-tokyo.ac.jp/chi06-sketch-ws/

Warr, A. (2006). Situated and Distributed Design. In the Workshop: Distributed Participatory Design. At the 4th Nordic Conference on Human-Computer interaction (Oslo, Norway, October 14 - 18, 2006). NordiCHI'06.
Available at: http://extra.shu.ac.uk/paperchaste/dpd/

Warr, A. & O'Neill, E. (2007). Tool Support for Creativity using Externalisations. In the Proceedings of the 6th Conference on Creativity and Cognition (Washington D.C., USA, June 13 - 15, 2007). C&C'07. ACM Press.

Warr, A. and O'Neill, E. (2007). Tools To Support Collaborative Creativity. In the Workshop: Tools in Support of Creative Collaboration. At the 6th Conference on Creativity and Cognition (Washington D.C., USA, June 13 - 15, 2007). C&C'07.
Available at: http://orchid.cs.uiuc.edu/CreativeCollaboration/

Appendix B

Companion to Chapter 3

Section B.1 presents an excerpt from the novelty assessment schema.

Section B.2 presents five example statistical tests - t-tests, ANOVA, Mann-Whitney, Kruskal-Wallis, Chi-squared tests.

Section B.3 presents an excerpt from the appropriateness questionnaire administered to 63 judges to determine the degree of appropriateness of the creative ideas reported by participants during the experiment.

Section B.4 presents the questionnaire administered to participants after the experiment.

B.1 The novelty assessment schema

In chapter 3, novelty (i.e. p-novelty [Boden, 1994]) was determined through the retrospective protocol administered after the experiment. An excerpt can be found below:

Post-analysis of ideas

Participant: <Auto-generated participant identifier (e.g. P1)>
Name: <Participants name handwritten by the experimenter>
Date and Time: <Auto-generated date and time stamp>
Condition: <Auto-generated condition label for the experiment>

Ideas:

1) <Idea 1>
A new idea - combination of two or more exisitng ideas [ ]
An old, existing idea applied to a new context [ ]
Other [ ]
If other, please specify:

...

n) <Idea n>
A new idea - combination of two or more exisitng ideas [ ]
An old, existing idea applied to a new context [ ]
Other [ ]
If other, please specify:

B.2 Example statistical calculations

In chapter 3 we ran five types of statistical tests - t-tests, ANOVA, Mann-Whitney, Kruskal-Wallis and Chi-squared tests. In the following sections we provide example calculations for each of these tests, including full data tables and associated pre-tests.

B.2.1 A t-test

This example is based on the number of duplicated creative ideas produced. Table B.1 shows the full data table for the number of duplicated creative ideas for the nominal and real group conditions.

Before running any statistical test we had to determine whether the data was parametric or non-parametric. In order for the data to be considered parametric it had to satisfy three assumptions: the data was interval data; there was an equality of variance; and the data was normally distributed. If one or more of these assumptions were not met, the data was non-parametric. To determine whether the data was parametric or non-parametric, a number of pre-tests were conducted:

The data was interval data.

A Levene's test showed the data to be of equal variance ($F_{1,4} = 0.04$, p = 0.95).

Table B.1: The number of duplicated creative ideas for nominal and real group conditions.

	N	R
	6	4
	17	7
	8	1
	19	4
	10	17
	11	1
Total	71	34
Mean	11.83	5.67
SD	5.12	5.99

> A Kolmogorov-Smirnov test showed the data to be normally distributed for each of our variables: nominal (K-S Z = 0.57, p = 0.91) and real (K-S Z = 0.68, p = 0.75).

These pre-tests indicated that our data had met the assumptions for parametric tests. Therefore, the appropriate test to be conducted to determine if there were significant differences between the two conditions was a t-test.

Using the data presented in table B.1, a t-test was run to determine if there was any significant difference between the nominal and real group conditions for the number of duplicated creative ideas produced. T-tests were run using SPSS. The output from the t-test can be seen in table B.2.

As we had hypothesied the direction of difference, the one-tail p value indicated the appropriate confidence level ($p = 0.04$). Hence, a significant difference was found as $p < 0.05$.

B.2.2 An ANOVA test

This example is based on the number of duplicated creative ideas produced. Table B.3 shows the full data table for the number of duplicated creative ideas for the nominal, nominal-real, real-nominal and real group conditions.

Table B.2: The t-test output.

	T-test output
Hypothesised Mean Difference	0
df	10
t stat	1.92
p (T <= t) one-tail	0.04
t critical one-tail	1.81
p (T <= t) two-tail	0.08
t critical two-tail	2.23

Table B.3: The number of duplicated creative ideas for nominal, nominal-real, real-nominal and real group conditions.

	N	N-R	R-N	R
	6	8	7	4
	17	9	11	7
	8	8	10	1
	19	8	5	4
	10	4	9	17
	11	14	11	1
Total	71	51	53	34
Mean	11.83	8.50	8.83	5.67
SD	5.12	3.21	2.40	5.99

Before running any statistical test we had to determine whether the data was parametric or non-parametric. In order for the data to be considered parametric it had to satisfy three assumptions: the data was interval data; there was an equality of variance; and the data was normally distributed. If one or more of these assumptions were not met, the data was non-parametric. To determine whether the data was parametric or non-parametric, a number of pre-tests were conducted:

The data was interval data.

A Levene's test showed the data to be of equal variance ($F_{3,20} = 1.45$, p = 0.26).

A Kolmogorov-Smirnov test showed the data to be normally distributed for each of our variables: nominal (Kolmogorov-Smirnov Z = 0.57, p = 0.91), nominal-real (Kolmogorov-Smirnov Z = 0.67, p = 0.77), real-nominal (Kolmogorov-Smirnov Z = 0.48, p = 0.98) and real (Kolmogorov-Smirnov Z = 0.68, p = 0.75).

These pre-tests indicated that our data had met the assumptions for parametric tests. Therefore, the appropriate test to be conducted to determine if there were significant differences between the four conditions was an ANOVA.

Using the data presented in table B.3, an ANOVA was run to determine if there were any significant differences between the nominal, nominal-real, real-nominal and real group conditions for the number of duplicated creative ideas produced. ANOVA were run using SPSS. The output from the ANOVA can be seen in table B.4.

Table B.4: The ANOVA output.

	Between group	Within Group
SS	114.45	390.50
df	3	20
MS	38.15	19.525
F	1.95	
p value	0.15	
F critical	3.10	

The p value indicated the confidence level ($p = 0.15$). Hence, no significant differences were found as $p > 0.05$.

B.2.3 A Mann-Whitney test

This example is based on the percentage of refined creative ideas generated, including duplicated creative ideas. Table B.5 shows the full data table for the percentage of refined creative ideas for the nominal and real group conditions.

Table B.5: The percentage of refined creative ideas including duplicated creative ideas, for nominal and real group conditions.

	N	R
	33.33	22.58
	25.00	53.19
	26.19	42.86
	16.67	33.33
	15.79	32.08
	9.38	31.25
Total	126.35	215.29
Mean	21.06	35.88
SD	8.67	10.65

Before running any statistical test we had to determine whether the data was parametric or non-parametric. In order for the data to be considered parametric it had to satisfy three assumptions: the data was interval data; there was an equality of variance; and the data was normally distributed. If one or more of these assumptions were not met, the data was non-parametric. To determine whether the data was parametric or non-parametric, a number of pre-tests were conducted:

> The data was ordinal data.
>
> A Levene's test showed the data to be of equal variance ($F_{1,4} = 0.18$, $p = 0.74$).
>
> A Kolmogorov-Smirnov test showed the data to be normally distributed for each of our variables: nominal (Kolmogorov-Smirnov $Z = 1.15$, $p = 0.15$) and real (Kolmogorov-Smirnov $Z = 0.61$, $p = 0.85$).

These pre-tests indicated that our data had not met one of the assumptions for parametric tests. Therefore, the appropriate test to be conducted to determine if there were significant differences between the two conditions was a Mann-Whitney test.

Using the data presented in table B.5, a Mann-Whitney testwas run to determine if there was any significant difference between the nominal and real group conditions for the percentage of refined creative ideas, including duplicated creative ideas. Mann-Whitney tests were run using SPSS. The output from the Mann-Whitney test can be seen in table B.6.

Table B.6: Mann-Whitney test output.

	Mann-Whitney output
Mann-Whitney U	5.50
Exact Sig. [2*(1-tailed Sig.)]	0.04
Exact Sig. [1-tailed Sig.]	0.02

As we had hypothesied the direction of difference, the one-tail p value indicates the appropriate confidence level ($p = 0.02$). Hence, a significant difference was found as $p < 0.05$.

B.2.4 A Kruskal-Wallis test

This example is based on the percentage of refined creative ideas produced, including duplicated creative ideas. Table B.7 shows the full data table for the percentage of refined creative ideas including duplicated creative ideas, for the nominal, nominal-real, real-nominal and real group conditions.

Before running any statistical test we had to determine whether the data was parametric or non-parametric. In order for the data to be considered parametric it had to satisfy three assumptions: the data was interval data; there was an equality of variance; and the data was normally distributed. If one or more of these assumptions were not met, the data was non-parametric. To determine whether the data was parametric or non-parametric, a number of pre-tests were conducted:

The data was ordinal data.

A Levene's test showed the data to be of equal variance ($F_{3,20} = 0.22$, $p = 0.88$).

Table B.7: The percentage of refined creative ideas including duplicated creative ideas, for nominal, nominal-real, real-nominal and real group conditions.

	N	N-R	R-N	R
	33.33	13.51	15.15	22.58
	25.00	16.13	35.29	53.19
	26.19	21.21	25.00	42.86
	16.67	27.78	32.14	33.33
	15.79	50.00	24.14	32.08
	9.38	23.21	35.90	31.25
Total	126.35	151.85	167.62	215.29
Mean	21.06	25.31	27.94	35.88
SD	8.67	13.12	8.02	10.65

A Kolmogorov-Smirnov test showed the data to be normally distributed for each of our variables: nominal (K-S Z = 0.49, p = 0.97), nominal-real (K-S Z = 0.63, p = 0.82), real-nominal (K-S Z = 0.49, p = 0.97) and real (K-S Z = 0.64, p = 0.81)..

These pre-tests indicated that our data had not met one of the assumptions for parametric tests. Therefore, the appropriate test to be conducted to determine if there were significant differences between the four conditions was a Kruskal-Wallis test.

Using the data presented in table B.7, a Kruskal-Wallis test was run to determine if there was any significant difference between the nominal, nominal-real, real-nominal and real group conditions for the percentage of refined creative ideas including duplicated creative ideas. Kruskal-Wallis tests were run using SPSS. The output from the Kruskal-Wallis test can be seen in table B.8.

Table B.8: The Kruskal-Wallis test output.

	Kruskal-Wallis output
Chi-square	5.12
df	3
Asymp. Sig.	0.16

The p value indicated the confidence level ($p = 0.16$). Hence, no significant differences were found as $p > 0.05$.

B.2.5 A Chi-square test

This example is based on the frequency of refined creative ideas that resulted from either self-think or group think. Table B.9 shows the full data table for the frequency of refined creative ideas for the real group condition.

Table B.9: The frequency of refined creative ideas for the real group condition.

	Self-think	Group-think
Total	18	58
Mean	3.00	9.67
SD	2.09	4.37

Using the data presented in table B.9, a Chi-square test was run to determine if there was any significant difference between the frequency of refined ideas produced as a result of self-think and group think. The Chi-square test was run using SPSS. The output from the Chi-square test can be seen in table B.10.

Table B.10: The Chi-square output.

	Chi-square output
df	1
Chi-square	11.31
p value	≤ 0.001

The p value indicated the confidence level ($p \leq 0.001$). Hence, a significant difference was found as $p < 0.05$.

B.3 The appropriateness questionnaire

In chapter 3, the degree of appropriateness was determined using a simple 'yes' or 'no' questionnaire administered to a wide community to act as judges. Each judge was asked whether they considered the reported ideas appropriate for use. An excerpt of the questionnaire can be seen below:

> Dear Judge,
>
> This questionnaire is part of research being conducted by Dr Eamonn ONeill & Andy Warr in the Department of Computer Science at the University of Bath, UK (eamonn@cs.bath.ac.uk & cspaw@cs.bath.ac.uk) is looking at improving the process of design leading towards the design of more usable and useful software applications and computer systems.
>
> The following questionnaire is designed to assess which of the following ideas for scrolling a pervasive computer screen (i.e. a 61" plasma screen) you would find appropriate for use - a simple yes or no questionnaire.
>
> In a study 96 participants were asked to generate ideas to the following problem:
>
>> *'You have been asked to design an interaction technique for scrolling on a pervasive computer screen (i.e. a 61 plasma screen). The technique should allow the user or users to scroll up and down, and left and right.'*
>
> The participants were told the scrolling technique could be used for a pervasive screen which could be located in their home, their office or in the street. They were also told they did not have to worry about the technical details or the requirements for ideas they generated for scrolling the pervasive screen.
>
> In this questionnaire you will find all of the ideas (without replication) generated by all the participants in our study. Each idea is structured in the following format:
>
> <Index>) <The idea.> <An extended description of the idea.>
> <An example of the idea for scrolling up and left.>

You do not need to concern yourself with the indexing as this is for the experimenter to reference the ideas. The idea gives an overview of the interaction technique using the same words used by the participants during our study. The extended description tries to provide a simpler description of the idea. The example provides an instance of the idea for scrolling up and for scrolling left - please note each interaction technique can scroll up, down, left and right scrolling up and left are just documented to provide an overview of vertical and horizontal scrolling, while saving space.

Please take the time to answer ALL the questions in the questionnaire below, taking into account these are just initial ideas - some technologies may not be yet exist, ideas may not be fully specified and partially incomplete. It should also be noted no specific user, task or domain where specified, so please consider each idea as a generic scrolling technique. If you are answering the questions electronically using Word on your computer, please highlight your answer for each question in bold. If you are answering the questions using paper and pen, please circle the appropriate answer. If you have any comments regarding the appropriateness of an idea please write them under the relevant idea.

Once you have completed the questionnaire please e-mail electronic versions of the questionnaire to Andrew Warr (cspaw@cs.bath.ac.uk) or if you have completed a paper version of the questionnaire please mail it to: Andrew Warr, HCI Group, Department of Computer Science, University of Bath, Bath, BANES, BA2 7AY, UK. The deadline for completed questionnaire is Friday 19th August.

We would like to thank you in advance for your time and effort in completing this questionnaire and participating in our research.

Best Regards

Andrew Warr

Participant details:

Name:
Age:
Occupation:

1.1) **A bicycle, like the ones you get in a gym -** The handle bars control direction, while the pedals control the rate of movement
i.e. turning the handle bars to face up and then pedalling would cause upward scrolling; turning the handle bars to face to the left and then pedalling would cause scrolling to the left; etc

Yes No

1.2) **Four bicycles, like the ones you get in a gym -** Pedalling on each bicycle controls the scroll motion for a given direction
i.e. pedalling on the bicycle for scrolling up would cause upward scrolling; pedalling on the bicycle for scrolling left would cause scrolling to the left; etc

Yes No

...

B.4 The post-experiment questionnaire

In chapter 3, a questionnaire was administered to participants after the experiment. The questionnaire can be found below:

Post-experiment questionnaire

Name:
Age:
Course:

The following questionnaire is designed to collect information on your opinions of the experiment and the operational mechanisms of design to compliment the data collected in experiment you have just participated in. This information will be used to try to improve the operational mechanisms of design. Please can you take the time to fill in this questionnaire and return it to the experimenter before you leave. No data provided in this questionnaire will be passed on to any third party.

1) Would you agree: 'It was easy to submit an idea using the Idea Generator software'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

2) Were you constrained by the number of ideas you could contribute because you had to type your ideas? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

3) If the Idea Generator software were different, what types of interaction would you suggest for contributing ideas? (Please tick one or more)

Hand Written (i.e. words) [ ]
Typed (i.e. words) [ ]
Drawn (i.e. pictures) [ ]
Verbal (i.e. spoken) [ ]
Gesture (i.e. video) [ ]
Other [ ]

If other, what types of interaction would you like:

4) Would you agree: 'The presentation of pooled ideas was useful'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

5) Would you agree: 'I made use of the pooled ideas by combining ideas'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

6) Would you agree: 'I made use of the pooled ideas by improving upon ideas'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

7) Which ideas did you combine most? (Please tick)

My own ideas [ ]
Other group members' [ ]
Both [ ]
I did not combine ideas [ ]

8) Which ideas did you improve most? (Please tick)

My own ideas [ ]
Other group members' [ ]
Both [ ]
I did not improve ideas [ ]

9) Would you agree: 'Osborn's fundamental rules for brainstorming helped me in the process of generating ideas'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

10) What is your opinion of Osborn's fundamental rules for brainstorming?

a) Criticism is ruled out? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

b) Freewheeling is welcomed? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

c) Quantity is wanted? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

d) Combination and improvement are sought? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

11) Can you think of any rules for improving the process of generating ideas?

12) What was your opinion of how the group communicated together? (i.e. do you feel you were able to express your ideas effectively?) (Please circle one)

Very positive	positive	Average	Negative	Very negative	No Opinion

Comments:

13) What was your opinion of the groups composition? (i.e. do you feel you were able to contribute lots of good ideas) (Please circle one)

Very positive	positive	Average	Negative	Very negative	No Opinion

Comments:

14) What was your opinion of the groups composition? (i.e. do you feel the group were able to contribute lots of good ideas) (Please circle one)

Very positive	positive	Average	Negative	Very negative	No Opinion

Comments:

15) What was your opinion of the group climate? (i.e. did you find the process of design cooperative, fun, easygoing) (Please circle one)

Very positive	positive	Average	Negative	Very negative	No Opinion

Comments:

16) What was your opinion of the design process? (i.e. do you think the design process went well)
(Please circle one)

Very positive	positive	Average	Negative	Very negative	No Opinion

Comments:

17) Would you agree: 'I was free to report an idea whenever I wished'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

18) Would you agree: 'I was able to contribute an idea without fear of criticism'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

19) Would you agree: 'Everyone in my group contributed equally'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

20) If you have any other comments, could you please note them below?

Appendix C

Companion to Chapter 4

Section C.1 presents the diary study sheet used in our diary study.

Section C.2 presents an excerpt from the spreadsheet used to analyse the data from the diary study.

Section C.3 presents an example statistical test - a Pearson's corelation test.

Section C.4 presents an excerpt from the encoded video data of the ethnographic observations.

Section C.5 presents an excerpt from the lab-based observations foci analysis.

Section C.6 presents the questionnaire administered after lab-based observations.

C.1 A diary study sheet

The diary study sheet given to participants of the diary study as reported in chapter 3 is as follows:

CM20143 Creativity Diary

Name:

Group:

Date and Time:

Context of Idea (Tick appropriate box):
a) Individually [ ]
b) In a Group [ ]

Origin of Idea (Tick appropriate box):
a) A new idea a combination of two or more existing ideas [ ]
b) An old, existing idea applied to a new context [ ]
c) Other [ ]
If Other, please specify:

Idea Details (expand upon details of ideas as much as possible):

...

C.2 The diary study analysis

In chapter 4, a spreadsheet was used to identify patterns from the diary study data. An excerpt can be seen below:

Table C.1: An excerpt from the diary study data spreadsheet.

Group	NameID	WeekID	Idea type	Origin	Reference
1	cb	1	ri	I	G1CBW1
1	dm	1	ri	I	G1DMW1
1	hp	1	ni	I	G1HPW1
1	ms	1	ni	I	G1MSW1
1	rw	1	ri	g	G1RWW1

Table key:

Group: Group identifier - from 1 to 12
NameID: Initials of participants diary sheet
WeekID: Week of the software development project - from 1 to 9
Idea type: The type of idea generated - ni = new idea; ri = refined idea
Origin: Who generated the idea - I = individual; g = group
Reference: A diary sheet identifier - <Group identifier><NameID><WeekID>

C.3 An example statistical calculation

In chapter 4 we ran Pearson's correlation test to determine the relationship between the number of new ideas generated and the number of ideas generated by individuals. We also used the Pearson's correlation test to determine the relationship between the number of refined ideas generated and the number of ideas generated by a group. In the following section we provide an example calculation for 1 of the Pearson correlation tests, including full data tables and associated pre-tests.

C.3.1 Pearson's correlation test

This example is based on the relationship between the number of new ideas generated and the number of ideas generated by individuals. Table C.2 presents the full data table.

Table C.2: The number of new ideas generated and the number of ideas generated by individuals.

New Ideas generated	Ideas generated by individuals
3.25	3.00
4.92	3.58
0.42	0.67
0.25	1.00
0.33	0.67
0.00	0.17
0.17	0.58
0.00	0.08
0.08	0.08

Using the data presented in table C.2, a Pearson's correlation test (2-tailed) was run to determine if there was a relationship between the number of new ideas generated and the number of ideas generated by individuals. The Pearson's correlation test was run using SPSS. The output from the Pearson's correlation test can be seen in table C.3.

The p value indicated the confidence level ($p = 7.07\text{x}10^{-6}$). In this test a significant difference was found as $p < 0.05$.

Table C.3: The Pearson's correlation test output.

		New Ideas	Ideas generated by individuals
New Ideas	Pearson correlation	1	0.976
	Sig. (2 - tailed)		$7.07\text{x}10^{-6}$
	N	9	9
Ideas generated by individuals	Pearson correlation	0.976	1
	Sig. (2 - tailed)	$7.07\text{x}10^{-6}$	
	N	9	9

C.4 The field-based observations video encodings

In chapter 4, the video data from the field-based observations was encoded. Encoding was achieved through the use of Noldus Observer, Windows Media Player and Microsoft Excel. Table C.4 presents an excerpt from field-based observation video encodings.

Table key:

Time: The time of the conversation sequence - hh:mm:ss
Participant: Participant identifier
Composition: The group composition - I = individual; SG(P?) = sub-group, including information on the collaborating parties; G = group
Social influences: The occurrence of social influences - PB = production blocking; EA = evaluation apprehension; FR = free-riding
Creative process phase: The phase(s) of the creative process engaged in - PF = problem framing; NI = new idea; RI = refined idea; IF = idea framing; IE = idea evaluation

C.5 The lab-based observations foci analysis

In chapter 4, our analysis of the video data from our lab-based observations involved recording and tallying our observations. Table C.5 presents an excerpt from the lab-based observations foci analysis.

Table C.4: An excerpt from the field-based observation video encodings.

Time	Participant	Composition	Social Influence	Creative process phase	Comments/Notes
00:00:17	P2	G		PF	P2 states requirements for the system
00:00:30	P5	SG(P2)	PB(P2)	IE	P5 critiques 1 of P2's requirements
00:00:48	P2	SG(P5)		PF	P2 states another requirement that addresses P5's point

Table C.5: An excerpt from the lab-based observations foci analysis.

Observation	Tally
Multiple solutions on 1 sheet of paper	4
Multiple sheets of paper used	3
Uses the entire width or height of the paper	6

C.6 The lab-based observations questionnaire

In chapter 4, a questionnaire was administered to participants after the lab-based observations. The questionnaire can be found below:

Post-study questionnaire

Name:
Age:
Gender: male/female

1) What did you like about the sketching?

2) What did you not like about the sketching?

3) Would you agree, 'When sketching I drafted the idea first and then added detail'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

4) How did you manipulate the pencil during sketching? (Please tick one or more)

Pencil hardness/pressure [ ]
Pencil size [ ]
Pencil shape [ ]
Other:

5) Would you agree, 'I scaled different sketches (i.e. making them bigger and smaller)'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

6) Would you agree, 'I moved your face closer and further away from the paper to get a different focus'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

7) Would you agree, 'I rotated the paper to sketch at a different angle'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

8) Would you agree, 'I moved the paper to work on the sketch (i.e. place of the paper on the table)'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

9) Would you agree, 'I used multiple sheets of paper to do your sketching'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

10) Would you agree, 'I used annotation with your sketches'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

11) Would you agree, 'Did the collaborative sketching allow information to be socially constructed and shared by the group'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

12) Would you agree, 'The process of sketching supported the development of new ideas'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

13) Would you agree, 'The process of collaborative sketching enhanced the development of new ideas'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

14) Would you agree, 'The process of sketching (on my own) supported the development/evolution of existing ideas'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

15) Would you agree, 'The process of collaborative sketching enhanced the development/evolution of existing ideas'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

16) Would you agree: 'I was able to present ideas in an effective and useful manner'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

17) Would you agree: 'I made use of existing ideas by combining them'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

18) Would you agree: 'I made use of existing ideas by improving upon them'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

19) During the collaborative sketching task whose ideas did you combine most? (Please tick)

My own ideas [ ]
Other group members' [ ]
Both [ ]
I did not combine ideas [ ]

20) During the collaborative sketching task whose ideas did you improve most? (Please tick)

My own ideas [ ]
Other group members' [ ]
Both [ ]
I did not improve ideas [ ]

21) Would you agree, 'I was able to organise your ideas/solutions'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

22) Would you agree, 'I was able to evaluate your ideas effectively'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

23) Would you agree, 'I was always able to contribute an idea whenever you had one without obstruction'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

24) Would you agree, 'I were always able to contribute an idea without fear of criticism'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

25) Would you agree, 'During the collaborative sketching everyone contributed equally'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

26) Would you agree, 'I was forced to work as a group'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

27) Would you agree, 'I was able to work individually'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

28) What was your opinion of how the group communicated together? (i.e. do you feel you were able to express your ideas effectively?) (Please circle one)

Very positive	Positive	Average	Negative	Very negative	No Opinion

Comments:

29) What was your opinion of the groups composition? (i.e. do you feel you were able to contribute lots of good ideas) (Please circle one)

Very positive	Positive	Average	Negative	Very negative	No Opinion

Comments:

30) What was your opinion of the group climate? (i.e. did you find the process of design cooperative, fun, easygoing) (Please circle one)

Very positive	Positive	Average	Negative	Very negative	No Opinion

Comments:

31) What was your opinion of the design process? (i.e. do you think the design process went well) (Please circle one)

Very positive	Positive	Average	Negative	Very negative	No Opinion

Comments:

32) If a computerised sketch tool were to be developed, which of the below functionality would you like to be available for drawing and manipulating? (Please tick one or more)

Pencil Hardness [ ]
Pencil Size [ ]
Pencil Shape [ ]
Pencil Colour [ ]
Scaling [ ]
Zooming [ ]
Rotating [ ]
Moving [ ]
Selecting [ ]
Copy/Cut/Paste [ ]
Add Layers [ ]
Remove Layers [ ]
Show Layers [ ]
Hide Layers[ ]

If other, what would you like:

33) What additional hardware features would you add to better support sketching?

34) What additional software features would you add to better support sketching?

35) If you have any other comments, could you please note them below?

Appendix D

Companion to Chapter 5

Section D.1 provides a list of the available functionality provided by the EDC.

Section D.2 provides the script containing a list of practice tasks used to familarise the participants with the functionality provided by the EDC.

Section D.3 presents the questionnaire administered after the EDC evaluation.

Section D.4 reports an evaluation of the EDC based on our heuristics for CST, derived from the our requirements for CST.

Section D.5 presents an excerpt from the encoded video data of the EDC evaluation.

D.1 The Envisionment and Discovery Collaboratory functionality

In chapter 5, a list of the available EDC functionality as described in an audio recording was available on the wall next to the EDC and could be referred to by the participants at any time during the evaluation. This list can be seen below:

The EDC Functionality

The available functionality provided by the EDC during the task is as follows:

The EDC table - This is a physical table with a projected graphical image on the surface. The table comprises of an embedded grid structure for detecting physical objects and an ultra-sonic sketching tool. Projected onto the centre of the table is a map showing the Gunbarrel area of Boulder. Each grid represents one block. At the top and bottom of the table is a tool menu and to the slides of the table is functionality specifically for the sketching tool.

The tool menu - This menu can be found at the top and bottom of the table. From the options available you only need to concern yourself with the aerial, map and hide options.

Aerial option - This is the current view being shown. This view is a satellite image of the Gunbarrel area of Boulder.

Map option - This view provides a simplified map image of the Gunbarrel area of Boulder.

Hide option - This option removes the land-use colouring. Pressing it again reveals the land-use colouring.

The sketch menu - This menu can be found at the top and bottom of the table below the tool menu. From the options available you only need to concern yourself with the new sketch option.

New sketch - This provides a layer which allows you to draw lines and shapes over the map. Once a new sketch layer is created three options will appear at the top and bottom of the table: minimise, overlay and close.

Minimise - This option allows you to minimise the sketch to a panel at the side of the table. The sketches are store in the order in which they where minimised with the most recent at the bottom. To bring a minimised sketch back into the map area, choose the desired sketch from the side panel (you will see it enlarge), click the sketch again to confirm. You can scroll through the minimised sketches by using the up and down scroll arrows.

Overlay - If you have multi sketches on the map, this option brings the selected sketch to the top.

Close - This option removes the sketch.

Sketch colour option - This functionality can be located at the one side of the table. Here you have the options to choose the line colour, the fill colour and an erase option.

The line colour - After a sketch is created, or selected, selecting the current colour option and selecting your desired colour from the colour palette, with set the current line colour.

The fill colour - After a sketch is created, or selected, you can also select a fill colour. Selecting the fill colour option and selecting your desired colour from the colour palette, will select the current fill colour. Selecting the fill colour option again with remove the fill option and allow you to go back to sketching lines.

Erase - To erase lines or shapes select the erase option. To remove the line or the filled shape, select the line or the edge of the shape to remove it.

Blocks - These are physical objects which can interact with the embedded grid structure. However, by using the blocks you are constrained to the grid structure. You may use the sketch tools, but please keep to the same colour scheme.

Admin - This is a selection block. Use this block to change between the aerial, map and hide options.

Single-family residential (Yellow) - This indicates low-density housing i.e. detached housing.

Multi-family residential (Orange) - This indicates high-density housing i.e. apartments.

Agricultural (Brown) - This indicates farm land.

Light industrial (Blue) - Warehouses and small factories.

Commercial (Red) - Shops and offices.

Open Space/Parks - Open land suitable for walking, playing and relaxing.

Remove - This removes a land-use type and resets it to neutral.

D.2 The Envisionment and Discovery Collaboratory practice session script

In chapter 5, a list of tasks were read aloud from a script to participants. These tasks aimed to allow the participants to familiarise themselves with the EDC's functionality. This script can be seen below:

The EDC Practice Session

You now have the opportunity to familiarise yourself with the functionality of the EDC. Please carry out the following tasks as a group.

1. Map tasks
   (a) Change between the aerial and map view, and back again.
2. Sketching Functionality
   (a) Create a new sketch
   (b) Select the colour red for the line colour
   (c) Draw a large circle
   (d) Select white as the fill colour
   (e) Imagine the circle to be a head, draw two eyes.
   (f) Remove the fill colour
   (g) Draw a nose
   (h) Create a new sketch
   (i) Draw a mouth
   (j) Minimise the first sketch, just to leave the sketch of the mouth on the map area
   (k) Erase the drawing of the mouth
   (l) Maximise the 1st sketch which you minimised containing a sketch of a head with eyes and a nose
   (m) Close the sketch
3. Blocks
   (a) Use the blocks to define some land types.
   (b) Use the sketch tool to define some land types
   (c) Hide the current defined land types and then make them reappear.
   (d) Use the remove block to remove some of the land types defined by the blocks.

D.3 The Envisionment and Discovery Collaboratory post-evaluation questionnaire

In chapter 5, a questionnaire was administered to participants after the EDC evaluative task. The questionnaire can be found below:

Post-evaluation questionnaire

Name:
Age:
Occupation (plus course if a student):
Assigned role:

The following questionnaire is designed to collect information on your opinions of the Envisionment and Discovery Collaboratory (EDC) as a support tool for design to compliment the data collected during the study. Please can you take the time to fill in this questionnaire and return it to the experimenter before you leave. No data provided in this questionnaire will be passed on to any third party.

1) What did you like about the EDC?

2) What did you not like about the EDC?

3) Would you agree, 'The EDC brought a variety of aspects (social, cultural, physical, virtual) together to support the creation of shared understanding'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

4) Would you agree, 'The EDC allowed you to develop as you learned new information and the task progressed'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

5) Would you agree, 'The EDC evolved and met the needs of the users as both the user and task progressed'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

6) Would you agree, 'The EDC motivated me to become engaged in the task'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

7) Would you agree, 'I was an active contributor throughout the task'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

8) Would you agree, 'I was in control of the EDC'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

9) Would you agree, 'The EDC allowed information to be socially constructed and shared by the group'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

10) Would you agree, 'The EDC supported the development of new ideas'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

11) Would you agree, 'The EDC supported the development/evolution of existing ideas'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

12) Would you agree: 'The EDC presented existing ideas in an effective and useful manner'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

13) Would you agree: 'I made use of existing ideas by combining them'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

14) Would you agree: 'I made use of existing ideas by improving upon them'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

15) Whose ideas did you combine most? (Please tick)

My own ideas [ ]
Other group members' [ ]
Both [ ]
I did not combine ideas [ ]

16) Whose ideas did you improve most? (Please tick)

My own ideas [ ]
Other group members' [ ]
Both [ ]
I did not improve ideas [ ]

17) Would you agree, 'The EDC supported the organisation of my ideas/solutions'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

18) Would you agree, 'The EDC allowed me to evaluate my ideas effectively'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

19) Would you agree, 'I always able to contribute an idea whenever I had one without obstruction'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

20) Would you agree, 'I was always able to contribute an idea without fear of criticism'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

21) Would you agree, 'Everyone within the group contributed equally'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

22) Would you agree, 'The EDC supported me to work as a group'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

23) Would you agree, 'The EDC supported me to work in sub-groups'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

24) Would you agree, 'The EDC supported me to work individually'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

25) What was your opinion of how the group communicated together? (i.e. do you feel you were able to express your ideas effectively?) (Please circle one)

Very positive	Positive	Average	Negative	Very negative	No Opinion

Comments:

26) What was your opinion of the groups composition? (i.e. do you feel you were able to contribute lots of good ideas) (Please circle one)

Very positive	Positive	Average	Negative	Very negative	No Opinion

Comments:

27) What was your opinion of the group climate? (i.e. did you find the process of design cooperative, fun, easygoing) (Please circle one)

Very positive	Positive	Average	Negative	Very negative	No Opinion

Comments:

28) What was your opinion of the design process? (i.e. do you think the design process went well) (Please circle one)

Very positive	Positive	Average	Negative	Very negative	No Opinion

Comments:

29) If the EDC were different, what types of interaction would you suggest? (Please tick one or more)

Typed (i.e. words) [ ]
Drawn (i.e. pictures) [ ]
Verbal (i.e. spoken) [ ]
Gesture (i.e. video) [ ]
Other [ ]

If other, what types of interaction would you like:

30) What additional hardware features would you add to the EDC to better support design?

31) What additional software features would you add to the EDC to better support design?

32) If you have any other comments, could you please note them below?

D.4 A heuristic evaluation of the Envisionment and Discovery Collaboratory

In chapter 5 we focussed on our three high-level requirements for supporting creativity. Here we present an evaluation of the EDC based on our heuristics for CST, derived from the our requirements for CST.

Heuristic 1) Does the CST support the creation and dissemination of externalisations to support the phases of the creative process.

Summary:
Heuristics satisfied: 4
Heuristics partially satisfied: 3
Heuristics not satisfied: 3

Heuristic 1.1) Does the CST support the creation of sketches?

Satisfied? - Yes

Description: Users can use the ultrasonic sketch tool to create sketches.

Heuristic 1.2) Does the CST support the creation of annotations?

Satisfied? - No

Description: The EDC is not suitable for the creation of annotations due to permanent presentation of the map view nor does it provide an alternative support for their creation.

Heuristic 1.3) Does the CST support the creation of text?

Satisfied? - No

Description: The EDC is not suitable for the creation of text due to permanent presentation of the map view nor does it provide an alternative support for their creation.

Heuristic 1.4) Does the CST provide an accessible interaction space supporting users pointing interactions?

Satisfied? - Yes

Description: The tabletop provides an accessible interaction space for pointing interactions.

Heuristic 1.5) Does the CST provide an accessible interaction space supporting users gesture interactions?

Satisfied? - Yes

Description: The tabletop provides an accessible interaction space for gesture interactions.

Heuristic 1.6) Does the CST support the creation of new externalisations - divergent thinking?

Satisfied? - Partially

Description: New layers can hold different designs. However, layers tend not to be used for this propose, holding components of design, rather then independent designs. This causes more of a trail-and-error production of ideas.

Heuristic 1.7) Does the CST support the refinement of existing externalisations - convergent thinking?

Satisfied? - Partially

Description: Externalisations can be modified. However, this is done in a trail-and-error fashion.

Heuristic 1.8) Does the CST constrain the ways users externalise their ideas?

Satisfied? - Partially

Description: The ultrasonic sketch tool provides flexibility in the externalisation of sketches. However, the RFID blocks constrain the users externalisations.

Heuristic 1.9) Does the CST provide users with an unobstructed solution space?

Satisfied? - No

Description: The EDC displays a map view of the Gunbarrel area of Boulder, Colorado. Users have to work within this framework.

Heuristic 1.10) Does the CST allow its users to change the orientation and position of an externalisation and/or the CST?

Satisfied? - Yes

Description: Users can freely move around the EDC tabletop.

Heuristic 2) Does the CST need to support the various group compositions of a group?

Summary:
Heuristics satisfied: 1
Heuristics partially satisfied: 0
Heuristics not satisfied: 4

Heuristic 2.1) Does the CST provide personal interaction spaces to support individual creative activities?

Satisfied? - No

Description: The EDC only provides a public interaction space - the EDC tabletop.

Heuristic 2.2) Does the CST provide social interaction spaces to support sub-group activities?

Satisfied? - No

Description: The EDC only provides a public interaction space - the EDC tabletop.

Heuristic 2.3) Does the CST provide large interaction spaces to support group creative activities?

Satisfied? - Yes

Description: The EDC provides a public interaction space - the EDC tabletop.

Heuristic 2.4) Does the CST support the transitions between individual, sub-group and group activities?

Satisfied? - No

Description: The EDC did not support individual and sub-group activities and therefore could not support the transition between these compositions.

Heuristic 2.5) Does the CST support creative activities beyond the collaboratory?

Satisfied? - No

Description: The EDC is constrained to the collaboratory. (In another EDC application, the EDC does extend beyond the collaboratory [Giaccardi *et al*, 2005])

Heuristic 3) Does the CST support the control of social influences?

Summary:
Heuristics satisfied: 0
Heuristics partially satisfied: 1
Heuristics not satisfied: 4

Heuristic 3.1) Does the CST provide synchronous forms of interaction reducing the effects of production blocking?

Satisfied? - No

Description: Only a single interaction space is provided - the EDC tabletop.

Heuristic 3.2) Does the CST support multiple inputs?

Satisfied? - Partially

Description: The sketch tool only support single inputs. However, multiple RFID blocks can be used at once, however there is only one block for each functionality. The ultrasonic sketch tool has the potential to support multiple inputs.

Heuristic 3.3) Does the CST remove identification with one's ideas to reduce the effects of evaluation apprehension?

Satisfied? - No

Description: Ideas can only be inputted through the EDC tabletop in the presence of the group.

Heuristic 3.4) Does the CST provide group members with privacy, thus reducing the effects of evaluation apprehension?

Satisfied? - No

Description: The EDC only provides a public interaction space - the EDC tabletop.

Heuristic 3.5) Does the CST make individuals accountable for their own productivity?

Satisfied? - No

Description: As the EDC only provides a single, public interaction space, the group work as a collective.

Overall analysis:
Heuristics satisfied: 5
Heuristics partially satisfied: 4
Heuristics not satisfied: 11

D.5 The Envisionment and Discovery Collaboratory evaluation video encodings

In chapter 5, the video data from the EDC evaluation was encoded. Encoding was achieved through the use of Noldus Observer, Windows Media Player and Microsoft Excel. Table D.1 presents an excerpt from the encoded video data.

Table key:

Time: The time of the conversation sequence - hh:mm:ss
Participant: Participant identifier
Interaction class: A set of interactions - VC = verbal communication; IWE = interaction with externalisation; IWBO = interaction with boundary object *Interaction types:* Specific interactions - T = talking; S = using sketching tool; B = using block tool; P = pointing; G = gesturing *Group composition:* The group composition - I = individual; SG(P?) = sub-group, including information on the collaborating parties; G = group
Social influences: The occurrence of social influences - PB = production blocking; EA = evaluation apprehension; FR = free-riding
Creative process phase: The phase(s) of the creative process engaged in - PF = problem framing; NI = new idea; RI = refined idea; CI = combined ideas; IF = idea framing; IE = idea evaluation

Table D.1: An excerpt from the Envisionment and Discovery Collaboratory evaluation video encodings.

Time	Participant	Interaction class	Interaction type	Composition	Social influence	Creative process phase	Comments/Notes
00:00:19	P2	VC	T	G		NI	P2 states she needs a bus stop
00:00:21	P2	I	P	G		NI	P2 points to where she wants the bus stop
00:00:23	P3	VC	T	SG(P2)		IE; NI	P3 agree; land to be developed there
00:00:25	P3	I	P	SG(P2)		NI	P3 points to potential development

Appendix E

Companion to Chapter 6

Section E.1 presents the technical details of the PSPD implementation.

Section E.2 presents the questionnaire administered after the initial evaluation of PSPD.

Section E.3 presents an excerpt from the initial evaluation of PSPD foci analysis.

Section E.4 presents an example statistical test - a Wilcoxon test.

Section E.5 presents the questionnaire administered after the effect of screen size on sketching experiment.

Section E.6 presents a list of step-by-step instructions describing how to use PSPD.

Section E.7 presents the questionnaire administered after the PSPD evaluation.

Section E.8 reports an evaluation of PSPD based on our heuristics for CST, derived from the our requirements for CST.

Section E.9 presents an excerpt from the encoded video data of the PSPD evaluation.

E.1 The implementation of Public Social Private Design

In chapter 6 we presented a high-level overview of the design and development of PSPD. In this section we present some of the technical aspects of the PSPD implementation.

PSPD was made up of an interactive tabletop, two tablet PC and four PDA. Each of these devices communicated with a server (i.e. the PSPD server) over a wireless network (802.11b). Furthermore, each device ran the PSPD software - a custom built .NET C♯ application that supported the creation, manipulation and dissemination of externalisations.

E.1.1 The creation of externalisations

The PSPD software presented the user with a completely blank canvas (i.e. a white window form). Like a pen to paper, when the style was dragged cross the blank canvas a line would be left in the trail of the stylus. When the mouse was pressed down the software would record the starting location of the line to be drawn. As the stylus moved the points for that line were stored into a vector array and the line was drawn on the canvas. Finally, when the stylus was lifted off the canvas, the vector array of points making up the line was added to an array of lines. The line vector array was then reset ready for a new line to be drawn. Hence, each canvas was made up of a vector array of lines, where each element was a vector array of points for that line.

In addition to the creation of vector based graphics, annotations and text could be associated with externalisations using coloured identifier markers. These annotations and text were stored in an annotations panel that could be shown and hidden by selecting the appropriate option from the pie menu or performing the appropriate gesture for the marked menu (menu selection discussed below).

Once the annotation option had been selected from the pie menu or marked menu a text field would appear allowing an annotations to be written. The annotation could be written using the onscreen keyboard that was available on the tabletop, tablet PC and PDA. Once the annotation had been entered the user could press the 'OK' button. This would cause an annotation object to be saved in an annotations array. The object would contain information such as, the associated sketch identifier, the location of the annotation marker, the colour of the annotation marker and the text string of the annotation. Then the marker would be drawn to the canvas.

When the annotations panel was opened, the annotations would be presented to the user with an associated marker from the array of annotations.

Hence, the PSPD software was able to support the creation of both free-hand vector graphics and marked annotations. We shall next discuss the manipulation of the free-hand vector graphic externalisations.

E.1.2 The manipulation of externalisations

In this section we shall discuss how externalisations were manipulated.

E.1.2.1 Pie menus and marked menus

The functionality to manipulate the externalisations was accessed through pie menus and marked menus. Pie menus are radial menus, where each segment of the menu represents a selection. Marked menus are gesture-based, where a gesture in a given direction indicates a selection. We shall describe the implementation of these menus in turn.

A pie menu was selected by holding the style still on the canvas for 0.6 seconds. When the style was pressed down on the canvas a timer would start. The MouseMove() method determined whether the style moved beyond a given threshold (3 pixels from the stylus down location). If the style was moved more than three pixels within the 0.6 seconds the software would assume the user was trying to draw and would therefore reset the timer and enter draw mode. If the style had not moved three pixels and the timer event was fired after 0.6 seconds, the pie menu would appear. Pie menus were presented as images drawn on the canvas.

If the stylus was pressed down on a segment in the pie menu, the segment that the stylus was pressed down on would be determined. Using the current pie menu identifier (i.e. the identifier of the pie menu being shown) and the segment identifier, the associated functionality would be executed

The marked menus worked in a very similar way to the pie menus and most of the code was re-used. A marked menu was selected by holding the stylus down for 0.3 seconds. Once again, when the stylus was pressed down the timer would start - the same timer used for the pie menu. If the stylus was not move beyond its threshold to reset the timer, after 0.3 seconds the cursor would change to indicate a gesture could be performed - gesture mode was entered. If the stylus was moved, points would be recorded. A dotted line was drawn to indicate the direction of the gesture. This line disappeared when the stylus was lifted off the canvas.

When the stylus was lifted up off the canvas the points were translated into a direction or directions dependent on the angle created by two points [Kostakos & O'Neill, 2003].

Each point i was compared to its neighbour j and assigned a compass direction (N = 1, NE = 2, E = 3, SE 4 , S = 5, SW = 6, W = 7, NW = 8).

Once the angle and appropriate directions had been calculated, a gesture signature would exist. If a sequence of compass directions exceeded a threshold (e.g. ten sequential compass directions) a gestured direction was assumed.

The directions of the gestures mapped to the segments of the pie menu. Therefore, the associated functionality would be executed dependent on the direction of the gesture, as described above.

From the pie menu and the marked menu the user(s) could execute the available functionality made available by the PSPD software. Before we discuss the functionality available, we shall describe a control used to manipulate the pen and externalisations - the gesture pad.

E.1.2.2 The gesture pad

The gesture pad was used as a control to manipulate some of the pen and externalisation functionalities. With the gesture pad users could perform either clockwise or anti-clockwise gesture.

As the user performs a clockwise or anti-clockwise gesture, the gesture pad algorithm determined the bearing of the stylus movement. Comparing this bearing with the centre of the gesture pad allows the direction and degree of movement to be determined. This input was then translated to manipulate either the pen or externalisation.

E.1.2.3 Pen manipulations

When the stylus was pressed down and dragged across the canvas a line would be drawn. The style of the line could be changed by manipulating the pen. Using the PSPD software the user(s) were able to change the colour of the pen, the size of the pen and the hardness of the pen.

When the user selected the menu option to change the pen colour, the pie menu would be replaced by a circular colour palette. The user could then select the colour of the pen they wanted.

Once the colour had been selected the border of the colour palette would change to reflect the selected colour and the pen object would be set to the appropriate colour.

When the user selected the menu option to change the pen size, the pie menu would be replaced by the gesture pad. The user could then perform a clockwise gesture to increase the pen size or an anti-clockwise gesture to decrease the pen size.

As the user performed a clockwise or anti-clockwise gesture the border of the gesture pad would increase or decrease respectively in real time and the pen width value would be set dependent on the gesture performed on the gesture pad.

When the user selected the menu option to change the pen hardness, the pie menu would be replaced by the gesture pad. The user could then perform a clockwise gesture to increase the pen hardness or an anti-clockwise gesture to decrease the pen hardness.

As the user performed a clockwise or anti-clockwise gesture the hardness of the filled colour in the gesture pad would increase or decrease respectively in real time.

E.1.2.4 Externalisation manipulations

Externalisations created by the user could be manipulated. Using the PSPD software the user(s) were able to rotate, scale, zoom and move externalisations.

When the user selected the menu option to rotate the canvas, the pie menu would be replaced by the gesture pad. The user could then perform a clockwise gesture to rotate the externalisation to the right or perform an anti-clockwise gesture to rotate the externalisation left. (The point of rotation was where the stylus was pressed down to make the pie menu appear.)

As the user performed a clockwise or anti-clockwise gesture the externalisation would rotate in real time.

When the user selected the menu option to scale/zoom the canvas, the pie menu would be replaced by the gesture pad. The user could then perform a clockwise gesture to scale up/zoom in on the externalisation or perform an anti-clockwise gesture to scale down/zoom out on the externalisation.

The pie menu and marked menu also provided the option for the externalisation to be move. However, this functionality was not implemented.

E.1.3 The dissemination of externalisations

The PSPD software allowed externalisations to be disseminated between devices. A user could either save or share an externalisation selecting the appropriate option from the pie menu and marked menu. We shall next describe the save and share functionality.

E.1.3.1 The save functionality

The save function saved the externalisation to the publicness of the device it was created on. The tabletop table provided a public interaction space, the tablet PC provided a social interaction space and the PDA provided a private interaction space. These devices had a public, social and private publicness level respectively. The publicness of the device was hardcoded into the software that ran on the device.

When an externalisation existed and the save option was selected from the pie menu or the marked menu, a header file would be appended to an array of lines that made up the externalisation, which was then sent to the PSPD server.

<id><user><publicness><width><height><image>

When saving an externalisation the identifier was 1. This would indicate to the PSPD server that the attached externalisation was to be saved. The PSPD server would use the user and publicness identifiers to determine where to save the externalisation.

The user identifier could be determined for the PDA and the tabletop. Each individual had a PDA and therefore could be associated with a hardcoded identifier (e.g. p1 = 1, p2 = 2, p3 = 3, p4 = 4). The tabletop was a public device and could be assigned a hardcoded identifier - 1234. However, due to the variety of sub-groups who could use a tablet PC, the PSPD software had to ask who was saving the externalisation. This was achieved by presenting the use with a small form, which asked the users to check the appropriate boxes identifying the creators of the externalisation. This information could then be inserted into the header file (e.g. 12 or 234).

As mentioned the publicness level was hardcoded into the software for the device it was created for.

The width and height variables were exacted from the width and height of the canvas respectively.

The vector array of lines, which contained vector arrays of points was stored in the canvas class. This was the array needed to recreate an image.

The header file and array of lines representing the externalisation were then converted into a memorystream. The memorystream could then be sent to the server.

The PSPD server constantly listened for incoming connections. When a stream was received the server would determine the identifier of the stream - this would indicate what functionality needed to be executed. In the case of an externalisation being saved - identifier 1 - the PSPD server would save the externalisation dependent on the user and publicness identifiers.

As mentioned above, the externalisation was saved according to the user and publicness identifiers. If the externalisation had a private publicness level the externalisation would be saved in a vector array for the appropriate user.

If the externalisation had a social publicness level the externalisation would be saved in a vector array for the users of the sub-group and a vector array for the sub-group.

If the externalisation had a public publicness level the externalisation would be saved in the public vector array.

E.1.3.2 The share functionality

The shared functionality was almost identical to the save function with the exception of a publicness level being specified, rather than the publicness of the device assigned. The PDA which provided a private publicness level could disseminate externalisations both socially and publicly. The tablet PC could disseminate externalisations publicly.

When sharing an externalisation from a PDA, a small form popped up asking the user if they wished to disseminate the externalisation socially or publicly. The user made their selection by pressing the appropriate button.

If the user decided to socially disseminate an externalisation another small form popped up asking the user who they wished to disseminate the externalisation with. The user made their selection by checking the appropriate checkboxes.

The user identifier would then be set in the header as the sub-group the user had specified and the publicness level was set. The header would then be appended to the externalisation and sent to the PSPD server as described above.

If the user decided to publicly disseminate an externalisation from a PDA the public publicness level would be set in the header. The header would then be appended to the externalisation and sent to the PSPD server as described above.

When sharing a sketch from the tablet PC, s small form popped up asking the user who was sharing the externalisation. The users made their selection by checking the appropriate checkboxes. This information specified the user identifier in the header. The public publicness level would also be set in the header. The header would be appended to the externalisation and sent to the PSPD server as described above.

In the next section we shall discuss how saved or shared externalisations were viewed and retrieved.

E.1.4 Viewing and retrieving externalisations

As well as disseminating externalisations, the PSPD software allowed externalisations to be retrieved. We shall next describe how externalisations were retrieved.

The first thing to note is what externalisations could be viewed on each of the technologies - this was specified by the PSPD framework. A user using a PDA could view their private externalisations, the externalisations created by sub-groups they belonged to and all public externalisations. A sub-group using a tablet PC could view all externalisations created by the sub-group and all public externalisations. The entire group using the tabletop could only view the public sketches. These access controls protected users privacy as specified by the publicness of the externalisations.

Externalisations could be viewed by selecting the 'View/retrieve' option from the pie menu. This would initiate a series of actions. The first step was for the PSPD software running on the device to ask the PSPD server how many externalisations it had. This required a message to be sent to the PSPD server. This message would include information on the user(s) requesting the externalisations and the level of publicness of the externalisations required.

The user identifier could be determined for the PDA and the tabletop. Each individual had a PDA and therefore could be associated with a hardcoded identifier (e.g. p1 = 1, p2 = 2, p3 = 3, p4 = 4). The tabletop was a public device and could be assigned a hardcoded identifier - 1234. However, due to the variety of sub-groups who could use a tablet PC, the PSPD software had to ask who was viewing/retrieving the externalisations. This was achieved by presenting the user with a small form, which asked the users to check the appropriate boxes identifying the intended viewers of the externalisation.

The publicness of the externalisations required differed between devices. The PDA needed to know how many private externalisations the PSPD server had for the user of the PDA; how many social externalisations the PSPD server had for the user of the PDA; and how many public externalisations the PSPD server had. The tablet PC needed to know how many social externalisations the PSPD server had for the users of the tabletPC; and how many public externalisations the PSPD server had. The tabletop needed to know how many public externalisations the PSPD server had. The PSPD software would send a message to the PSPD server asking how many externalisations it had for each publicness level it required. The PSPD software would then wait for a response from the server.

The PSPD server constantly listened for incoming connections. When a stream was received the server would determine the identifier of the stream - this would indicate what functionality needed to be executed. If the case of a message requesting the count for a given user(s) and level of publicness - identifier 2 - the PSPD server would send a reply message with the appropriate count.

Then the PSPD software received a count for the number of externalisations the PSPD server had for a given user and publicness the PSPD software compared this count with the number of externalisations it had stored for that given user and publicness. If the PSPD software had less externalisations than the PSPD server it would request all the externalisations is was missing.

When the PSPD server received a request for an externalisation it would send the externalisation to the PSPD software whom requested it.

Once the PSPD software received the externalisation from the PSPD server it saved the externalisation in the appropriate vector array for that externalisation.

The PSPD software and PSPD server repeated this process describe in this section until the PSPD software had retrieved all the externalisations it required.

Once all the required externalisations had been retrieved from the PSPD server the PSPD software drew the images as thumbnails and added the thumbnails to the externalisations panel. Thumbnails were categorised by level of publicness and ordered by the time when they were created. The externalisations panel was then made visible.

To retrieve an externalisation the user could select the desired thumbnail. The appropriate externalisations would then be set to the background of the canvas.

E.2 The Public Social Private Design initial evaluation questionnaire

In chapter 6, a questionnaire was administered to participants after the initial evaluation of PSPD. The questionnaire can be found below:

Post-study questionnaire (PDA)

Name:
Age:
Gender: male/female

1) What did you like about using the PDA?

2) What did you dislike about the using the PDA?

3) Would you agree, 'The PDA supported me externalising my ideas (e.g. sketching)?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

4) Would you agree, 'The PDA allowed me to clearly present my externalised ideas?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

5) Would you agree, 'The PDA was accurate in representing my externalised ideas?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

6) Would you agree, 'The PDA screen was a suitable size for creating externalisations?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

7) Would you agree, 'The PDA screen was a suitable size for viewing externalisations?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

8) Would you agree, 'The stylus was a suitable tool for creating externalisations?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

9) Would you agree, 'When externalising an idea I first drafted the idea and then added detail?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

10) Would you agree, 'I moved my face closer and further away from the PDA to get a different perspective?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

11) Would you agree, 'I rotated the PDA when externalising ideas?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

12) Would you agree, 'I moved the PDA when externalising ideas?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

13) Would you agree, 'I created multiple externalisations?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

14) Would you agree, 'The process of externalising ideas on the PDA supported the development of new ideas?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

15) Would you agree, 'The process of externalising ideas on the PDA supported the refinement of existing ideas?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

16) Would you agree, 'I was able to present ideas in an effective and useful manner using the PDA?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

17) Would you agree, 'I made use of existing ideas by improving them?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

18) Would you agree, 'I was able to organise my ideas using the PDA?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

19) Would you agree, 'I was able to evaluate my ideas effectively using the PDA?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

20) Would you agree, 'I did not have any problems using the PSPD software on the PDA after ten minutes training?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

21) Would you agree, 'I did not have any unexpected results when using the PDA?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

22) Would you agree, 'I was able to carry out the tasks requested using the PDA more effectively than if I had used paper?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

23) Would you agree, 'It was easy to transform externalisations (moving and rotating)?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

24) Would you agree, 'Transforming externalisations (moving and rotating) allowed me to improve upon my existing ideas?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

25) Would you agree, 'Did the PDA allow information to be socially constructed and shared by the group?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

26) Would you agree, 'Collaboratively externalising ideas enhanced the development of new ideas?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

27) Would you agree, 'Collaboratively externalising ideas enhanced the refinement of existing ideas?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

28) Which ideas did you combine most? (Please tick)

My own ideas [ ]
Other group members' [ ]
Both [ ]
I did not combine ideas [ ]

29) Which ideas did you improve most? (Please tick)

My own ideas [ ]
Other group members' [ ]
Both [ ]
I did not improve ideas [ ]

30) Would you agree: 'I was free to report an idea whenever I wished'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

31) Would you agree: 'I was able to contribute an idea without fear of criticism'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

32) Would you agree: 'Everyone in my group contributed equally'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

33) Would you agree, 'During the collaborative task we were forced to work as a group'? (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

34) What was your opinion of how the group communicated together? (i.e. do you feel you were able to express your ideas effectively?) (Please circle one)

Very positive	positive	Average	Negative	Very negative	No Opinion

Comments:

35) What was your opinion of the groups composition? (i.e. do you feel you were able to contribute lots of good ideas) (Please circle one)

Very positive	positive	Average	Negative	Very negative	No Opinion

Comments:

36) What was your opinion of the group climate? (i.e. did you find the process of design cooperative, fun, easygoing) (Please circle one)

Very positive	positive	Average	Negative	Very negative	No Opinion

Comments:

37) What additional functionalities would you like to see in our application? (Please tick one or more)

The ability to change the pencil the hardness [ ]
The ability to change the pencil the size [ ]
The ability to change the pencil shape [ ]
The ability to change the pencil colour [ ]
The ability to scale [ ]
The ability to zoom [ ]
The ability to copy/cut/paste [ ]
The ability to add/remove/show/hide layers [ ]
Other [ ]

If other, what would you like:

Comments:

38) If you have any other comments, could you please note them below:

E.3 The Public Social Private Design initial evaluation foci analysis

In chapter 6, our analysis of the video data from the initial evaluation of PSPD involved recording and tallying our observations. Table E.1 presents an excerpt from the PSPD initial evaluation foci analysis.

Table E.1: An excerpt from the Public Social Private Design initial evaluation foci analysis.

Observation	Tally
The pie menu was retrieved	10
The user created a new sketch	3
Uses the entire width or height of the paper	12

E.4 An example statistical calculation

In chapter 6 we ran Wilcoxon test to determine the effect of screen size on sketching. In the following section we provide an example calculation for one of the Wilcoxon tests, including full data tables and associated pre-tests.

E.4.1 A Wilcoxon test

This example is based on the time to sketch a simple image for the small and large canvas sizes. Table E.4.1 presents the full data table.

Before running any statistical test we had to determine whether the data was parametric or non-parametric. In order for the data to be considered parametric it had to satisfy three assumptions: the data was interval data; there was an equality of variance; and the data was normally distributed. If one or more of these assumptions were not met, the data was non-parametric. To determine whether the data was parametric or non-parametric, a number of pre-tests were conducted:

> The data was interval data.
>
> A Levene's test showed the data was not of equal variance ($F_{1,4} = 9.716$, $p = 0.02$).
>
> A Kolmogorov-Smirnov test showed the small canvas data to be normally distributed (Kolmogorov-Smirnov $Z = 0.81$, $p = 0.53$). However, the large canvas data was skewed (Kolmogorov-Smirnov $Z = 1.61$, $p = 0.01$).

These pre-tests indicated that our data had met the assumptions for parametric tests. Therefore, the appropriate test to be conducted to determine if there were significant differences between the two conditions was a Wilcoxon test.

Using the data presented in table E.4.1, a Wilcoxon test was run to determine if there was a significant difference between the small and large canvas sizes when sketching a simple image. The Wilcoxon test was run using SPSS. The output from the Wilcoxon test can be seen in table E.3.

As we had hypothesied the direction of difference, the one-tail p value indicates the appropriate confidence level ($p = 0.204$). Hence, a significant difference was not found as $p > 0.05$.

Table E.2: The time taken sketching simple sketches on the small and large canvas sizes.

	Small canvas	Large canvas
Simple sketches	17.79	15.59
	13.40	14.51
	18.88	16.17
	16.15	16.01
	15.98	31.43
	24.64	31.43
	22.46	28.09
	27.65	23.23
	32.24	28.07
	29.88	31.93
	18.43	28.36
	24.04	22.45
	27.80	18.24
	18.30	22.16
	22.41	25.30
	13.74	13.20
	12.46	11.02
	13.80	11.19
	13.29	10.32
	13.31	11.63
	12.33	17.59
	11.95	15.11
	12.27	15.11
	12.90	15.72
	13.72	13.54
	7.761	11.50
	6.018	9.90
	7.16	10.32
	6.36	15.54
	10.92	9.48
	17.11	53.99
	21.60	58.42
	30.68	61.01
	25.36	34.12
	26.50	69.10
	23.99	14.89
	14.86	13.98
	18.61	14.82
	14.17	23.43

	15.16	35.61
	12.61	18.61
	15.36	13.11
	17.18	11.53
	12.75	12.67
	18.85	13.07
	26.37	21.01
	24.76	20.95
	31.12	26.13
	19.74	24.53
	19.85	40.79
	21.09	22.55
	18.29	12.46
	28.30	12.73
	14.35	11.75
	17.31	20.28
	13.74	14.86
	14.59	12.83
	15.73	11.60
	16.60	15.62
	18.51	16.30
Total	1090.20	1259.11
Mean	18.17	20.99
SD	6.33	12.90

Table E.3: The Wilcoxon test output.

	Wilcoxon Output
Wilcoxon Z	-0.828
Asymp. Sig. (2-tailed)	0.408

E.5 The effect of screen size on sketching questionnaire

In chapter 6, a questionnaire was administered to participants after the effect of screen size on sketching experiment. The questionnaire can be found below:

Post-study questionnaire

Name:
Age:
Gender: male/female
Occupation:

The following questionnaire is designed to collect information on your opinions of the experiment and the effect of screen size on sketching to compliment the data collected in experiment you have just participated in. This information will be used to inform the design of our design environment: PSPD. Please can you take the time to fill in this questionnaire and return it to the experimenter before you leave. No data provided in this questionnaire will be passed on to any third party.

1) What did you like about the sketching?

a) For the small screen:

b) For the large screen:

2) What did you not like about the sketching?

a) For the small screen:

b) For the large screen:

3) Would you agree: ‘It was easy to create a sketch of the image shown’? (Please circle one for each part a, b)

a) For the small screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

b) For the large screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

4) Would you agree: 'It was easy to create the outline of the sketch'? (Please circle one for each part a, b)

a) For the small screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

b) For the large screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

5) Would you agree: 'It was easy to add detail to the sketch'? (Please circle one for each part a, b)

a) For the small screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

b) For the large screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

6) Would you agree: 'I could quickly create a sketch of the image shown'? (Please circle one for each part a, b)

a) For the small screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

b) For the large screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

7) Would you agree: 'I could quickly create an outline of the sketch'? (Please circle one for each part a, b)

a) For the small screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

b) For the large screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

8) Would you agree: 'I could quickly add detail to the sketch'? (Please circle one for each part a, b)

a) For the small screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

b) For the large screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

9) Would you agree: 'I could accurately create a sketch of the image shown'? (Please circle one for each part a, b)

a) For the small screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

b) For the large screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

10) Would you agree: ‘I could accurately create an outline of the sketch’? (Please circle one for each part a, b)

a) For the small screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

b) For the large screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

11) Would you agree: ‘I could accurately add detail to the sketch’? (Please circle one for each part a, b)

a) For the small screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

b) For the large screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

12) Would you agree: ‘My sketches were approximately of the same aesthetic quality as the images shown’? (Please circle one for each part a, b)

a) For the small screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

b) For the large screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

13) Would you agree: ‘I scaled sketches (e.g. made them bigger and smaller) to fit the screen size’? (Please circle one for each part a, b)

a) For the small screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

b) For the large screen:

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

14) Which of the following functionality would you like to be available for drawing and manipulating? (Please tick one or more)

Pencil Hardness [ ]
Pencil Size [ ]
Pencil Shape [ ]
Pencil Colour [ ]
Scaling [ ]
Zooming [ ]
Rotating [ ]
Moving [ ]
Selecting [ ]
Copy/Cut/Paste [ ]
Undo [ ]
Add Layers [ ]
Remove Layers [ ]
Show Layers [ ]
Hide Layers [ ]
Other [ ]

If other, what would you like:

Comments:

15) What additional hardware features would you add to better support sketching?

16) What additional software features would you add to better support sketching?

17) If you have any other comments, could you please note them below?

E.6 The Public Social Private Design step-by-step instructions

In chapter 6, a list of step-by-step instructions describing how to use PSPD was available on the wall and could be referred to by the participants at any time during the PSPD evaluation. The list of instructions can be found below:

PSPD - Step-by-step instructions

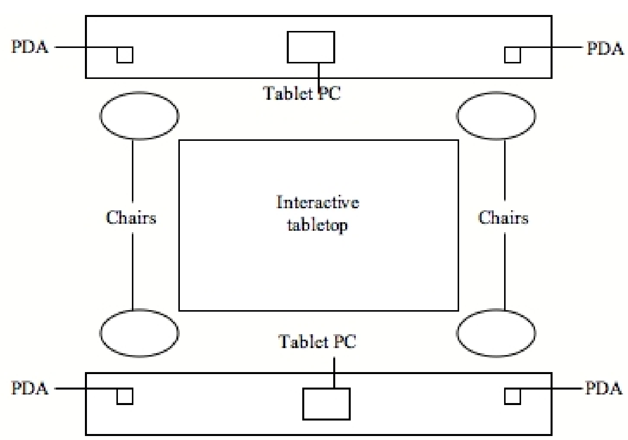
Public Social Private Design (PSPD) consists of four PDA, two tablet PC and one interactive tabletop. Each of these devices provides a private, social and public interaction space respectively, for the creation and dissemination of externalisations to be used in the design process.

PDA - this device is intended for individual activities

Tablet PC - this device is intended for sub-group activities

Interactive tabletop - this device is intended for group activities

The hardware set-up is as follows:



The PSPD hardware set-up.

Each piece of hardware runs a concept sketching application. The functionality of the software is as follows:

Sketching

Hold and drag the stylus across the canvas. This will leave a black line, such as a pencil on paper.

Please note: only one person can draw at a time using the PDA, Tablet PC or interactive tabletop.

Please also note: do not touch inside the interactive tabletop unless you intend to draw or use the application functionality. Please do not leave objects on the surface of the interactive tabletop either.

Viewing the pie menu

Hold the stylus still on the canvas. After 1/2 a second the pie menu with appear.

Interacting with the pie menu

There are two methods of interaction for making selections using the pie menu:

1) Click down on the desired pie menu section and lift the stylus up

2) Drag the stylus over the desired pie menu section and lift the stylus up

Closing the pie menu

There are two methods of interaction for closing the pie menu:

1) Click outside the area of the pie menu

2) Click the 'Back' option from the main pie menu

Navigating the pie menu

You can navigate forward through the pie menu by selecting the desired option. You can navigate backwards through the pie menu by selecting the Back option from the pie menu.

Clearing the canvas

When viewing the pie menu, select the 'Sketch' option. Then select the 'New/Clear' option to clear the canvas. A message box will appear to inform you the canvas has been cleared. Press 'OK' or the 'X' button to close the message box.

Disseminating a sketch

Disseminating a sketch differs depending on the device being used. Sketches may be disseminated through 'Save' or 'Share' options. To save or share a sketch, when viewing the pie menu, select the 'Sketch' option. Then select either the 'Save' or 'Share' option as desired. Once a sketch has been saved or shared, a message box will inform you. Press 'OK' or the 'X' button to close the message box.

Save:

This allows the sketch to the disseminated to the publicness of the device it was created on:

PDA - A private level of publicness. Only the user of the PDA may see the sketch disseminated.

Tablet PC - A social level of publicness. Only the users of the sub-group using a PDA or the sub-group itself using a tablet PC may see the sketch disseminated. The users of the tablet PC must specify who they are by selecting the appropriate checkboxes.

Interactive tabletop - A public level of publicness. All members of the group may see the sketch disseminated.

Share:

This allows the sketches to be disseminated to a publicness level above that of the device it was created on:

PDA - A sketch can be socially or publicly disseminated - the user selects the appropriate button. If the user chooses to socially disseminate the sketch the user must specify the sub-group they wish to disseminate it to - the user of the PDA will already be selected. Only the users of the sub-group using a PDA or the sub-group itself using a tablet PC may see the sketch disseminated. A sketch can also be publicly disseminated - All members of the group may see the sketch disseminated.

Tablet PC - A sketch can be publicly disseminated - All members of the group may see the sketch disseminated.

Interactive tabletop - A sketch can be publicly disseminated - All members of the group may see the sketch disseminated.

Please note - A device can not disseminate a sketch lower than its own publicness level.

E.7 The Public Social Private Design evaluation questionnaire

In chapter 6, a questionnaire was administered to participants after the PSPD evaluation. The questionnaire can be found below:

Post-evaluation questionnaire

Name:
Age:
Gender: male/female

The following questionnaire is designed to collect information on your opinions of the Public Social Private Design (PSPD) environment to compliment the video data and log files collected in evaluation you have just participated in. This information will be used to assess the effectiveness of PSPD as a design environment/CST and help improve its design and generalise to other environments/support tools. Please can you take the time to fill in this questionnaire and return it to the evaluator. No data provided in this questionnaire will be passed onto any third party.

1) What did you like about the PSPD environment?

2) What did you dislike about the PSPD environment?

3) Would you agree, 'The Public Social Private architecture (i.e. allowing the user to view and disseminate sketches at various levels of publincess) was effective and useful?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

4) Would you agree, 'The PSPD environment supported means for an understanding of the design problem to be developed?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

5) Would you agree, 'The PSPD environment supported the development of new ideas?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

6) Would you agree, 'The PSPD environment supported the refinement of existing ideas?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

7) Would you agree, 'The PSPD environment supported the combination of existing ideas?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

8) Would you agree, 'The PSPD environment allowed me to externalise ideas in an effective and useful manner?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

9) How did you represent your ideas using the PSPD environment? (Please tick as required)

Sketches [ ]
Sketches with annotations [ ]
Textual [ ]
Other [ ]

If other, what types of interaction would you like:

Comments:

10) Would you agree, 'The PSPD environment presented ideas in an effective and useful manner?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

11) Would you agree, 'The PSPD environment allowed me to evaluate ideas effectively?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

12) Would you agree, 'The PSPD environment supported group work?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

13) Would you agree, 'The PSPD environment supported sub-group work?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

14) Would you agree, 'The PSPD environment supported individual work?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

15) Would you agree, 'I was always able to contribute an idea whenever I had one without obstruction?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

16) Would you agree, 'I was always able to contribute an idea without fear of criticism?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

17) Would you agree, 'Everyone within the group contributed equally?' (Please circle one)

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	No Opinion

Comments:

18) What additional hardware features would you add to the PSPD environment to better support design?

19) What additional software features would you add to the PSPD environment to better support design?

20) If you have any other comments, could you please note them below?

E.8 A heuristic evaluation of Public Social Private Design

In chapter 6 we focussed on our three high-level requirements for supporting creativity when evaluating the PSPD environment. Here we present an evaluation of PSPD based on our heuristics for CST, derived from the our requirements for CST.

Heuristic 1) Does the CST support the creation and dissemination of externalisations to support the phases of the creative process?

Summary:
Heuristics satisfied: 11
Heuristics partially satisfied: 2
Heuristics not satisfied: 0

Heuristic 1.1) Does the CST support the creation of sketches?

Satisfied? - Yes

Description: Users can use the stylus on each of the available devices to create sketches.

Heuristic 1.2) Does the CST support the creation of annotations?

Satisfied? - Yes

Description: Users can write free-hand annotations on the sketch. Annotations can also be stored in the annotations panel (i.e. marked annotations)

Heuristic 1.3) Does the CST support the creation of text?

Satisfied? - Yes

Description: Users can write free-hand text on the sketch. Text can also be stored in the annotations panel

Heuristic 1.4) Does the CST provide an accessible interaction space supporting users pointing interactions?

Satisfied? - Yes

Description: The PSPD technologies provides an accessible interaction space for pointing interactions.

Heuristic 1.5) Does the CST provide an accessible interaction space supporting users gesture interactions?

Satisfied? - Yes

Description: The PSPD technologies provides an accessible interaction space for gesture interactions.

Heuristic 1.6) Does the CST support the creation of new externalisations - divergent thinking?

Satisfied? - Partial

Description: PSPD allows new canvases to be created allowing new externalisations to be created. However, users have been shown to verbally discuss ideas and then externalise their chosen idea to develop further.

Heuristic 1.7) Does the CST support the refinement of existing externalisations - convergent thinking?

Satisfied? - Yes

Description: Externalisations can be modified.

Heuristic 1.8) Does the CST constrain the ways users externalise their ideas?

Satisfied? - Yes

Description: Users may externalise ideas however they wish. However, as with any tool, the users must work with the functionality they have available to them.

Heuristic 1.9) Does the CST provide users with an unobstructed solution space?

Satisfied? - Yes

Description: Each solution space/canvas is like a blank sheet of paper. Tools menus are hidden until requested.

Heuristic 1.10) Does the CST allow its users to change the orientation and position of an externalisation and/or the CST?

Satisfied? - Yes

Description: Users can freely move around the PSPD tabletop. Plus, the PDA and tablet PC are mobile devices.

Heuristic 1.11) Does the CST support the combination of previously generated ideas?

Satisfied? - Yes

Description: Users can combine sketches using the PSPD software.

Heuristic 1.12) Does the CST support the storage and protection of generated ideas?

Satisfied? - Yes

Description: An externalisation can not be destoryed using the PSPD software. Even when a sketch was modified the original sketch remains.

Heuristic 1.13) Does the CST support the comparison of generated ideas?

Satisfied? - Partially

Description: Externalisation could be compared between devices. However, externalisations could not be compared on a single device, less thumbnails were compared.

Heuristic 2) Does the CST need to support the various group compositions of a group?

Summary:
Heuristics satisfied: 4
Heuristics partially satisfied: 1
Heuristics not satisfied: 0

Heuristic 2.1) Does the CST provide personal interaction spaces to support individual creative activities.

Satisfied? - Yes

Description: The PSPD environment provides a private/personal interaction space - a PDA.

Heuristic 2.2) Does the CST provide social interaction spaces to support sub-group activities?

Satisfied? - Yes

Description: The PSPD environment provides a social interaction space - a tablet PC.

Heuristic 2.3) Does the CST provide large interaction spaces to support group creative activities?

Satisfied? - Yes

Description: The PSPD environment provides a public interaction space - a tabletop.

Heuristic 2.4) Does the CST support the transitions between individual, sub-group and group activities?

Satisfied? - Yes

Description: PSPD supported the dissemination of externalisations between individual, sub-group and group activities based on the PSPD framework.

Heuristic 2.5) Does the CST support creative activities beyond the collaboratory?

Satisfied? - Partially

Description: The PDA and Tablet PC can be moved beyond the collaboratory. However, at present their functionality is limited to the interaction space of the PSPD wireless network. Warr [2006] illustrates how PSPD can extend beyond the collaboratory.

Heuristic 3) Does the CST support the control of social influences?

Summary:
Heuristics satisfied: 3
Heuristics partially satisfied: 1
Heuristics not satisfied: 1

Heuristic 3.1) Does the CST provide synchronous forms of interaction reducing the effects of production blocking?

Satisfied? - Yes

Description: The PSPD devices can be used simultaneously.

Heuristic 3.2) Does the CST support multiple inputs?

Satisfied? - No

Description: The PSPD devices only support single inputs. However, the tablet PC and tabletop do have the potential to support multiple inputs.

Heuristic 3.3) Does the CST remove identification with one's ideas to reduce the effects of evaluation apprehension?

Satisfied? - Yes

Description: All ideas are anonymised.

Heuristic 3.4) Does the CST provide group members with privacy, thus reducing the effects of evaluation apprehension and free-riding?

Satisfied? - Yes

Description: The PSPD environment provides a private interaction space (i.e. PDA) for individual work and a social interaction space (i.e. Tablet PC) for sub-group work, thereby providing a degree of privacy.

Heuristic 3.5) Does the CST make individuals accountable for their own productivity?

Satisfied? - Partially

Description: The PSPD environment enables the delegation of tasks which makes individuals accountable for their own performance. However, no graphical representation is provided for comparison.

Overall analysis:
Heuristics satisfied: 19
Heuristics partially satisfied: 3
Heuristics not satisfied: 1

E.9 The Public Social Private Design video encodings

In chapter 6, the video data from the PSPD evaluation was encoded. Encoding was achieved through the use of Noldus Observer, Windows Media Player and Microsoft Excel. Table E.4 presents an excerpt from the encoded video data.

Table key:

Time: The time of the conversation sequence - seconds
Participant: Participant identifier
Interaction types: Specific interactions - V = verbal communication; S = sketching; A = annotation; T = writing text; P = pointing; G = gesturing *Technology:* The technology used - TT = tabletop; TPC = Tablet PC; P = PDA *Group composition:* The group composition - I = individual; SG(P?) = sub-group, including information on the collaborating parties; G = group
Social influences: The occurrence of social influences - PB = production blocking; EA = evaluation apprehension; FR = free-riding
Creative process phase: The phase(s) of the creative process engaged in - PF = problem framing; NI = new idea; RI = refined idea; CI = combined idea; IF = idea framing; IE = idea evaluation

Table E.4: An excerpt from the Public Social Private Design evaluation video encodings.

Time	Participant	Interaction type	Technology used	Composition	Social influence	Creative process phase	Comments/Notes
2417	P4	S	P	I		RI	P4 sketches on his PDA. The PDA is landscape
2427	P4	V + P	P	SG(P3)		IE	P4 shows sketch to P3
2440	P3	V		SG(P4)		IF	"Not sure what kind of shape we want?"

Appendix F

Companion to Chapter 7

Section F.1 presents a list of requirements for creativity support tools.

Section F.2 presents a list of heuristics for creativity support tools.

F.1 Requirements for creativity support tools

Through the thesis we elicited a number of requirements for CST. A complete list of these requirements is as follows:

High-level requirement 1: Support the creation and dissemination of externalisations to support the phases of the creative process.

Requirement 1.1: Creativity support tools should support the creation of sketches.

Requirement 1.2: Creativity support tools should support the annotation of sketches.

Requirement 1.3: Creativity support tools should support the creation of text.

Requirement 1.4: Creativity support tools should support users' pointing interactions with externalisations.

Requirement 1.5: Creativity support tools should support users' gesture interactions with externalisations.

Requirement 1.6: Creativity support tools should support the generation of new ideas: divergent thinking.

Requirement 1.7: Creativity support tools should support the refinement of ideas: convergent thinking.

Requirement 1.8: Creativity support tools should not constrain the way users externalise their ideas.

Requirement 1.9: Creativity support tools should provide users with an unobstructed solution space.

Requirement 1.10: Creativity support tools should allow users to change the orientation and position of an externalisation and/or the creativity support tool.

Requirement 1.11: Creativity support tools should support the combination of previously generated ideas.

Requirement 1.12: Creativity support tools should support the storage and protection of externalisations created throughout the creative process.

Requirement 1.13: Creativity support tools should support the comparison of generated ideas.

High-level requirement 2: Support the various compositions of a group using appropriately sized interaction spaces.

Requirement 2.1: Creativity support tools should support individual activities using small interaction spaces.

Requirement 2.2: Creativity support tools should support sub-group activities using interaction spaces that create a sense of social inclusion.

Requirement 2.3: Creativity support tools should support group activities using large interaction spaces.

Requirement 2.4: Creativity support tools should support the transitions between individual, sub-group and group activities.

Requirement 2.5: Creativity support tools should support creative activities beyond the meeting room.

High-level requirement 3: Support the control of social influences..

Requirement 3.1: Creativity support tools should support synchronous forms of interaction, thereby reducing the effects of production blocking.

Requirement 3.2: Creativity support tools should support multiple inputs, thereby reducing the effects of production blocking.

Requirement 3.3: Creativity support tools should support the removal of a user's identity from their ideas, thereby reducing the effects of evaluation apprehension.

Requirement 3.4: Creativity support tools should support individual/private interactions, thereby reducing the effects of evaluation apprehension and free-riding.

Requirement 3.5: Creativity support tools should make individuals accountable for their own productivity, thereby reducing the effects of free-riding.

F.2 Heuristics for creativity support tools

Our requirements for CST also provided a framework for evaluating CST. A list of heuristics for CST is as follows:

Heuristic 1) Does the creativity support tool support the creation and dissemination of externalisations to support the phases of the creative process?

Summary:
Heuristics satisfied:
Heuristics partially satisfied:
Heuristics not satisfied:

Heuristic 1.1) Does the creativity support tool support the creation of sketches?

Satisfied? - Yes/No

Description:

Heuristic 1.2) Does the creativity support tool support the creation of annotations?

Satisfied? - Yes/No

Description:

Heuristic 1.3) Does the creativity support tool support the creation of text?

Satisfied? - Yes/No

Description:

Heuristic 1.4) Does the creativity support tool provide an accessible interaction space supporting users pointing interactions?

Satisfied? - Yes/No

Description:

Heuristic 1.5) Does the creativity support tool provide an accessible interaction space supporting users gesture interactions?

Satisfied? - Yes/No

Description:

Heuristic 1.6) Does the creativity support tool support the creation of new externalisations - divergent thinking?

Satisfied? - Yes/No

Description:

Heuristic 1.7) Does the creativity support tool support the refinement of existing externalisations - convergent thinking?

Satisfied? - Yes/No

Description:

Heuristic 1.8) Does the creativity support tool constrain the ways users externalise their ideas?

Satisfied? - Yes/No

Description:

Heuristic 1.9) Does the creativity support tool provide users with an unobstructed solution space?

Satisfied? - Yes/No

Description:

Heuristic 1.10) Does the creativity support tool allow its users to change the orientation and position of an externalisation and/or the creativity support tool?

Satisfied? - Yes/No

Description:

Heuristic 1.11) Does the creativity support tool support the combination of previously generated ideas?

Satisfied? - Yes/No

Description:

Heuristic 1.12) Does the creativity support tool support the storage and protection of externalisations created throughout the creative process?

Satisfied? - Yes/No

Description:

Heuristic 1.13) Does the creativity support tool support the comparison of generated ideas?

Satisfied? - Yes/No

Description:

Heuristic 2) Does the creativity support tool need to support the various group compositions of a group?

Summary:
Heuristics satisfied:
Heuristics partially satisfied:
Heuristics not satisfied:

Heuristic 2.1) Does the creativity support tool provide personal interaction spaces to support individual creative activities?

Satisfied? - Yes/No

Description:

Heuristic 2.2) Does the creativity support tool provide social interaction spaces to support sub-group activities?

Satisfied? - Yes/No

Description:

Heuristic 2.3) Does the creativity support tool provide large interaction spaces to support group creative activities?

Satisfied? - Yes/No

Description:

Heuristic 2.4) Does the creativity support tool support the transitions between individual, sub-group and group activities?

Satisfied? - Yes/No

Description:

Heuristic 2.5) Does the creativity support tool support creative activities beyond the collaboratory?

Satisfied? - Yes/No

Description:

Heuristic 3) Does the creativity support tool support the control of social influences?

Summary:
Heuristics satisfied:
Heuristics partially satisfied:
Heuristics not satisfied:

Heuristic 3.1) Does the creativity support tool provide synchronous forms of interaction reducing the effects of production blocking?

Satisfied? - Yes/No

Description:

Heuristic 3.2) Does the creativity support tool support multiple inputs?

Satisfied? - Yes/No

Description:

Heuristic 3.3) Does the creativity support tool remove identification with one's ideas to reduce the effects of evaluation apprehension?

Satisfied? - Yes/No

Description:

Heuristic 3.4) Does the creativity support tool provide group members with privacy, thus reducing the effects of evaluation apprehension and free-riding?

Satisfied? - Yes/No

Description:

Heuristic 3.5) Does the creativity support tool make individuals accountable for their own productivity?

Satisfied? - Yes/No

Description:

Overall analysis:
Heuristics satisfied:
Heuristics partially satisfied:
Heuristics not satisfied:

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