FACULTY OF SOCIAL SCIENCE AND HUMANITIES
DEPARTMENT OF DESIGN AND TECHNOLOGY

AN EMPIRICAL INVESTIGATION OF THE RELATIONSHIP OF CAD USE IN DESIGNING AND CREATIVITY THROUGH A CREATIVE BEHAVIOURS FRAMEWORK

By

AEDE HATIB MUSTA'AMAL

A Doctoral Thesis

Submitted in partial fulfilment of the requirements for

The award of

Doctor of Philosophy
Of Loughborough University

CERTIFICATE OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this thesis, that the original work is my own except as specified in acknowledgements or in footnotes, and that neither the thesis nor the original work contained therein has been submitted to this or any other institution for a degree.

.... (Signed)

.... (Date)

Contents

Figures and tables in text

Figures in text

Tables in text

Abstract

This thesis reports a study of the relationship of CAD use in designing and creativity through a Creative Behaviours Framework.

This thesis provides a description of the establishment of a framework for gathering empirical evidence to support the analysis of links between CAD and creativity. The Creative Behaviours Framework consists of seven categories including novelty, appropriateness, motivation, fluency, flexibility, sensitivity, and insightfulness. The framework was developed from published literature largely relating to the area of cognitive psychology.

The research reports findings concerning the use of this framework in analysing the use of CAD at Loughborough University and involved four postgraduates, two finalist undergraduates, and the researcher's own design project. Multiple data gathering methods including interviews, observations, protocol analysis, and design diaries have been used in this study to provide data reliability and validity.

The results demonstrate the occurrence of creative behaviours in relation to the use of CAD when designing. Most of the categories had a significant number of occurrences observed and identified in the case studies using the data gathering methods (in particular protocol analysis and design diaries). However, novelty was only reported from the design diaries in Case studies 1 and 2. Some findings that linked the emergence of

creative characteristics of product outcomes with CAD usage were also established from data analysis of the design diaries. Hence, a key research output is the development of a framework which enabled researchers to observe and identify creative behaviours whilst CAD was used in designing.

This framework has shown its reliability by also capturing creative behaviours in other than CAD activities such as 2D sketching and 3D sketch modelling. The findings from Case studies 1 and 2 indicated that creative behaviours were consistently identified during the observations of these design modelling activities. It shows that the Creative Behaviours Framework is not exclusively useful to observe creative behaviours during CAD use, but can also be applied in identifying these behaviours in other designing activities. An online questionnaire explored whether this framework could also be useful in wider application such as in supporting teachers in developing effective classroom and studio practice to encourage the emergence of creative behaviours by their students.

The research study (using case studies and paper questionnaires) was undertaken with students of the Design and Technology Department, Loughborough University and the findings could be biased to this particular population. Hence, the online questionnaire was carried out with Malaysian CAD users to provide broader feedback. Although there was a small number of responses received from Malaysia, the data still provided a useful foundation to make the comparison between the UK and Malaysian CAD users' perceptions about the relationship between creativity, in particular creative behaviours and the use of CAD in designing.

Keywords: CAD, creativity, creative behaviours, interviews, protocol analysis, design diaries, questionnaire.

Acknowledgements

First of all, I would like to express my gratitude to all those who have gave me support and strength to the completion of this thesis.

I am deeply indebted to both my supervisors: Professor Eddie Norman for his guidance, advice, encouragement and patience in supervising this research, and Tony Hodgson for his suggestions, comments and support throughout my study period. Their willingness to accept me as their research student and friend in Loughborough University is invaluable.

My appreciation goes to my sponsor Universiti Teknologi (UTM) Malaysia for giving me the opportunity to have full scholarships to further my study abroad.

To my parents Hj Musta'amal and Zaharah, my father and mother in-law, Hj Rosmin and Hjh Alminah, my brothers and sister who constantly pray my success, special thanks to all of you.

Last but never least, to my wife, Norzanah Rosmin, for her love, patience, understanding and unwavering support, and my wonderful children, Aqil, Nabil, Arif, Hajidah and Warid. I am grateful to have all of you as my family.

To all who have helped me, I forever grateful and perpetually indebted to you. Thank you.

List of Publications

Musta'amal, A H, Norman, E W L, and Hodgson, A R (2007). CADCAM and its Relationship to Creativity in Designing. In Norman, E.W and Spendlove, D (Eds). *The Design and Technology Association: Education & International Research Conference 2007,* Telford, 4 – 6 July 2007. Wellesbourne, UK: The Design and Technology Association.

Musta'amal, A H., Hodgson, A R, Norman, E N (2008). CAD and Creativity: Reality or Myth? *New Perspective in Design Education, Engineering and Product Design Education Conference,* Glasgow: The Design Society.

Musta'amal, A H, Norman, E W L, and Hodgson, A R (2008). CAD as a 'Recording' or 'Designing Tool: Evidence from User Behaviours. In Norman, E.W and Spendlove, D (Eds.). *DATA Education & International Research Conference 2008,* Loughborough, 2 – 4 July 2008. Wellesbourne, UK: The Design and Technology Association.

Musta'amal, A H, Norman, E W L, and Hodgson, A R (2009). Gathering Empirical Evidence Concerning Links Between Computer Aided Design (CAD) and Creativity. *Design and Technology Education: an International Journal.* 14 (2).

Musta'amal, A H, Norman, E W L, and Hodgson, A R (2009). Observing Creative Behaviours. In Norman, E.W and Spendlove, D. (Eds.). *The Design and Technology Association: Education & International Research Conference 2009,* Loughborough, 30 June – 2 July. Wellesbourne, UK: The Design and Technology Association.

Musta'amal, A H, Hodgson, A R, Norman, E N (2009). Creative Behaviours Observed When 2D and 3D Sketch Modelling and When Using CAD Modelling. *Engineering and Product Design Education Conference,* Brighton, 10-11 September. Glasgow: The Design Society.

Used Abbreviations

2D	- Two dimensional
3D	- Three dimensional
CAD	- Computer Aided Design
CAM	- Computer Aided Manufacturing
CG	- Computer Graphic
VR	- Virtual Reality

1 Chapter One: Introduction

1.1 Chapter Overview:

This chapter briefly describes the background of this research. It describes its origins and their contribution to the research aim and objectives. It states the research questions and provides an overview of activities involved throughout this research programme.

1.2 Research Background

The introduction of Computer Aided Design (CAD) has brought a new era in how designers deal with their design tasks. CAD has gone through a progressive technology evolution for a wide range of users from those undertaking less complex product design to more sophisticated and complex design tasks (Zeid, 2005). This tool could provide 'changes in the way products are developed' (Robertson and Allen, 1993: 275). However, they further suggested that CAD's benefit can only be comprehended by making full use of the tool's capacity, and being willing to adapt to the way it operates.

CAD technology has shown how it is able to facilitate various users' needs in designing activities. Some of the significant uses and features of CAD, including sketching tools in two-dimensions (2D) and three-dimensions (3D) (Zeid, 2005), allow the generation of manufacturing information from CAD models (McCartney, *et al*, 2000), enable generation of 'rendered images, engineering (working) drawings and manufacturing (prototyping)', and provide advanced simulation tools such as Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD)' (Hodgson, 2006: 12).

With such great functions and facilities, CAD has been widely accepted as an 'important and widely used technology' in industry (Robertson and Allen, 1993: 274). In addition, it has been introduced in design education in countries worldwide such as United Kingdom (Hodgson and Allsop, 2003), Malaysia (Sharif and San, 2001), Australia (Chester, 2007), and Austria (Asperl, 2005). CAD has not only been available for higher education, but also offered at lower levels of the educational systems. For example, *The CAD in Schools Programme* was introduced in the UK in 1999 as part of the subject of Design and Technology (Hodgson, 2006; Hodgson and Allsop, 2003; Barlex and Miles-Pearson, 2008) and CAD was part of the Invention subject in Malaysia (Sharif and San, 2001). Both these initiatives aimed to start exposure to CAD from secondary school level.

The introduction of CAD in this type of design-based subject was 'to promote the practical application of abstract ideas and knowledge using up-to-date and appropriate technologies' (Sharif and San, 2001: 3). The wide use of CAD in design and education has driven the initiatives from researchers to explore its implications for designing. In a pilot study conducted by Kimbell *et al* (2002), they suggested that students displayed their enthusiasm for using CAD in designing as it helped them to present designing professionally, visualize the ideas/objects, and work accurately.

Research reported by Hodgson and Allsop (2003) found that skill was an essential factor in enabling CAD to be used effectively and with confidence for design development and modelling tasks. Later studies by Hodgson and Fraser (2005) showed that CAD was successfully supporting 'post processes' in design development. It is a useful presentation tool, and the virtual reality features in CAD provide designers with an efficient environment to communicate their design thinking with adequate aesthetic quality and design details (Fraser and Hodgson, 2006).

As research agendas relating to the introduction of CAD into schools have been developing, there has also been growing interest in creativity as a key aspect of designing. In this context, Spendlove and Hopper (2004: 2) suggested that CAD 'should therefore be seen as a set of tools, which can be adopted as and when they are appropriate within the broad creative process'. Although there have been indications that the research agendas concerning CAD and creativity are linked (Robertson and Radcliffe, 2008), there has been a lack of systematic efforts to articulate and clarify what the nature of the links might be (Lawson, 1999). Creativity has also been overlooked from design research agendas although it plays a great role in designing (Demirkan and Hasirci (2009).

1.2.1 Author's Motivation

The author graduated from Universiti Teknologi Malaysia with a Diploma in Mechanical Engineering, and B.Sc (Hons) in Manufacturing Technology. The exposure to various design tools during these undergraduate courses provided different perspectives on how each tool facilitated designers' tasks and influenced their potential, and, in particular, creativity.

Having the opportunity to become part of the academic staff in the same university has increased the author's motivation to explore the potential links between CAD and creativity, especially when most users predominantly perceived CAD as a presentational tool rather than considering it as a creative design tool.

The author believes that with such an academic background, it is appropriate for him to be involved with this area of research.

1.3 Research Aims, and Research Questions

There has always been a tension between designing and its associated technologies, and much debate about whether the knowledge of such technologies supports or inhibits the designers' capability (Charlesworth, 2007). The changes in designing behaviours arising from the use of CAD need further research (Kimbell *et al*, 2002;

Hanna and Barber, 2001). Hence, the aim of this research is mainly to investigate the relationship between CAD and creativity in designing by observing creative behaviours.

1.3.1 Research Objectives

To achieve the research aim, these objectives were listed:

a) To explore, understand, and develop a framework for gathering empirical evidence to support the analysis of links between CAD and creativity.
b) To analyse, and develop methods of analysis for creativity occurrences to be identified during the use of CAD in designing
c) To analyse, and determine whether the use of CAD in designing has significant links with creativity.
d) To evaluate the framework developed with modelling activities which are recognised as creative approaches to designing such as 2D sketching and 3D sketch modelling
e) To explore the potential of the framework for use in wider contexts, such as teaching and learning.

1.3.2 Research Questions

a) Can a theoretical framework be developed to support empirical investigations of creativity during the use of CAD in designing?

b) Can methods be developed for creativity to be observed, identified, and described during the use of CAD in designing?

c) Are there any significant links between creativity and the use of CAD in designing?

d) Does the theoretical framework developed apply to modelling activities widely recognised as creative?

e) Does the theoretical framework have potential applications beyond the analysis of creativity and CAD use?

1.4 Literature Review

The literature review that was undertaken enabled the researcher to pose questions relating to the research, and look into finding answers to them. From the literature, the researcher attempted to develop an understanding of the context of creativity for this research. Initially, the key questions that needed to be understood were, ‘what is creativity?’, and ‘how would it relate with the use of CAD in designing?’ Various resources such as books, journals, conference papers, periodicals, and online resources were reviewed. Some of the keywords that were used in searching relevant references are shown in Table 1-1.

Table 1-1: Keywords used in literature search

Keywords	
CAD	**Creativity**
Computer Aided Design Research in CAD CAD and Creativity CAD non creative tool CADCAM	Creative Creativity Creative behaviours Creative product Creative process Creative person Creative press
Other design tool	**Design**
Sketching 2D sketching 3D modelling 3D sketch modelling 3D physical modelling Conventional designing tool Creative tool	Design Design process Design and creativity Creative design
Research Methods	
Qualitative Quantitative Interviews Observation Protocol Analysis Verbal Protocol Analysis Diaries Questionnaire	

Online resources that were available were sought through MetaLib, Loughborough University Institutional Repository, Loughborough University Online Public Access Catalogue (OPAC), and Google Scholar. The lists of references from the publications found also provide potential references.

1.5 Research Strategy

As indicated in section 1.3, the aim of the study is to investigate the relationship between creativity and CAD in designing. In order to accomplish the aim, an appropriate framework is required to facilitate a data capturing processes that enables creativity aspects to be recognised. From the literature, it is perceived that creativity has been seen by many researchers as vague and multifaceted (see Section 2.5). Further complexity occurs because the design act is the manipulation of designer's knowledge, skills, and values in revealing useful design outcomes (see Figure 2-6). To articulate which of these elements were involved in the series of decisions made throughout the design processes is problematic.

The complexity in researching design has also been highlighted in the literature review (refer section 2.10). Hence, efficient data gathering and analysis methods are necessary to provide empirical evidence from observable phenomena. Through the literature review, creative behaviours (which are an aspect of creativity) have been considered for use in searching for its possible link with CAD. The difficulty in observing and analysing designers' mental activity means there is little alternative, but to focus on the behavioural aspects of CAD. Any evidence found of such relationships would strongly suggest links between CAD and creativity. This strategy is illustrated in Figure 1-1.

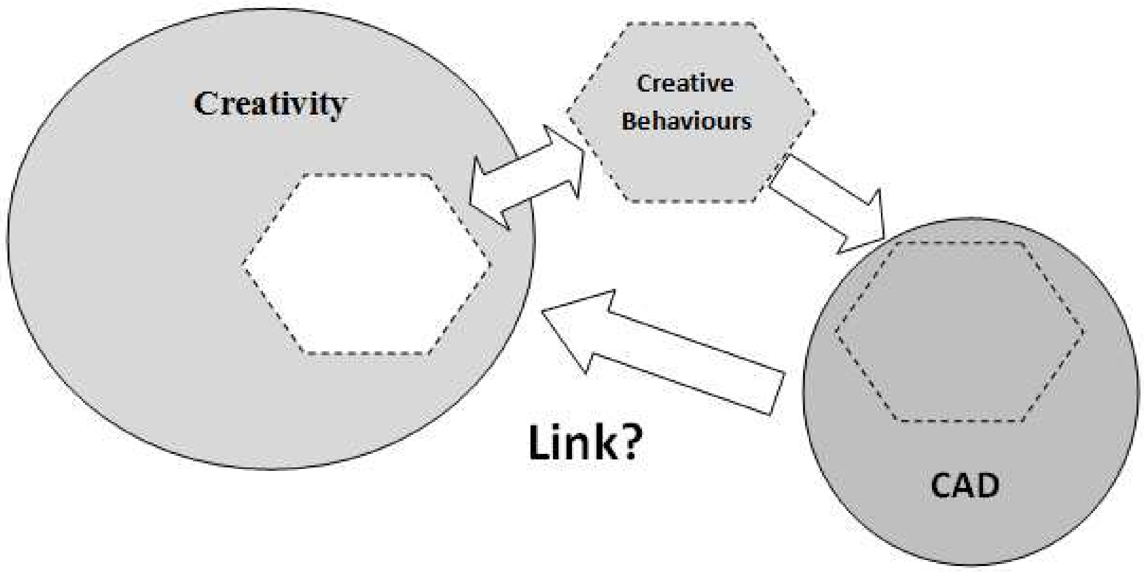


Figure 1-1: Research strategy

1.6 Empirical Data Collection

An overview of the research programme is shown in Figure 1-2

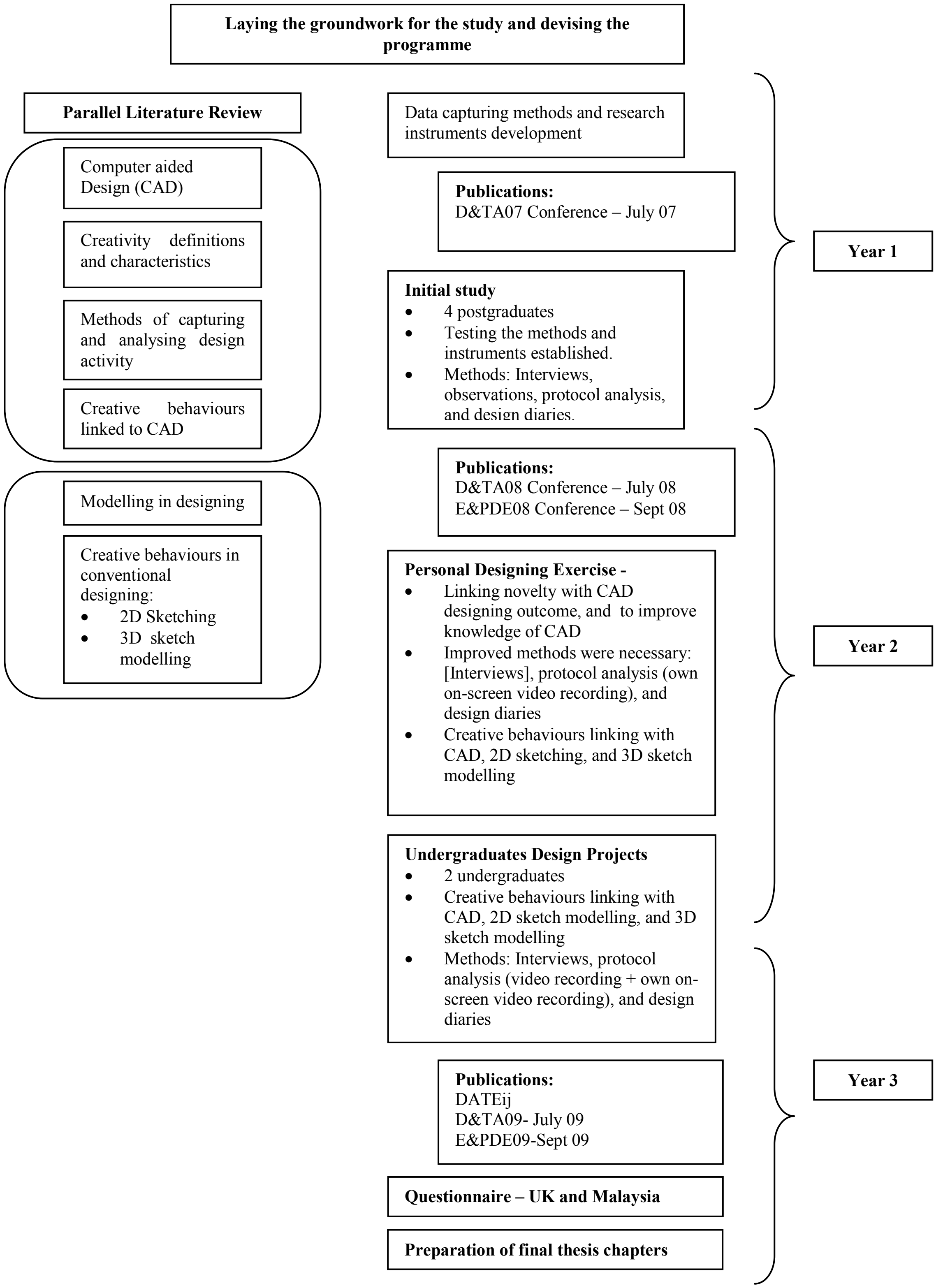


Figure 1-2 Research programme overview

In gathering appropriate data for the research, the following data sources were used:

1.6.1 Initial Study

- Four postgraduate students were involved as participants in preliminary interviews prior to their final master design projects.
- Three of them were involved in further data collections. Each of them participating in:
    - a protocol analysis of a CAD session. The session was audio and video recorded.
    - an observation of a CAD session. The session was audio and video recorded.
    - the completion of design diaries every time they engaged with CAD sessions.

1.6.2 Personal Designing Exercise

- The author undertook a personal designing exercise of a music therapy instrument for autistic children.

- Verbalisation and protocol analysis of a sketching, a 3D physical modelling, and a CAD session. The sessions were audio and video recorded including an on-screen CAD video recording.
- Design diaries were completed every time CAD was used.

1.6.3 Undergraduate Finalist Project

- Two undergraduate students were involved in the data collection process.
- Each of them participated in verbalization and protocol analysis of a sketching, a 3D physical modelling, and a CAD session. The sessions were audio andvideo recorded.
- All were involved in their own on-screen videoing of a CAD session using CAMTASIA software.
- Design diaries were completed every time they engaged with CAD sessions.

1.6.4 Questionnaires Survey

- Questionnaires (online and paper) were responded to by CAD users (professionals/instructors/students).
- The online questionnaire url:http://www.lboro.survey.co.uk/cadcreativity/ was intended for Malaysian CAD users

- The paper questionnaires were distributed within the Design and Technology Department at Loughborough University (e.g. lecturers, researchers, designers, teachers) and students (e.g. Ph.D researchers, Masters students, undergraduates)

1.7 The Organisation of the Thesis

This thesis consists of ten chapters and the skeletal outline of the relationship between these chapters is shown in Figure 1-3. Chapter One introduces the research background and highlights the research questions. Chapter Two reviews the literature relating to creativity, CAD and its roles in designing. Its primary aim is to seek understanding on CAD usage implications for users' performances and to what extent this issue has been explored. Chapter Three describes the research strategy approach and intended methods used for data gatherings. Chapter Four, Five and Six were reporting findings from the three case studies. Chapter Seven presents findings from questionnaires which aimed to affirm findings from the case studies in larger samples. In Chapter Eight, all the findings are brought together to check similarities and differences between them. Chapter Nine discusses the results and whether they link with the literature and provides answers to the research questions. Finally, Chapter Ten concludes by drawing the conclusion, stating the contribution to knowledge and suggesting some directions for future work.

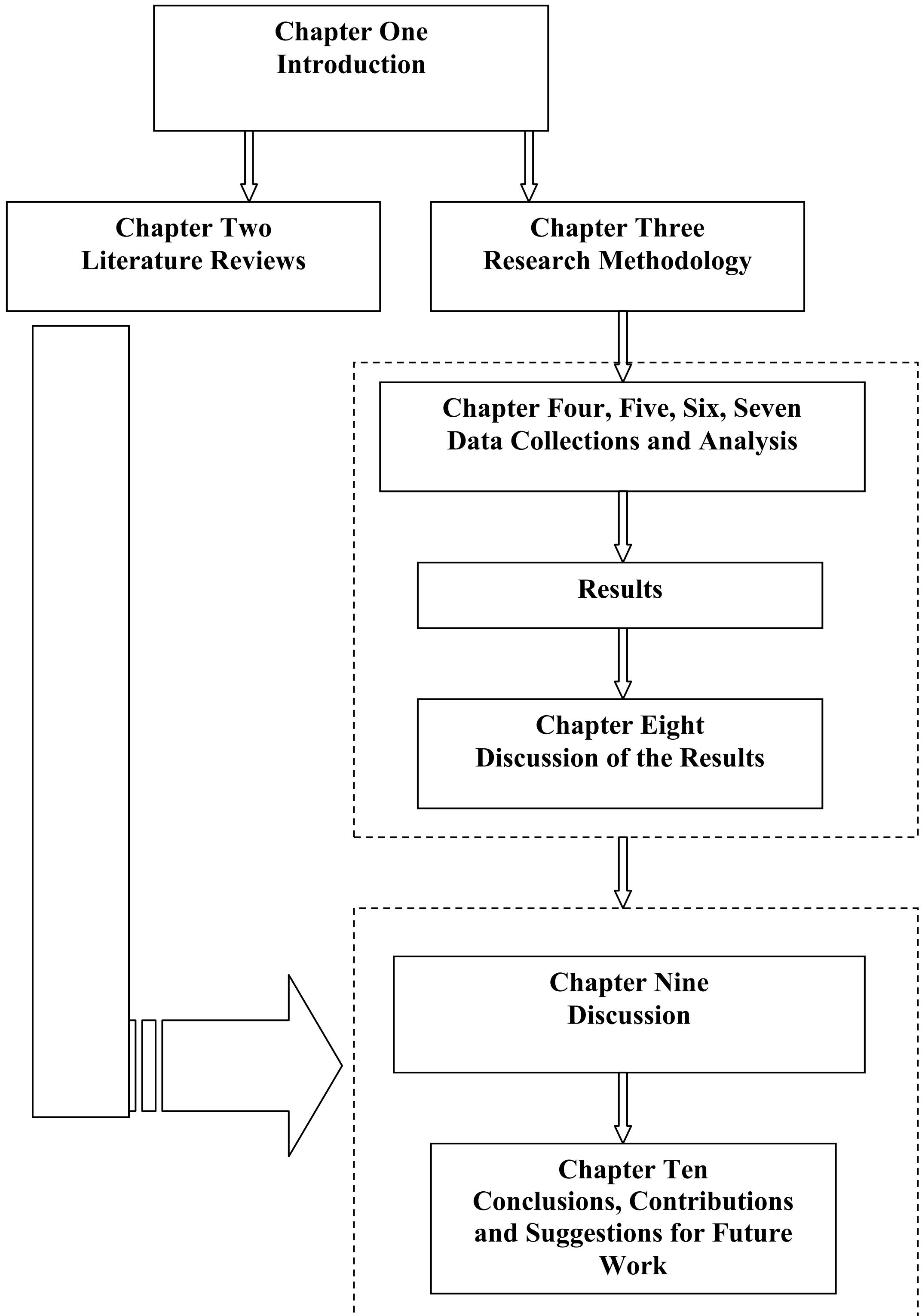


Figure 1-3: Chapters inter-relationship

2 Chapter Two: Literature Review

2.1 Chapter Overview

This chapter identifies the issues relating to CAD and its roles in designing. It explores previous research which attempted to discover the impact of CAD usage on users' performance including creativity. Creativity definitions, mostly from the perspectives of cognitive psychologists, have been explored, and have demonstrated the complexity in defining it. Literature on conventional design tools such as 2D sketching, and 3D physical modelling have also been explored to seek information about creative behaviours which have been reported by researchers whilst engaged with these methods. This could provide further understanding of creative behaviours as they are considered by many as creative tools.

2.2 Computer Aided Design (CAD) in Designing

The design process which is facilitated by computer is generally known as CAD. This technology gains more attention from designers as the computer technology has advanced and contributed 'to improving the efficiency and productivity of the design process' (Lee and Fulton, 2003: 1-4). Thistlewood expressed the following view about the roles of technologies and associated issues in designing which clearly establish the agenda for this thesis.

> ‘Designing with technologies, in order that they may be put to appropriate uses, is an important responsibility of the designer. There is also a concomitant responsibility to respond to new technological development, be informed – even led – by them. And there is a corresponding requirement to conceive of designs that test the present limits of technological feasibility, and thus demand their further advancement’ (Thistlewood, 1990: 19).

Since being developed, Computer-aided Design (CAD) has been going through a rapid technological evolution in terms of its capabilities and use in designing. Its widespread adoption by designers has led to a range of views on the significant consequences it could bring for individual design ability and efficiency, and the quality of the output. Researchers have made continuous efforts to explore the potential for CAD to make a greater contribution to the performance of designers (Bhavnani *et al*, 1993)

For some, CAD is a useful drafting tool which could help designers to effectively communicate and present their design intent accurately, but it is less likely to facilitate designing in particular in the initial stage (Cao and Protzen, 1999). This was supported by Charlesworth who suggested that ‘CAD should only be used after development, in order to refine and troubleshoot a final proposal. Its value as a development tool is extremely limited.’ (2007:43).

However, Hodgson and Fraser emphasized that ‘we must better understand the contribution that CAD makes to the design process and be careful that its implementation does genuinely bring about change in the awareness and capabilities of the participants [designers] that may be regarded as central to capability in design’ (2005: 97).

Due to the inconclusive evidence of CAD’s contributions in designing, additional research has been undertaken to explore this matter (Fraser and Hodgson, 2006). Data samples from prior study were further analysed through retrospective folio analysis and interviews with teachers and school children. They found that CAD played a significant role in the majority of departments sampled and allowed a significant proportion of pupils to not only be motivated to engage in design activity but to succeed in producing high quality outcomes in response to design problems’ (ibid: 6).

Nonetheless, they also noted that ‘the impact of Computer Aided ‘design’ and the role it can play in the activity of ‘designing’ is an area of potential not very well established or often recognised.’ (ibid: 9).

Their research had implied the occurrence of designing within CAD, but with restricted evidence, due to the limited design development recording strategy employed by participants. In a later study, Fraser and Hodgson (2007) have continuously emphasized the potential of CAD's capacity as a designing tool, but there is still limited evidence of its application in this way.

Prior to this, Stappers and Hennessy suggested that although CAD has been widely used by designers, still, 'these tools have little help for conceptualising' (1999: 177). They implied that the 'reason is that current CAD programs focus on producing end-product: a form or a rendered view of a form' (ibid: 177). Consequently, CAD has a lack of capabilities and 'cannot match design sketching', 'inhibits fluid design thinking', and 'inhibits fluid design modelling' (Tovey, 1989).

Despite the emergence of numerous CAD products with advanced features, still 'very little exists in the way of support for the earlier stages of the design process.' (Sedivy and Johnson, 1999: 43). Accordingly, Verstijnen *et al* (1998: 543) note that 'these programs [CAD], therefore, failed to meet the requirement of being helpful as tools for idea-generation sketching in the early creative phases of the design process'.

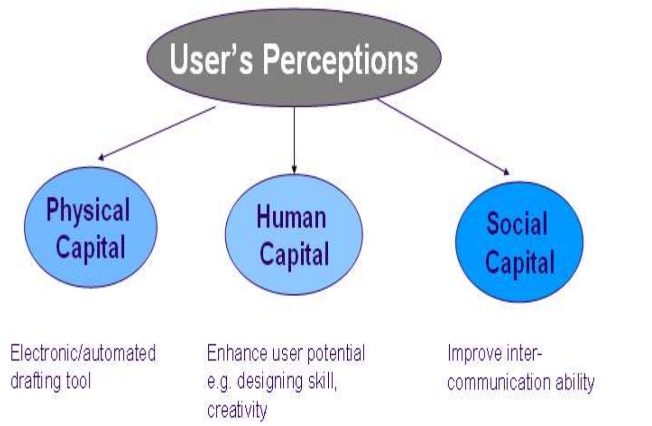
People and technology can be seen as a pair, which complement each other in most activities that take place. Accordingly, Cooley (1977: 239) notes that ideally 'in the man-machine interaction, man is the dialectical opposite of the machine in that he is slow, inconsistent, unreliable and highly creative. The machine is fast, consistent, reliable and totally non-creative.'

It seems unavoidable for humans to be involved with technology in their work especially when it related to creative aspects. It has been noted that 'technology has always been part of the creative process, whether in Leonardo's paint and canvas or Pasteur's microscopes and beakers. Supportive technologies can become the potter's wheel and mandolin of creativity -- opening new media of expression and enabling compelling performances' (Schneiderman, 1999: 15). He also added that creative beings 'have always used advanced technology to raise their [creative] potential' (ibid: 15).

This is something to take note of for this research, especially in the context of whether designers could creatively use CAD in facilitating design activity. Searching previous research in relation to the implications of CAD usage to users' abilities and performances would provide insight to what extent this issue had been explored.

2.3 Reported Links between CAD and Designers' Performances

An early research study by Robertson and Allen (1991) was conducted to investigate the link between the use of CAD for design, analysis, and communication and engineering performances. Two gas turbine manufacturers which used the same CAD system were involved in this study and seventy-five design engineers participated in the surveys. The study was based on the hypothesis that user perceptions would influence the way CAD was used.



(illustrated by Aede Musta'amal based on Coleman users' perceptions typology in CAD cited in Robertson and Allen, 1991, 1993)

Figure 2-1: CAD user's perceptions

Three categories of CAD users' perceptions were used as the research framework as shown in Figure 2-1. The surveys involved a baseline questionnaire and random occasional daily questionnaires to participants, which focused on documenting CAD usage and communication activities. Interviews with the engineers' manager were undertaken at the end of their project in order to evaluate their performances. The results indicated that CAD could facilitate designers in analysing and communicating design work efficiently. Using CAD for initial designing tasks enabled its later use for design analysis activities and this was clearly supported by the data. It also distinguished that the three-dimensional features in CAD facilitated communication and implied that greater use of CAD communication features might lead to better engineering performance (Robertson, 1993).

There have been growing concerns that using complex CAD software might have detrimental effects on user performance (e.g. ability, creativity, output), and having 'adaptive interfaces' within the system was one possible approach to resolving this issue. Bhavnani *et al* (1993) studied these concerns in relation to three different levels of CAD users' experience (e.g. novice, regular, and expert). This research was necessary to contribute to the development of adaptive interfaces to increase CAD user performance. The research was aimed at establishing the key criteria that could facilitate the recognition of the CAD user's level of experience. Six participants were recruited among students from Carnegie Mellon University and the faculty of Architectural and Civil Engineering departments. They formed three pairs and categories of user:

- low CAD experience (less than a week's experience of using CAD)
- high CAD experience (undertaken at least two projects using 'non CANVAS' CAD software in the past six months)
- high Canvas[1] (frequent CANVAS users)

Participants were given a drawing and required to reproduce it accurately using CANVAS software. Protocol analysis was used as the data collection approach where participants' verbalisations were audio recorded, and completed CAD drawings were saved for analysis. The results indicated that those with high CAD experience showed the ability to transfer their 'knowledge of CAD concepts' and

[1] CANVAS is a technical illustrations and graphics software package.

‘procedural knowledge’ in different CAD systems to establish high quality outcomes’ (ibid: 327). However, they spent longer than their normal time in completing the task due to the unfamiliar software. The lack of CAD conceptual knowledge prevented the novices from producing an accurate drawing within a sensible time frame. The CANVAS experts produced high quality drawings in the shortest times as a result of their prior experience. These results established a significant link between the prior expertise of the users and their approach to using CAD, the time consumed, and the quality of output produced (ibid:332).

So it has been known for some time that both the perceptions that users have of CAD systems and their expertise can significantly influence their performance. More recent studies have begun to look beyond the designer’s performance with the CAD system itself towards its broader designing context (Charlesworth, 2007; Robertson *et al*, 2007).

A recently reported study by Charlesworth (2007) explored the way in which design students used virtual and physical modelling during design development. The study was based on 39 Year 2 product design students at the University of Huddersfield completing a one day project. The students spent the morning developing ideas on paper and the afternoon either modelling these physically or virtually. The study concluded that CAD ‘has little or no value as a stimulus for ideas’ (ibid: 35). It was claimed that CAD had less significance as a designing tool and suggested that it was only appropriate as a finishing tool to finalise design proposals.

Robertson *et al* (2007) conducted a more substantial research programme based on industry case studies and an online survey of 200 CAD practitioners from 32 different countries. The findings from the case studies indicated both positive and negative influences on the creative process. The positive effect was found to be related to enhanced visualisation and communication enabled by CAD, and the negative effects were described as premature fixation, circumscribed thinking and bounded ideation. The online survey confirmed that enhanced visualisation and communication, premature fixation and circumscribed thinking were quite widespread in engineering design practice, but that bounded ideation occurs relatively infrequently. It was also found that 'in the early conceptual stages, skills such as sketching, communication and teamwork should take precedence over CAD' (ibid: 754), which could be taken as support for Charlesworth's position. Robertson *et al* (2007) go on to discuss the significance of their findings for design education and the following quotation is from the conclusions of their paper.

> 'Enhanced visualisation and circumscribed thinking cause students to develop a false sense of reality of CAD models, which is divorced from the realities of design in industry. It also influences the students' abilities to creatively develop and effectively communicate their design ideas. These findings point to the need for engineering educators to introduce CAD as part of a more holistic approach, situated within realistic scenarios that foster creativity in the context in which engineered products and systems are made and used. Mastery of CAD is not a substitute for design education. Although CAD has an important role to play, it is

but one of many skills needed for a complete design education, and it is one that is in danger of dominating the design education process and the students' conceptions of design. One strategy to achieve a more holistic approach is the wider adoption of Problem Based Learning in the early stages of engineering education programs at the point where design and CAD are introduced; not merely in the capstone experience'. (2007: 759)

A Keynote Address by Hodgson at the 2005 Design and Technology Association International Research Conference began to explore some of these complexities and in particular the changing situation as a result of the improved skill in using CAD that current students can demonstrate. This improvement is no doubt partly related to improvements in the software and its availability, but Hodgson's concept of the 'malleable' CAD prototype (2006) is indicating how rapidly this area of design education is moving.

Meanwhile, Lawson (1999) has made arguments on whether CAD would affect individual creativity through experiential examples from a number of architects. He implied that CAD could support designers in exploring design ideas and give freedom to visualise their creative imagination. Although expressing concern about the quality of the design outcomes, he clearly agreed that CAD enabled designers to produce 'convincing and original designs'.

Further, he noted concern about the lack of research that critically investigates the consequences of using CAD in designing and called for more substantial and appropriate research to be undertaken. These concerns not only related to design practice, but also to design education.

2.4 Creativity

> ‘Creativity is among the most complex of human behaviours. It seems to be influenced by a wide array of developmental, social, and educational experiences, and it manifests itself in different ways in a variety of domains. The highest achievements in the arts are characterized by their creativity, as are those in sciences’ (Runco and Sakamoto, 1990: 62).

This statement has shown that creativity has been recognized to have great impacts on many aspects of human activities. It has been acknowledged as one of the hallmarks of a human’s utmost achievement.

However, Nicholl and McLellan (2007: 34) suggested that ‘one of the issues may be competing and confusing definitions and conceptualisations of creativity’. Hence, this research tried to understand ‘creativity’ definitions from a number of researchers including cognitive psychologists.

2.5 Understanding Creativity from its Definitions

Creativity is a complex topic and one that remains a ‘slippery concept’ (Spendlove, 2005: 9). Dakers considered it as something that is ‘ambiguous and problematic’ to understand (2004: 29). It has an ‘elusive definition’ (NACCCE, 1999) with a wide range of possibilities of meanings. Creativity rather than having one universal definition, embodies a variety definitions (Dewulf and Baillie, 1999: 5) that have been defined in many ways by researchers, based on their perspectives and interests. These, according to Taylor, have ‘made research in creativity especially difficult’ (1975: 12).

Creativity has always been perceived as having connections with terms such as ‘creative thinking’ or ‘ability’, ‘problem solving’, ‘imagination’ or ‘innovation’ (El Murad and West, 2004: 189). It is also regarded as ‘something associated with new product’ (Altiers, 1988: 155). Generally, many authors defined creativity as the ability to generate products (e.g. ideas, methods and forms) that are meaningful and uncommon to others (e.g. Sternberg and Lubart, 1999; Amabile, 1996; Gardner, 1989; Barron, 1969; Jackson and Messick, 1965).

Creative people have a quality such as they are ‘more clever problem solvers; they have fertile imaginations and lots of different ideas; they are more open to new experiences and may take higher risks than their less creative peers’ (Ripple, 1989: 189) which distinguished the difference between the ordinary and the creative ones.

Gilchrist reported Laswells who defined creativity as 'the disposition to make and to recognize valuable innovations.' (1972: 10). According to Smith (1995: 27) Bowers has defined creativity as 'a novel form or product that has been generated'. While De Bono (1994: 128) suggested that creativity is dealing with the transformation of existing ideas, views, and approaches to doing things to the new ones. Other such as Nicholl and McLellan (2007: 35) defined creativity from the perspective of the creative cognition approach in problem solving that 'the ability to think creatively, that is, to generate novel, purposeful ideas, is an important and necessary part of solving design [creative outcome]'.

El Murad and West suggested that creative ideas 'must be new, unique, and relevant to the product and to the target audience in order to be useful as solutions' (2004: 188). Accordingly, this parallels with Martindale's views who defined a creative idea as 'one that is both novel and useful' (1995: 250). However, he also suggested that novelty does not necessarily exist from something which is totally new, but could also emerge from the 'new combinations of old ideas' (ibid: 250).

In defining creativity, Barron and Harrington (1981) had suggested two approaches which are based on 'socially valuable', and 'intrinsically valuable' outcomes. The first category described creativity as 'socially recognized achievement in which there are novel products to which one can point as evidence such as inventions, theories, buildings, published writings, paintings and sculptures and films;…and so on'(ibid: 442). Whilst the second category defined creativity as an 'ability manifested by performance in critical trials, such as tests, contests, etc, in which one individual can be compared with another on a precisely defined scale' (ibid: 442).

Yet the exact and precise definition of creativity is still arguable. It is not this researcher's intention to argue particularly for any of the definitions proposed, but to take into consideration most of them to provide better, and richer understanding of this terminology.

Altiers criticized much of the literature that exists for 'making the creativity seems complex' (1988: 155) and as the consequence it has been perceived as 'mystical, elusive ether '(ibid: 155). However, he implied that an appropriate mind set is necessary in exploring this field as 'creativity can be impossible if you will it to be so. Creativity can be simple if you just let it to be so' (ibid: 155).

One way of understanding creativity is by building on four aspects which are the product, the person, the process (Amabile, 1983; Balchin, 2005) or press (the environment) (Balchin, 2005; Amabile, 1996). These are widely known as the '4Ps' (Richards, 1999; Bostrom and Nagasundram, 1998). This is supported by El Murad and West who suggested that '…knowledge of creativity may be gained by studying any of these four [4Ps'] interlinked elements.' (2004: 192)

To comprehend any particular element of these four, they elaborate further, 'the creativity of people can be evaluated by direct study of the creative person, or by assessing the quality/or quantity of the creative product.' (ibid: 192). On the other hand, for those who are interested in researching the aspect of creative process, El Murad and West suggested that 'the process may be inferred by observing the person and the product in combination, whilst press may be studied for its effect on the other three.' (ibid: 192). A summary of some creativity definitions were shown in Table 2-1.

Table 2-1: Example of Creativity Definitions

Author	Definition of creativity
Laswells (cited by Gilchrist, 1972)	'the disposition to make and to recognize valuable innovations
Bowers (cited by Smith, 1995)	'a novel form or product that has been generated'
De Bono (1994)	'creativity is dealing with the transformation of existing ideas, views, and approaches to doing things to the new ones
Nicholl and Mc Lellan (2007)	'the ability to think creatively, that is, to generate novel, purposeful ideas...'
El Murad and West (2004)	must be new, unique, and relevant to the product and to the target audience in order to be useful as solutions
Martindale (1995)	'one that is both novel and useful'
Candy and Edmonds (1999)	'a set of activities that give rise an outcome or product that is recognized to be innovative as judged by an external standard'

2.6 Identifying Creativity

The issue is how creativity can be identified when it occurs? Are there any particular set of rules besides the general definition of creativity for factors which can be regarded as creative? Candy and Edmonds suggested a rather generic view that creativity can be identified by 'a set of activities that give rise to an outcome or product that is recognized to be innovative by an external standard' (1999: 4). In other words, to capture creativity in a design outcome, one must be able to obtain the creative aspects distinguished and acceptable by others.

Amabile's 'Consensual' creativity definition provides a more comprehensive description, that 'a product or response is creative to the extent that appropriate observers independently agree it is creative. Appropriate observers are those familiar with the domain in which the product was created or the response articulated' (Amabile, 1996: 33).

According to Rogers in distinguishing creativity, 'there must be something observable, some product creation.' (1970: 138). He further elaborated that 'though my fantasies may be extremely novel, they cannot usefully be defined as creative unless they eventuate in some observable product – unless they are symbolized in words, or written in a poem, or translated into a work of art or fashioned into an invention' (Rogers, 1970: 138). These views are supported by Dakers who stated:

> 'It is in the eye of the beholder, however, that the notion of creativity is invested upon the actor's performance, the painter's painting or the vacuum cleaner's design. It is thus the signature of the creator……' (2004: 2).

These views emphasise that individuals manifest their creativity by producing visible and tangible outcomes as evidence of existence.

Creative outcomes are established from creative individuals' ability to explore and convert conceptual ideas into exceptional products. Nevertheless, different areas of interest would produce different forms of creative outcome which is either tangible or intangible (Goldschmidt and Tatsa, 2005: 593). These are the centre of attention that 'reflect some distinguishing signs of creativity' (Warr and O'Neill, 2005: 119).

A creative outcome from the perspective of Bostrom and Nagasundram (1998) is indicated by a degree of 'surprise' from its observer's point of view. The product makes the viewer feel the presence of amazement, wonder, and unexpectedness within it. This is supported by Macedo and Cardoso who then implied that 'surprise seems to play an important role both in the process of producing and in the process of evaluating a creative product [outcome]' (2001: 85).

More specific characteristics of creative outcomes had been suggested by MacCrimmon and Wagner through five key dimensions which are 'novelty, non-obviousness, workability, relevance, and thoroughness' (1994: 1516). Prior to this, Jackson and Messick (1965) had proposed four properties of creative outcomes that comprised of unusualness, appropriateness, transformation, and condensation. These properties were anticipated to be applicable for various disciplines or fields that possibly involved with creativity.

Nonetheless, reporting from the context of psychological perspective, he emphasized that, ’the focus of interest is, of course, a creative or novel act by an individual, whether or not the same novelty has been produced by any or many other individuals before’ (Mandler, 1995: 10).

In a rather extreme view, Rogers disputed views that rely on social acceptance before something can be regard as creative. He argued that:

> ‘to be regarded historically as representing creativity, the product must be acceptable to some group at some point of time. This fact is not helpful to our definition……. and because many creative products have undoubtedly never been socially noticed, have disappeared without ever having been evaluated. So this concept of group acceptance is also omitted from our definition.’ (1970: 140).

Rogers also avoided making any attempt at setting a level for ‘degree of creativity’ as he believed that there would be a wide spectrum of value employed in evaluating them (ibid: 140). In that sense he suggested anything which complies with the definition of creativity would be considered as a creative product.

2.7 Designing

Generally, many perceived designing as having something to do with activities such as ‘exploring’ (Warr and O’Neill, 2005: 120); ‘discovering’, ‘elaborating’, ‘continual appraisal and reappraisal’ (Archer and Roberts, 1992: 3); and ‘inclusive activity which begins by carefully observing and understanding people and sensitively shaping solutions’ (Southee, 2009: 184). Hence, in a concise manner, Roberts (1992: 32) defined designing as ‘the capacity to conceptualise and represent ideas, aspects of present realities and future possibilities.’

Goldschmidt exemplified her view about designing:

> ‘To design is to plan for the making of something new. Designing entails generating, transforming, and refining descriptions and specifications of different aspects of a still non-existent artefact and making the representations of it that enable communication and examination of the ideas involved, which ultimately enables the production or construction of the artefact.’ (1999: 525).

Hanna defined designing as ‘an act of continually making and then examining from a different point of view’ (2005: 7). The motive behind this is to ‘discover something new, rather than to return with yet another example of the already familiar’ (Cross, 1998: 28).

In the context of design educational activity, Archer and Roberts note that designing is ‘the manipulation of things and systems so as to achieve the most acceptable and practicable fit between a particular set of desires and needs, on the one hand, and a particular means for fulfilling them, on the other.’ (1992: 3).

Lawson considered design as a process which involved ‘a highly complex and sophisticated skill’ that could be acquired through learning and experiences (1997: 11). These are crucial as designers need to go through a lot of ‘exploratory process without necessarily fixed goals’ as part of their work practice (Hanna, 2005: 3). These are supported by Thistlewood (1990: 14) who suggested that designing is manifest by the ability ‘to perform activities beyond the unaided capabilities of human frame’. Further, he elaborated that the nature of work required ‘the coordination and efficient marshalling of all branches of knowledge’ (ibid: 14).

2.8 Modelling in Design

Humans like other species have a nature which is seeking to ensure their existence in this world. Their minds, thinking, and actions lead to continuous efforts to make themselves fit enough to adapt and survive in any changes that might occur. The difference between humans and other species is their ability to make use of every internal (e.g. mind, experience, knowledge, senses) and external (e.g. nature, climate) resources to their benefit.

Inspired by the evolutionary psychology study, Doyle (2004) has introduced the concept of ‘technicity’ and attempted to explore its link with the act of making or in a wider perspective, designing. He suggested that we have to look back not only over last the decades of human civilization, but as far back as pre-historic eras, in order to undertake retrospective analysis on how our ancestors made use of their capability, knowledge, and experience to make a difference to our present life. It might prove the hypothesis that it is the nature of humans to behave in innovative and creative ways. As he stated that 'no species, present or past, Homo or otherwise, other than ourselves is creative or innovative' (ibid: 70).

This ideology has introduced a modern perspective of understanding design behaviours based on three characteristics: language, deconstruction and construction, and drawing. These were derived from Doyle's 'technicity' definition that:

> '….the capacity of behaviourally modern humans to: deconstruct and reorder objects; and deploy an external memory system' (2004: 69)

Subsequently, Norman and Pedgley (2005) published a paper that provided such evidence from design diaries of the polymer guitar project. They redefined 'objects' as the element of nature which the designer had to deal with and exploit for the sake of human needs and interest. Drawing is identified as one vital medium for designers to archive and visualize the ideas into an understandable dimension. They interpreted Doyle's definition and suggested a better understanding of its concept, particularly in the context of design and technology education.

At the DATA International Research Conference 2008, Stables in her keynote speech gained the audience's attention by re-introducing the term she called ‘designerly’. A different term to that introduced by Doyle, but actually, shared the same vision on how the human nature of ‘doing’, ‘making’, or ‘designing’ could change the future. In describing the impact of ‘designerly’ behaviour on the way humans think and act, she had suggested three contributors to this behaviour:

- Ability to image in minds things we have experienced and also that we haven’t.
- Ability to manipulate those images both in our minds and through externalisation.
- Ability and determination to utilise imaging and modelling of ideas to create new future realities. (Stables, 2008)

She indirectly gave a similar message to Doyle which implied that people’s ability to visualize and manipulate their ideas in virtual and/or physical form creatively, would give impact as how the future is going to be. She clarified that:

‘In my experience, it takes little more than a split second for imaging and modelling solutions to kick in – at least as initial ideas – using magnets, Velcro, computer displays, mirrors are the ideas that typically emerge in the first few seconds. And once people try to explain their ideas, the need to be explicit causes them to clarify the image in their mind, which in turn causes them to develop it towards being a new idea [creative idea] to deal with the situation’ (Stables, 2008: 9)

Modelling is recognised as a key creative activity especially in designing (Tseng *et al, 2002;* Verstijnen *et al*, 1998; Suwa & Tversky, 1997; Tovey, 1989). In design, it plays a vital role in externalising cognitive thinking, and provides a medium for handling design ideas. The images of ideas in the designer's mind are translated into explicable ideas through modelling e.g. sketching, drawing, 3D-modelling etc. This is supported by Archer who described modelling activities as the way to represent the designer's 'external representations of ideas which were formulated and manipulated in the mind' (1992: 8).

Thus, it is inarguable that modelling is the language of designing (Archer, 1992; Smith, 2001). Such modelling provides rich information and explanation of the design not only to the designer but also to others. Tovey (1989: 24) suggested that '…..graphic ideation is important not only as part of the process of producing the design ideas, but also because it is an externalisation of the designing……'

Further, he elaborated that the interaction of seeing, imagining and drawing encourages creativity as it would provide designers with the opportunity to consider design alternatives efficiently.

According to Smith (2001: 6) modelling can be classified in two categories: two dimensional (2D), and physical three dimensional (3D) models. 2D modelling includes sketching and drawing, whilst the 3D modelling includes mock-ups, prototypes etc. However, with the advance of computer technology, design modelling could also take place virtually on computer screen monitor (e.g. CAD modelling (Hodgson, 2006))

Modelling (e.g. via drawing) has shown significant effects on the level of a designer's thinking. This is supported by Baynes (1992: 18) who acknowledged that 'the modelling methods available to designers do directly affect the thoughts they can think'. Further, he quoted Jones, an English design theorist, who stated that:

'The designer can (by use of a drawing) see and manipulate the design as a whole….predict the repercussions that changing the shape on one part will have upon design as a whole'. (ibid: 19)

Baskinger describes the three goals of drawing in designing as:

a) to externalize and convey the process of thinking – to transform intangible ideas to tangible information for others;
b) to reveal ideas or relationships, not results;
c) to engage discussion around the subject/problem as inclusive activities. (2008: 29)

Modelling via drawing can be seen as an interactive medium for design thinking and realisation. Baskinger notes that 'the common link to all of design drawing is in constructing a graphic representation in a coherent format, one that speaks to alternative ideas and the evolution of an idea' (ibid: 29). The exploration of ideas, elaboration of the potential design, and evaluation of its practicality and appropriateness could be established within a modelling application. This is a medium of interaction between designer and his/her cognitive thinking. It also allows others to understand and perceive what is actually being thought in the designer's mind in an explicit way.

Similarly, designing using CAD also involves modelling and visualisation activity in the virtual context. Hodgson notes that 'assuming that a design concept or idea can be suitably modelled in the CAD system, any of these outputs [e.g. rendered images, prototypes] will help students [designers] to better visualize and make what they design' (2006: 10). Hence, in studying the potential of CAD in encouraging creative behaviours while designing, it is important to explore how conventional designing approaches such as 2D and 3D modelling might promote these behaviours.

2.9 Designing and Creativity

Designing has been recognised as the translation of human creative thinking through planned action in achieving preferred needs or desires. Accordingly Dakers (2004: 1) stated that 'one common feature inherent within the concept of creativity is that something manifest is brought into being'.

While Gero and Kannengiesser clearly suggest the link between designing and creativity as following:

> 'We define the notion of novelty, and consequently creativity, relative to the process of designing: Creativity occurs whenever a new design property is introduced for the first time in the ongoing design process, thus changing the state space of possible designs' (2007: 57).

According to Archer and Roberts, a 'design activity is always a grappling with the unknown' (1992: 3). This is supported by Goel that 'the activity of design involves the mental formulation of future states of affairs. The products of design activity are external representations of such possible futures' (1992: 395). Obviously, these interpretations suggesting that design is involved with the act that to make existent something that did not exist previously, which according to Davies *et al* (2002) is referring to a creative act.

Lawson described design as 'one of the most creative of human pursuits' (1997: 148). He elaborated that the central designerly act is 'to create something which other people will experience and which is in some way or other original and new' (ibid: 148). Lawson also suggested that activities involved in design coincide with the creative process model as shown in Figure 2-2.

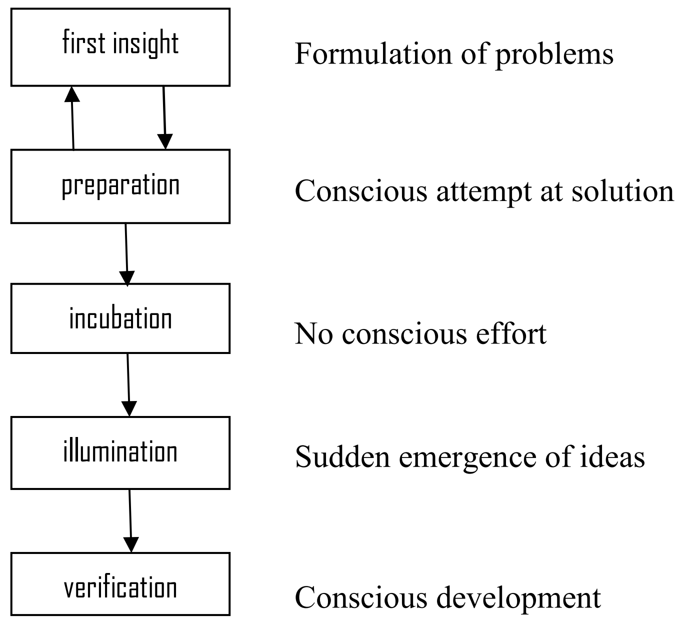
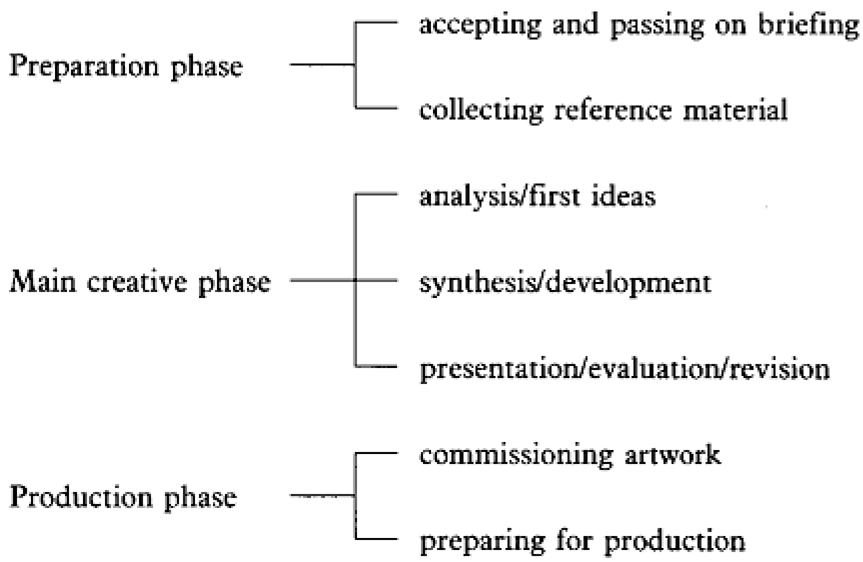


Figure 2-2: Five stage model of creative process

In studying the role of drawing in graphic design, Schenk has suggested a series of phases to illustrate the design activities involved as shown in the Figure 2-3. One of the phases was identified as 'main creative phase' because this is the stage where she implied most of the 'creative activity' emerged during the designing activities. Although such events are not absolute indicators of the emergence of creative outcome, however, awareness and observation of them can increase our understanding of creativity especially in design.



(Schenk, 1991: 180)

Figure 2-3: Graphic design phases

Consequently, designing and creativity are closely related research agendas and many researchers have tried to explore links from various perspectives. Some researchers study the state of designers' minds when engaged with creative thinking, and particularly through cognitive psychology approaches (e.g. Nagai and Taura, 2006; Goel and Pirolli, 1992). They have attempted to uncover possible links between designing and creativity through exploring designers' cognitive thinking when engaged with such activities.

The relationships between design and creativity were reflected through the roles of designers that were emphasized by Lawson who stated 'designers must [creatively] solve externally imposed problems, satisfy the needs of others [usefulness] and create beautiful objects [aesthethic].' (1997: 157). This was later reinforced by

Goldschmidt who suggested that ‘design has always been closely associated with creativity because new artefacts are often expected to be innovative and original – two hallmarks of creative products.’ (1999: 526).

2.10 Interim Conclusion: The Complexity in Researching Creativity in CAD

This interpretation of creativity as a spectrum of meanings is one of the reasons for the difficulties in researching this area, and a second is the requirement for any credible model of the act of designing to engage simultaneously with knowledge, skills and values. This has been well understood since at least the Assessment of Performance Unit Report (Hicks *et al*, 1982), which explored the nature of design and technology.

The constraints on the performance of an individual or group of designers need to be seen in relation to the knowledge, skills and values they possess or can access as shown in Figure 2-4 and Figure 2-5. The implications of this model concerning knowledge and values were discussed in the 2006 John Eggleston Memorial Lecture (Norman, 2006), and when reflecting on the skill of CAD as a tool supporting design decision-making, this must be considered alongside knowledge and values. This was supported by Suwa *et al* (1999) that believed the acquisition of skill is ‘often tacit and implicit’ which make it difficult to elucidate which and how they used these skills when designing.

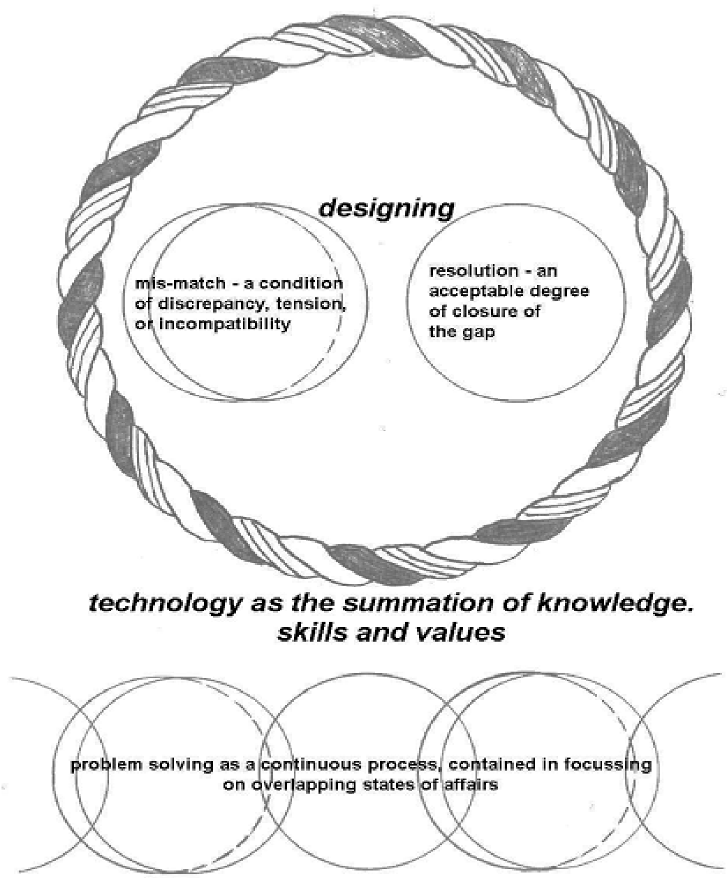


Figure 2-4: Technology as the summation of skills, knowledge and values (Norman, 2000: 129)

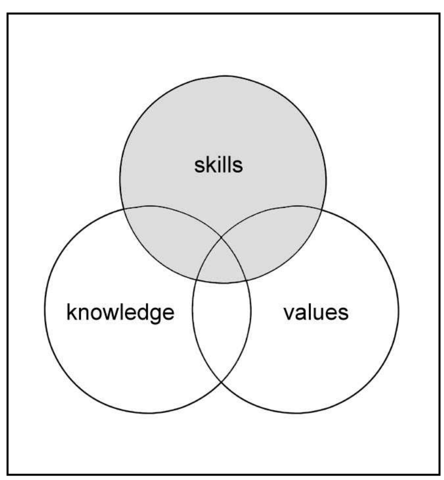


Figure 2-5: A cross-section of a boundary of designing represented by knowledge, skills and values

Accordingly, Norman notes the 'difficulty of capturing human expertise [skill]' (2000: 4) especially when related to design activity. The intricacy that surrounded every decision-making which is made throughout the design activities would provide an indication how complicated these processes are, and was highlighted in the following statement:

> 'Human decision-making is an expression of the art of making judgements based on incomplete information about existing factors and future consequences. This is the essence of design activity, hence then of the existence of products and their associated technology……In the same way that each game of chess is highly likely to be different, so with product design dependent on a multitude of sequential decisions, the designs will inevitably be different.' (Norman and Pedgley, 2005: 138)

The use of CAD is but one designing skill amongst many, and prior research has demonstrated that the skill levels in using CAD influences both its use and outcomes, alongside other strong influences such as user perceptions of CAD's potentials. According to Goel and Pirolli (1992: 396) the act of designing itself is a 'mental, representational, and a signature of human intelligence' which draws from a summation of various sources of knowledge and skills, which would include those related to CAD. The complexity in analysing the design activities to track back the link between the creativity of product design and the CAD usage that could be expected is shown in Figure 2-6. Each decision-making involved was likely bounded with the aspects of skills, knowledge, and values which then appear in the form of a decision from a few alternatives. To retrospectively analyse each decision-making involved is something that very difficult to do, and probably an unfeasible effort.

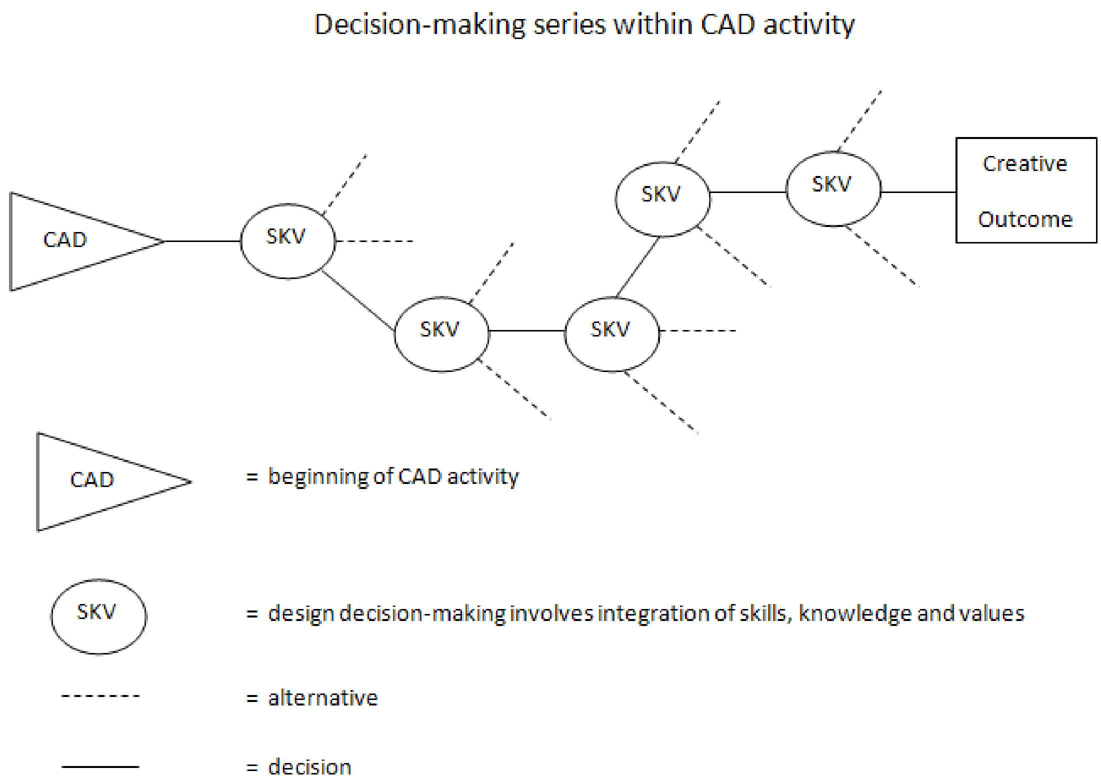


Figure 2-6: A series of decision making involved within CAD activity

These bring an initial conclusion of the complexity and difficulty in making interpretation of the data in an attempt to distinguish possible links between the use of CAD and creativity (e.g. creative outcomes) in designing. Hence, the research now attempted to find a more plausible aim to explore possible links between CAD usage and the emergence of creative behaviours in designers.

2.11 Creative Behaviours Literature

Alonso-Aguilar (1996: 959) reported from Eysenck that 'creativity is conceived as a latent trait underlying creative behaviour'. Behaviour can be defined as 'the way which someone or something behaves' (www.askoxford.com). This may also be perceived as the act or manner that is demonstrated by creative persons in forming creative outcome which Rogers (1970) named as creative acts. He described creative behaviour as 'the natural behaviour of an organism [e.g. people] which has tendency to arise when that organism is open to all its inner and outer experiencing, and when it's free to try out in flexible fashion all manner of relationships.' (ibid: 145). The consequences of these behaviours imprint in the creative outcomes and highlight the aspects of 'selectivity, or emphasis, an evidence of discipline, an attempt to bring out the essence' (ibid: 145). This is supported by Gilchrist (1972: 16) who stated that

> 'Creativity may refer to the process from which the end product emerges. In this sense it refers to behaviour which is directed towards creative achievement'.

Although creative behaviours are essential to the emergence of creativity; these do not necessarily lead to its appearance (Alonso-Aguilar, 1996). However these creative behaviours could possibly open the path to the potential surfacing of creativity.

Based on the published literature relating to cognitive psychology, a number of creative behaviours have been recognised (e.g. (Cropley 1967; Gilchrist 1972;

Amabile 1983; De Bono 1994; Balchin 2005)). These have been long-listed and grouped into seven categories as shown in Table 2-2.

Table 2-2: Summary table for creativity characteristics reported in literature relating to cognitive psychology

No	Characteristics	Author(s)
1	**Novelty**	
	Originality/novelty	Gilchrist, 1972; Finke *et al,* 1992*;* Lee, 2005; Davis, 1999; Amabile, 1996; Bull and Davis, 1982; El Murad and West, 2004; Thomson and Lordan, 1999; Sosa and Gero, 2005; Bostrom and Nagasundram, 1998; Aguilar-Alonso, 1996; Hocevar and Bachelor, 1987; Shalley *et al*, 2004)
	uncommon	Barron, 1969
2	**Appropriateness**	
	Appropriate for its purpose	Gilchrist, 1972; Ward *et al,* 1999; Warr and O'Neill, 2005; Brown, 1987
	Practical or sensible	Finke *et al*, 1992
	Operability	Balchin, 2005; Crutchfield, 1973
	Usefulness	Thomson and Lordan, 1999; Sosa and Gero, 2005; Bostrom and Nagasundram, 1998; Aguilar-Alonso, 1996; Shalley *et al;* 2004*)*
	Be adaptive to reality	Barron, 1969
3	**Motivation**	
	Motivation	Lee, 2005
	Willingness to take risks; have a go; run-a-risk; risk-taking	Cropley, 1967; Balchin, 2005; Cropley, 2001; Davis, 1999; Lee, 2005; Dacey and Lennon, 1998
	Self-confident	Davis, 1999
	Enthusiastic	Davis, 1999
	Independence	Amabile, 1983; Davis, 1999; Lee, 2005
	Willingness to be provocative	De Bono, 1994
	Preference/attracted for complexity	Amabile, 1983; Crutchfield, 1973; Davis, 1999
	Preference/seeks for challenges	De Bono, 1994; Epstein, 1999
	Complexity of thinking	Gilchrist, 1972
	Task commitment	Lee, 2005
	Perseverance/persistent	Dacey and Lennon; Turner and Dunn, 1970
4	**Fluency**	
	Spontaneity	Sinott (1970)
	Fluency	Lee, 2005; Hocevar and Bachelor, 1987
	Fluency of ideas	Gilchrist, 1972; Crutchfield, 1973; Guilford, 1973
	Receptive to new ideas	Davis, 1999
5	**Flexibility**	
	Flexibility	Lee, 2005; Dacey and Lennon, 1998; Hocevar and Bachelor, 1987
	Flexibility of ideas	Finke *et al*, 1992
	Flexibility of thinking	Gilchrist, 1972; Guilford, 1973
	Cognitive flexibility	Crutcfield, 1973
	Elaboration	Finke *et al*, 1992; Lee, 2005
	Redefinition	Crutchfield, 1973
	Possession of wide categories	Cropley, 1967
	Explore the creative possibilities of the ideas	Ward *et al,*1995
	Plays with ideas	Davis, 1999
6	**Sensitivity**	
	sensitivity	Amabile, 1983; Lee, 2005
	Sensitivity to problem	Gilchrist, 1972; Turner and Dunn, 1972
	curiosity	Lee, 2005; Bull and Davis, 1982; Turner and Dunn, 1970
	Sensitive to beauty	Davis, 1999
7	**Insightfulness**	
	Insightfulness	Finke *et al*, 1992
	Intuitive	Crutchfield, 1973; Davis, 1999
	Insight	Dorst and Cross, 2001

The seven categories identified were *novelty, appropriateness, motivation, fluency, flexibility, sensitivity,* and *insightfulness.* This is not claimed to be an exhaustive list of possible references, but sufficient to generate the majority of the creative behaviours that have been reported. No attempt has been made to select or rank these creative behaviours; they have simply been noted and classified. In order to clarify the nature of the 7 categories a brief discussion of each of them is presented as follows.

2.11.1 Novelty

Novelty (or originality, which is commonly seen as an interchangeable term) can be defined as creating something new and different from that which existed. As novelty is related to creative outcomes in the form of ideas or products, they will be expected to be 'original or, at the very least, uncommon' (Finke *et al*, 1992: 37). In supporting this, Lubart (1999: 339) stated that 'novel work' must have something to do with producing exceptional outcomes, which are 'unexpected or surprising', and completely unique.

Ward *et al* (1995), however, argues that novelty was not exclusively referring to something which is utterly different from existing artefacts or ideas. Creativity emerged from something that already existed being given new breath of ideas. They implied that creative outcomes 'are never completely novel', but 'they are always a marriage of old and new' (ibid: 10). They further emphasized that 'the ways in which creative ideas resemble old ideas are just as important as the ways in which they differ' (ibid: 10). This view was supported by Thomson and Lordan (1999: 18) who took a less prescriptive view by emphasizing that the amalgamation of existing ideas which form unusual outcomes can also be considered as novelty.

Most authors have considered novelty as one of the important elements in defining creativity (Amabile, 1988; Cropley, 2001). However, many share the view that novelty alone is not enough for an outstanding product to be accepted as creative unless accompanied by appropriateness to the task (Stokes, 1999; Warr and O'Neill, 2005; Weisberg, 1993). This obligation was also indicated by Sternberg and O'Hara's (1999: 255) who were of the opinion that:

'Creativity is often defined as the process of bringing into being something novel and useful'.

According to Mandler when discussing about novelty in creativity:

'A particular act may be novel for all of humanity, for a specific social-cultural unit, or for an individual. Along that continuum, anything new for all humanity is also novel for all levels below it, whereas a novel act for an individual may not be novel for each of the higher levels, a creation that is new only at a lower level may, or can be essentially uninteresting; "reinventing the wheel" has become the cliché to describe that disinterest' (Mandler, 1995: 10).

However, Cropley emphasised that ‘the novelty involves observable behaviours or other concrete products, is probably novel only for the producer (and perhaps adoring parents or enthusiastic teachers) and is based on concrete, physical properties of real objects.’ (2001: 89).

In similar view, Weisberg (1993: 4) suggested that appraisal of novelty for creative outcomes should not necessarily be only based on public views, but that the outcome should at least be novel in the eyes of the person who created it. This perception is most useful in assessing ‘everyday creativity’ (e.g. Ripple, 1989) such as the education context where children, students, and novices cannot be expected to produce something novel in its fullest sense on every occasion.

Hence, the National Advisory Committee on Creative and Cultural Education (NACCE) suggested three levels of ‘originality’ or novelty as a benchmark in assessing creativity in classroom activities. They were:

a) Individual

A person’s work may be original in relation to their own previous work and output.

b) Relative

It may be original in relation to their peer group.

c) Historic

The work may be original in terms of anyone’s previous output in a particular field: that is, it may be uniquely original.

(NACCE, 1999: 30)

2.11.2 Appropriateness

A novel outcome will not be accepted as creative if it is not accompanied by appropriateness in terms of use or purpose. Appropriateness can be defined as 'suitable; right and proper' (Hornby, 2000:72), and in the context of creativity research, it refers to a characteristic or behaviour which shifts the status of uncommon and surprising products from being only unique, to being regarded as creative (Gilchrist, 1972; Brown, 1987; Ward, 1999, Warr & O'Neill, 2005).

Some researchers use the term 'usefulness' (Aguilar-Alonso, 1996; Bostrom & Nagasundram, 1998; Thomson, 1999; Shalley, 2004; Sosa & Gero, 2005), Finke *et al* (1992) used 'practicality' or 'sensibility', whilst Balchin (2005:39) defined it as 'operability' which not only allowed creative products to be recognised, but also, enabled creative people to be identified.

Creative people are always involved with identifying problems and problem-solving activities. During problem identification and the exploration of potential solutions, the criteria for solutions are distinguished. These criteria are part of the strategy for assessing and measuring how effective solutions are in solving the problems identified. Creativity would be seen as justified if the outcome was shown to conform to the criteria distinguished (Warr and O'Neill 2005). Lubart (1999: 339) agreed, describing appropriateness as an act to 'satisfy the problem constraints, useful, or fulfils a need'. And for Gilchrist (1972: 14) satisfaction and conformity should either refer to an individual's (creative person's) contentment or to domain justification (e.g. society, association, and group). Prior to this, Jackson and Messick (1965: 313) had clearly defined appropriateness as:

'To be appropriate a product must fit its context. It must 'make sense' in light of the demands of the situation and the desires of the producer.'

2.11.3 Motivation

Creative people are motivated by challenging tasks, and excited by the opportunity to use their ability to solve problems in a novel way. They have a tendency to go further than their existing potentials. This is also known as 'self-actualization', a condition which indicates the need of individuals 'to sustain and enhance life in anticipation of their full potential' (Conti and Amabile, 1999: 251). Motivation in creativity can be classified into two categories (Collins and Amabile, 1999: 299):

a) Intrinsic Motivation

b) Extrinsic Motivation

Intrinsic motivation can be defined as 'the motivation to engage in an activity primarily for its own sake, because the individual perceives the activity as interesting, involving, satisfying, or personally challenging; it is marked by a focus on challenge and the enjoyment by the work itself' (Collins and Amabile, 1999: 299). Intrinsic motivation provides creative individuals with the ability to focus on the issues in their work, and consider them in great depth. Creative people will always be prepared to face any hitches in their search for a creative outcomes within, or maybe even outside their domain.

Extrinsic motivation has been defined by Crutchfield as follows:
'In extrinsic motivation the purpose is not simply the solutions of the problem or the achievement of the creative products per se; these are merely instrumental to further goals of the individual. He seeks to solve problems or to create because of the external rewards that this will bring him. (1973:70).

Extrinsic motivation is based on pursuing external factors such as reward, organisational requirements, competition, social prestige etc. However, some authors have suggested that intrinsic motivation is a contributing factor to creativity, while extrinsic motivation might possibly give the opposite effect (e.g. Amabile, 1983: 195).

Motivation leads to creative individuals having less fear of making mistakes especially when exploring new unexplored areas and willingness to take risks (Amabile, 1999; Cropley, 1967: 43; Balchin, 2005: 33; Thurston and Runco, 1999: 731).

This enables them to think and act ‘independently’ (Amabile, 1983: 201; Cropley, 2001: 11; Balchin, 2005: 33), although the consequences might challenge social norms (e.g. ideas, rules, cultures) and hence sometimes leads to disputes. This is supported by De Bono (1994: 128) who suggested that to be creative, individuals need to have attitudes which demonstrate their ‘willingness to be provocative and not easily swayed by social norms or beliefs’.

2.11.4 Fluency

Fluency can be defined as the ability to ‘perform an action smoothly, accurately, and with ease’ (Hornby, 2000: 697). In the context of creative processes, fluency has to do with the ability to facilitate the generation of a number or quantity of ideas (Crutchfield, 1973; Lee, 2005). A creative individual should have the ability to generate more than one idea that is suited to the tasks.

In the early research, it was hypothesised that fluency of thinking and ideational fluency would be useful in facilitating a creative individual in producing appropriate ideas in a restricted period of time (Gilchrist. 1972). To encourage the smooth and diverse flow of ideas, their spontaneous capturing and externalising should be facilitated (e.g. brainstorming).

Hence, the concept of fluency should not be limited to the amount of different useful ideas being produced, but the smoothness whereby a creative person elaborates from an idea should also be considered as an indicator of fluency.

Davis (1999) suggested that being open-minded is one 'attitude' that needs to be displayed by creative people and reported that satisfaction with only one idea without letting your mind explore other possibilities is a hindrance to creativity.

To generate creative ideas, it is necessary to look at the problems from different angles, and suggest solutions from various perspectives. Sinott (1970: 109) agreed as 'it is much more common for a new idea to arise almost spontaneously in the mind, often seemingly out of nothing and at a time when a person may be thinking of something quite different'.

2.11.5 Flexibility

The ability to view a problem as a whole and not in a limited perspective is known as flexibility. Thurston and Runco (1999: 729) explain the feature of flexibility in creativity as 'a capacity for change' which involves a way of interpreting, and using prevailing information, or approaching the comprehension of tasks, or changes in the plan for undertaking the task. They also elaborate that flexibility might influence an individual's way of thinking, so the task objectives could be interpreted differently.

Flexibility of thought will allow individuals to explore possible solutions to defined problems in numerous ways (Gilchrist, 1972: 5). This will then lead to the emergence of ideas that may affect not only the intended problems but also other uses or functions. This flexibility of ideas might be represented by a single concept that might be extended to multi dimension conceptual categories in terms of use or functions (Finke *et.al*, 1992: 39).

2.11.6 Sensitivity

One aspect that is also important in creative people is sensitivity which involves their acute consciousness of what they sense around them which appears to be imperfect, and be responsive to this deficiency. It is the ability 'to see problems' or having 'sensitivity to problems' (Amabile, 1983: 201). Creative people are not easily satisfied with the status quo. They have a tendency to question themselves and judge that things are not what they expected. They tend to see inappropriateness in things, and start to think creatively from their dissatisfaction. This leads them to discover the core of hidden problems which are invisible to other people. It is an ability to put together the preliminary problems which requires solution (Gilchrist, 1972: 5). The clear understanding of the real problems allows creative individuals to search with an array of approaches that may lead to possibly unique and apt solutions. They explore the solution to the problems not only for their own interests and satisfaction, but also with societal needs in mind. The outcomes of the creative acts will be instilled with aesthetic aspects to attract public acceptance for their works (Balchin, 2005: 39)

2.11.7 Insightfulness

Insightfulness can be defined as 'the number of different knowledge domains the product contacts' (Finke, *et al*, 1992: 40). The inter-relation of information between different areas might spark unpredictable answers or solutions to the identified problems. The outcomes of an insight by a creative person may have sensible inferences of use that lie outside of the framework in which it was initially visualised.

Sternberg and Davidson (1999) have suggested their own framework for defining insightfulness as a sudden vision of strategy for a long unsolved solution that comes from previous hard work. It involved the emergence of a new uncommon solution from the fusion of new 'know how' with preceding knowledge to unfold ambiguous problems. Insight is not something that appears from nowhere or which comes to the creative mind without any logical explanation. It is reported as occurring as a result of intense thought or action on the task, when the solution did not come into sight instantly, but through the process of time.

An insight can occur at any moment within creative people, whilst intuition plays a great role in creating an imaginary boundary for the divergent thinking process. It can also be seen as the phenomena of cognitive unconsciousness in creativity which prevents burden to the conscious mind during the processes of integrating various pieces of information (Weisberg, 1993: 42).

Policastro (1999: 89) defined intuition as information which influences individual consciousness of thought that leads to a potentially sensible decision. The intuition will lead to a possible outcome by combining new information and prior knowledge in a selective and reasonable manner. Based on this definition, intuition is seen to precede insight. It is the reconstruction process of the implicit form of knowledge to an integrated and explicit one.

2.12 Exploring Creative Behaviours in Conventional Design Tools

This section attempts to explore conventional design tools (e.g. 2D sketching, 3D sketch modelling) and behaviours possibly displayed by designer when using them. This would provide an understanding of what types of behaviours designers would exhibit when dealing with these tools which facilitate creativity (e.g. behaviours)

The abstract ideas, that exist loosely and unstructured in the designer's mind, need to be externalized by transforming them to an understandable form for reflection and communication. This can be achieved through modelling such as 2D and 3D sketch modelling and CAD modelling. 2D Sketching and 3D sketch modelling have been long recognised as creative designing tools, but the role that CAD plays remains contested.

There is a considerable body of published work concerning the roles of 2D modelling such as sketching in supporting designing (e.g. Yang and Cham, 2007; Kavakli *et al*, 1998; Rodgers *et al,* 2000 etc). 2D and 3D sketch modelling play vital roles in initiating and developing design ideas (Verstijnen *et a*l, 1998: 520). Several researchers have reported modes of behaviour that they have observed when researching such modelling activities.

2.13 Two Dimensional (2D) Sketching

Designers use sketching to deal with early phases of loose and unstructured initial design ideas. Through sketching, the interaction between a designer's cognitive thinking and the physical world takes place. Cognitive thinking, otherwise known as 'cognition' by Archer (1992: 5), refers to mental activity such as perception, interpretation, analysis, memory, understanding etc.

The vigorous involvement of sketching in the initial ideas development stage mean that it plays a vital role in creative processes (Verstijnen *et al*, 1998: 520). More concisely, Yang and Cham (2007: 482) emphasize the role of sketching in facilitating the generation and representation of novel ideas in the early stage of designing. This is also supported by Baskinger (2008: 28) who suggested that drawings and sketches would be a very powerful and persuasive tool in representing design ideas.

Designers use drawing as a vehicle to communicate their ideas from the imaginary state to the observable form. It is an effective method to convey new design thoughts and details innovatively (Pedgley, 2009). From his design experiences, Pedgley (2009) recognised five roles of drawing in facilitating designing including:

a) Explaining things to colleagues
b) Mementos of ideas coming from existing products
c) Restating design ideas and archiving information
d) Recording ideas and decisions taken at meetings
e) Generating and developing product designs

From a number of authors, it has been suggested that sketches have been widely used because of these reasons. They are used as:

- a medium for thinking and expressing design ideas (Yang and Cham, 2007; Cross, 1998; McGown and Green, 1997; Tovey, 1989)
- a way of supporting the idea generation and creative discovery (Kavakli et al, 1998; Rodgers, 2000)
- a medium to capture, explore, and perform 'reflective dialogue' (Yang and Cham, 2007; Sedivy and Johnson, 1999; Cross. 1998; Tovey, 1989)
- a medium to store design ideas for revisiting purpose (Van der Lugt, 2005)

Sketching enables designers to visualise ideas from their imagination which makes it possible for them to be manipulated, modified, communicated, and used to stimulate the development of new ideas by the designer himself or someone else.

Further, Sedivy and Johnson (1999: 43) believed that the explicit representation of ideas by sketching activity would additionally give better understanding of the problem resolution.

This was also suggested by Suwa and Tversky (1997: 385) who stated that sketching as part of external representation methods would not only be useful for 'memory aids but also to facilitate and constrain inference, problem-solving and understanding' design ideas. Several researchers have also indicated modes of behaviour that are characteristic of designers whilst involved with sketching activity as discussed below.

2.14 2D Sketching Behaviours

Rodgers et al (2000) reported from Goel that freehand sketches play a great role in the creative, explorative and open-ended phase of problem solving. Through sketching, designers are spontaneously brainstorming and capturing loose fragments of their initial ideas. When any of the fragments of ideas start making sense and become more structured, sketching allows the designer to initiate a movement from one idea to slightly different ideas before final ideas are distinguished.

Verstijnen et al (1998a: 522) suggested that cognitive thinking would facilitate initial ideas generation through 'mental imagery' operation which could lead to creative discovery. In 'mental imagery', the relevant information related to the design problem, potential solutions, and others exist in the form of loose and unstructured images. It is a process of producing and experiencing images in the designer’s mind (Arieti, 1976). It existed in the form of echoes, copies, or reconstructions of the designer’s previous experiences, perceptions, and knowledge. However, the act or mode of behaviours which are demonstrated by the designer during sketching is the focus of this section.

2.14.1 Combining and Re-structuring

In discussing aspects of imagery processes which link to designing particularly sketching activity, Verstijnen *et al*, (1998a, b) distinguished two types of process which were named as ‘combining’ and ‘restructuring’. Combining, also known as Figural Combination, referred to phenomena where ‘known components are joined to form a possibly novel whole’ (Verstijnen *et al*, 1998b: 180). It is happening when the designer mentally makes the effort to put together information (e.g. ideas, components, forms) to produce an object from these combinations. The amalgamation is taking place in designer’s mind without altering the initial structure or interpretation of each component. In certain circumstances, it is possible for the discovery of novel objects to be established in image form subsequent to the combining process.

Restructuring, however, has different characteristics compared to combining. Verstijnen *et al* (1998b: 179) defined the restructuring process as ‘the decomposition of the components into incidental parts, not previously known to exist in the configuration' (ibid: 179). The accompanying parts which were established as a consequence of the restructuring act were proposed to be significantly different from any representation of the figure (e.g. symbolic representation, segmented visual image). From previous research they found that it was difficult to restructure initial conception within mental imagery (Verstijnen *et al*, 1998a: 524). Thus, externalization such as sketching has been expected to be used to facilitate the restructuring process and perform design synthesis.

The presence of a novel part was frequently detected if designers externalizing their mental image in designing through sketching had performed restructuring activity better (Verstijnen *et al*, 1998a, b). This implies that restructuring might have links with the establishment of a novel aspect in designing.

2.14.2 Lateral and Vertical Transformation

Goel (2000) has studied the mode of designing behaviour displayed by the designer during designing activity. He has distinguished two types of designing behaviour by analysing the transformations movement between successive drawings. The transformation typology was known as Lateral transformation and Vertical transformation. During sketching, when the designer produced drawings that show a slight difference from the preceding ideas, it is identified as lateral transformation. Goel (2000: 12) has clearly defined lateral transformation as one where movement is from one idea to a slightly different idea rather than a more detailed version of the same idea. While vertical transformation was referred to an evolution of a design idea that moves from one to a more developed and detailed sketching from the same idea.

In initial design, ideas were in fragments, and each fragment was further explored and transformed into comprehensive proposal or solution for assessment (Goel, 2000). Lateral and vertical transformations were anticipated to be involved throughout the course. It is also suggested by Rodgers et al (2000: 457) research findings that vertical transformation demonstrated convergence thinking behaviour, while lateral transformation demonstrated divergence thinking. This implies that vertical transformation occurred to potentially promising design ideas and might take place when there will be no further major modification of an idea.

Lateral transformation most significantly occurred during the exploration of initial ideas. This was supported by Goel (2000: 12) who stated:

‘Preliminary design is a classical case of creative, ill-structured problem solving. It is a phase where alternatives are generated and explored. This generation and exploration of alternatives is facilitated by the abstract of nature information being considered, a low degree of commitment to generated ideas, the coarseness of detail, and a large number of lateral transformations’.

2.14.3 Part by Part and Non- Part by Part Drawing

Previous research by Kavakli *et al* (1998) and later by Tseng *et al* (2002) has investigated other forms of design behaviour distinguished by the character of drawing being produced. They suggest that designers demonstrated two different modes of behaviour when sketching, which respectively produced two types of drawing which are known as 'Part by part' and 'Non-part by part'. Designers who produced part by part drawing have a tendency to draw a part of the design product completely before they initiate others (Tseng *et al*, 2002: 57). From the result findings, Kavakli *et al* (2002: 500) reported that part by part drawings are realised when they come from recalled or imagined objects.

However, it is different for 'non-part by part' drawing, where the designer tends to draw an element of a part and then starts to move on to draw another part before it is even completed (Tseng *et al*, 2002: 57). This is an indication of designers' behaviour when they are involved with resolving problems which are facilitated by external resources e.g. prior sketches. Kavakli *et al* (1998: 509) supported this by suggesting that when internal resources alone are unable to facilitate designer thoughts in designing, non-part by part drawing will be obvious.

2.14.4 Reflective and Experimental Modes

The research discussed so far has been involved with the drawing characteristics in studying designers' behaviour while undertaking sketch activity. However, Tano *et al* (2003) has focused on studying designers' behaviour through their movements while designing. They categorized the designing phase into three steps which are:

- the Sketch – draw sketches by pen and paper,
- the Rendering – draw rough colourful sketches by pastels, and
- the Painting – a photo realistic drawing (ibid: 313)

The steps were studied and observed using design tools which respectively suits the nature of activity of each step which are Sketch, Rendering, and CG/VR. The study aim was to investigate the effect of information systems to designer cognitive modes of behaviour during designing e.g. sketching, drawing.

Designers were observed and a combination of fast and slow movements when undertaking sketching distinguished. These movements corresponded respectively to the experiment and reflective modes (ibid: 314). The experiment mode is related to 'experimental thought' e.g. brainstorming and spontaneous reaction to demonstrate the emergence of ideas. While in reflective mode, designers tend to slow down the sketch movement due to the rationalization involved at that moment such as making comparisons, thinking, decision-making etc. From the results, they found that by using a Sketch the designer has the ability to freely move between the reflective and experimental modes. Most of the designing activity involved reflective mode, and partially experiment modes which is a good way to produce good design (ibid: 314).

Sketching is profoundly recognized as a designing tool which is very useful in stimulating creativity (Tano *et al*, 2003; Verstijnen *et al*, 1998a, b; Sedivy and Johnson, 1999). It might be overstated to say that sketching is the key method for designing. However, in the initial ideas development, sketching provided a quick and uncomplicated representation medium for them to be evaluated and further developed. The relationship between sketching and creativity was also emphasized by Garner (1989) who suggested that it encouraged creative exploration and might stimulate creative ideas. This would imply that the act or behaviours (see Table 2-3) which are demonstrated during sketching is the representation of creative behaviours.

Table 2-3: Exhibited behaviours when engaged with 2D modelling design activities

Reported behaviour categories	**References**	**Examples of the authors' description of exhibited behaviours**

Combining	Verstijnen *et al* (1998b)	• Combined components into creative object without altering
		• Manipulation of components:
		    o size variation,
		    o position,
		    o orientation

Restructuring	Verstijnen *et al* (1998b)	• Change or alter the structure of the original components such as:
		    • Size differences between components
		    • Embedding in other components
		    • Modification into different form
		    • Substraction

Lateral transformation	Goel (2001), Rodgers *et al* (2000), McGown *et al* (1998), Prats and Earl (2006)	• Obvious change of one idea to another different idea. • Different form of solutions displayed • Widening the problem space
Vertical transformation	Goel (2001), Rodgers *et al* (2000), McGown *et al* (1998), Prats and Earl (2006)	• Elaboration of existing idea into more detailed version. • No modification of ideas, but clarification of neater lines and addition of dimension detail • More detailed or refined version of the same idea
Part by part drawing	Tseng et al, (2002)	• Drawing a part completely
Non part by part drawing	Tseng et al, (2002)	• Incomplete drawing of a part
Reflective	Tano *et a*l (2003)	• Display slow sketch movement (e.g. Thinking, making comparison, decision making)
Experimental	Tano *et a*l (2003)	• Display fast sketch movement (e.g. concept generation)

2.15 Three Dimensional (3D) Physical Modelling

According to Smith (2001: 9) 3D modelling is referring to a physical model that represents an aspect of the 3D form. It is involved in developing tangible presentations of design product as part of designing activity. Apart from that, Bairstow *et al* (1999: 24) described 3D modelling as an easy approach to the initial work for developing conceptual ideas, especially when involved with complex forms. They suggest that modelling enables designers to realise the design ideas which possibly are difficult to visualise and draw because of their complexity. Smith *et al* (2001: 132) from their research suggested:

'It seems clear that the designer gained from the physical nature of sketch modelling. It is as though the material itself provided them with a source of ideas. This is probably not just because the modelling material behaves more like the material that will eventually be used. It might also be that the 3D sketch model is more decisively 'out there' than the drawn sketch. We might say that the idea is more clearly realised, more accessible to the processes of judgement and change'.

3D modelling gives the designer the opportunity to externalize and deal with almost 'accurate' objects which are 'alive' and real, for further exploration of design ideas. Nakakoji and Yamamoto (2003) emphasize that the externalized representation of ideas which transform from imagery state to physical form will be different from what is seen in the designer's mind. However, a physical model established from the designer's mind would enable the assessment and modification of current ideas through looking and feel of its shape (Bairstow *et al*, 1999: 30). 3D modelling discussed in this context referred to physical iconic models (e.g. Smith, 2001) such as card, foam, clay, wooden 3D models etc.

2.15.1 Behaviours Reported when using Card or Paper Modelling

The ability to visualise ideas in the mind is crucial for designers in the initial design stage. Making the ideas tangible and visible is a potent way to further develop the ideas. Bairstow *et al* (1999: 24) suggest that materials such as card, paper would facilitate the exploratory process of the design ideas quickly. Hence, this would provide an effective tool for the designer to evaluate certain criterion of the design instantly. Paper and card are easy to get and cheap to buy. They are also not difficult to manipulate in making models for product design. In other words, 'By using very simple techniques such as cutting, scoring and folding you can easily explore both curved and rectangular forms. A few additional materials like string and wire will add further variety and allow you to extend the range of your initial idea development' (ibid: 27).

Welch and Lim (2000) have conducted a study about the way novice designers (students) would undertake designing acts in seeking design solutions. The aim of this research was to come out with evidence and suggestions that could be used to improve the teaching approach employed in Design and Technology. In one of the design activities, the students were assigned to design the tallest possible tower using a piece of paper entitled 'Paper Tower'. This would enable researchers to observe designer attitudes towards 3D modelling. Obviously, some predictable weaknesses from ordinary inexperienced designers were observed such as:

- unable to fully understand the design problem that affected the type of problem solution generated,

- unable to foresee potential problems which might arise from the solution,
- inability to generate more than one potential solution for the design problem.

However, the significant results from the study were the implications of modelling usage in designing to designer behaviour and ability in generating design solutions. In this context, Welch and Lim (2000) have observed behaviours such as:

- having better understanding of the problem,
- being stimulated in the generations of solutions,
- being able to see what a design would look like,
- carrying out design testing,
- continuously incorporating modifications and improvements into a solution.

They described these activities as ‘Model-test-refine-test’ iteration. 3D modelling using e.g. paper have developed students’ understanding of problems through solutions exploration. It has also been observed that the emergences, and ongoing developments of new ideas were encouraged whilst model making takes place. The visible and ‘touchable’ design ideas would allow students to continuously assess and improve their design solutions to the optimum.

2.15.2 Behaviours Reported When using Clay (Plasticine) Modelling

According to Molteni (1989: 54), traditionally clay modelling is involved with adding and subtracting act performed by hands and fingers which turn an idea into something physically visible by manipulating its material behaviour. The hands and fingers have a role as connector between the designer's inner mind and the external world. The 'sense of touch' is seen as an essential element in the content of any clay work (Rawson, 1971). This is clearly explained by Molteni (1989: 54) referred to in slightly different terminology:

'The great tactile sensitivity allows the hand to evaluate, weigh, measure and ascertain the state of the substance that it is touching'

When undertaking clay modelling, designers have to coordinate their imaginary thinking or ideas and hands into the act of making. This is supported by Molteni (1989: 60) who stated:

'The important thing is…to direct the coordination of hand and brain, gesture and desire, action and awareness of what must be done'.

Clay is a good way to facilitate the designer's visualization of their ideas or abstract concepts into a visible and tangible form. It is not the only good part of clay modelling, but, working with clay also provides stimulus to designer for undertaking novel work (ibid: 65). The link between the designer's inner mind and the external world could be established through clay modelling. Its plastic characteristic provides opportunity for designers to produce various types of shapes that become a medium in externalising ideas. Clay gives the designer freedom and flexibility to shape anything that makes the idea visible and tangible to others.

Designing through clay involves making forms in actual space. In this modelling process, the designer has to translate the in-mind conceptual ideas and transform them into physical forms. The clear vision and details of the ideas such as its shape, size, texture and material are vital for the modelling purpose. Speight (1983: 188) implies that clay modellers have to use their visual and tactile imagination when undertaking clay modelling. This is vital to enable the physical form of the ideas to be established in as 'accurate' and 'realistic' manner as appeared in mind. Externalizing which is involved in clay modelling activity would facilitate the creative process and enhance the designer's creativity (Nakakoji & Yamamoto, 2003).

Based on the literature, a number of behaviours which are displayed whilst designers engage with the modelling activity were distinguished. To make it easier to be understood, the behaviours were tabulated as shown in Table 2-4. The types of activity and the behaviour exhibited during the course were listed.

Table 2-4: Exhibited behaviour when engaged with 3D modelling activities

Reported behaviour categories	References	Examples of the authors' description of exhibited behaviours
Continuous modification and improvements	Welch & Lim (2000)	• Continuously incorporating modification and improvements into a solution
Sense of touch	Welch & Lim (2000), Molteni (1989), Rawson (1971), Bairstow *et al, (*2000), (Speight, 1983)	• Evaluate • To pick things up and play with them • Compose for making • Seeing what a design looks like • Able to feel the form
Adding and subtracting act	Molteni (1989), Bairstow *et al (*2000)	• ….draw, cut, make indentation, add, raise…[clay]

Although these behaviours are not directly linked to creativity in the same way that the creative behaviours reported by cognitive psychologists are, 2D and 3D modelling are widely recognised as creative processes by design researchers and consequently some relationship may be inferred. However the primary discussion in this thesis focuses on the Creative Behaviours Model directly derived from literature relating to creativity.

2.16 Chapter Summary

In this Chapter the author has reviewed the definitions of creativity from various authors, and rather than taking part in continuous debating agenda of creativity definition, the author chose to step on 'the giant shoulder' by using these definitions in the research. From the literature, the behaviours were grouped under seven categories of creative behaviours which are novelty, appropriateness, motivation, fluency, flexibility, sensitivity, and insightfulness.

From the literature, compilation of behaviours reported from 2D sketching and 3D sketch modelling undertaken were established in form of 2D sketching behaviours framework and 3D sketch modelling framework. Chapter 3 discusses on the research methodology for this study.

3 Chapter Three: Research Methodology

3.1 Chapter Overview

This section provides an explanation of the research methods of the study, which consist of interviews, protocol analysis, design diaries in the three case studies, and a questionnaire survey (online and paper). It discusses reasons why such methods were employed in this research.

3.2 Research Strategy

The main focus in this research is to acquire data and evidence that could shed light on the link between CAD and creativity through creative behaviours. For an empirical study, the links could either be observed by the researcher, if there was some external evidence of their existence, or reported by the participants. The seven categories of creative behaviours as shown in Figure 3-1 were used as a framework to observe and capture such behaviours that were previously reported by cognitive psychologists.

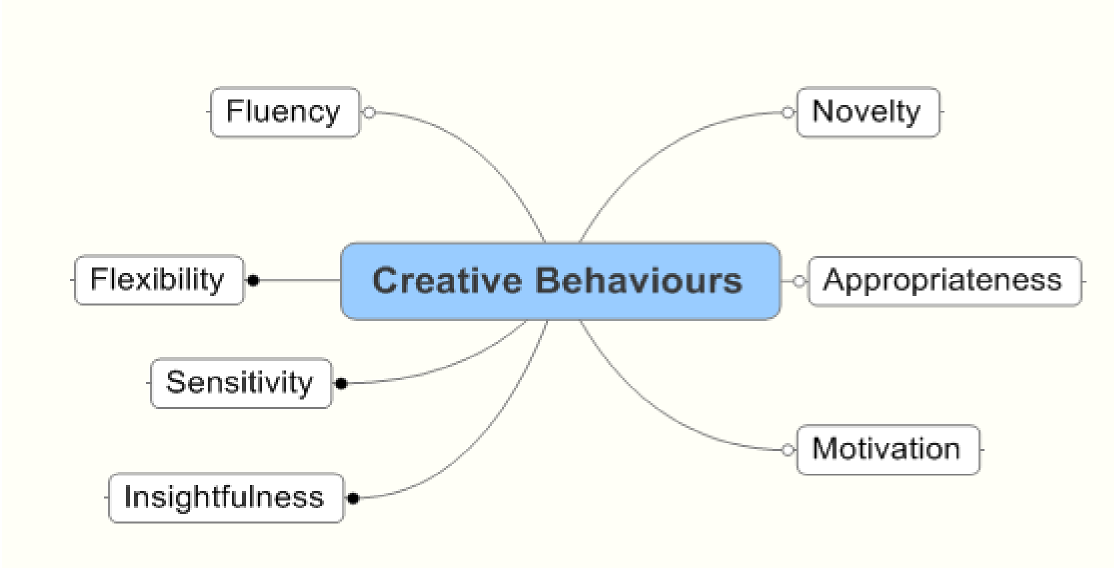


Figure 3-1 Creative Behaviours Framework

However, Barlex notes the necessity to provide ‘objective criteria’ that can be utilized to identify creativity aspects [creative behaviours] (2002: 12). Although his suggestion was intended to facilitate creativity assessment in educational settings (e.g. classrooms, studios, workshops) however, this would also be useful to this research. Hence, to explain the meaning of the seven terms chosen, each of the creative behaviours was assigned three descriptors as shown in Figure 3-2.

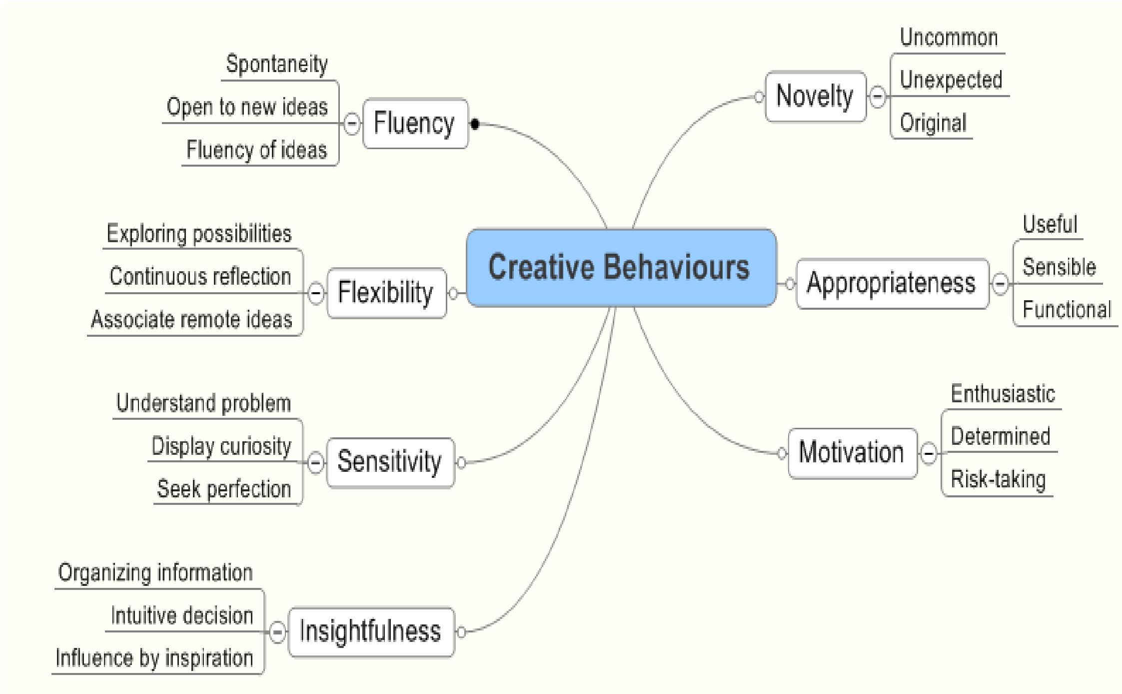


Figure 3-2 Creative Behaviours and their descriptors

The meaning of each descriptor was explained in Table 3-1. The descriptor was meant to provide context for both the researcher and participants in terms of identifying creative behaviours. Rather than having a general category of creative behaviours, the descriptor would make the model more structured and feasible to facilitate the observation and identification.

Table 3-1: Creative Behaviours descriptors

Creative behaviour categories	Creative behaviour descriptors assigned	Descriptor's description
Novelty	Uncommon	Ability to seek unusual idea(s) for solutions
	Unexpected	Ability to come up with surprising idea(s)
	Original	Ability to come up with unique idea(s)
Appropriateness	Useful	Ability to produce practical design idea(s) or solution(s)
	Sensible	Ability to suggest or make reasonable decision related to idea(s) or solution(s) that might have good chance to success
	Functional	Ability to propose idea(s) or solution(s) that it is possible to operate
Motivation	Enthusiastic	Showing excitement or interest with the activity
	Determined	Firmness in doing things to achieve satisfactory idea(s) or solution(s); feel confidence
	Risk-taking	Not afraid to try new idea(s) and willing to cope with the consequences; have a go
Fluency	Spontaneity	Ability to come up with sudden idea(s) or solution(s) without *logical* planning
	Open to new ideas	Receptive to new idea(s) and not only stick to one idea; ready to elaborate or make changes whenever possible
	Fluency of ideas	Ability to generate ideas to fulfil certain requirements in some degree of time
Flexibility	Exploring possibilities	Use a variety of approaches through which problems may be solved; playing with ideas
	Continuous reflection	continuously evaluate and consider previous or present ideas or solutions
	Associate remote ideas	Ability to combine disparate information to give meaningful idea(s)
Sensitivity	Understand problem	Ability to see the problem
	Display curiosity	Desire to ask or speculate about things
	Seek perfection	The act of perfecting previous or present ideas; not easily satisfied with present idea(s)
insightfulness	Organizing information	Ability to put together old and new information to gain new idea(s)
	Intuitive decision	Ability to come to a decision without support from logical reasoning; make speculation or assumption
	Influence by inspiration	Reaction which is stimulated by instinct or intuition

In the literature review, the 4P's (person, product, process, and press) have been recognized as important aspects in researching creativity. This research intended to distinguish the possible links between the use of CAD and creativity by exploring the behaviours of creative people. To capture the emergence of such behaviours in designing, the Creative Behaviours Framework was used in the establishment of the research instruments, and the data analysis methods.

An exploration of the creative products aspect was also attempted by trying to link the creative criteria from the design outcomes. Thus, a personal designing exercise was undertaken with the assumption that there is more likelihood for the link to be established as the data would be based on the researcher's own designing. Although this was not necessarily the case, the researcher has more potential to track back the creativity characteristics with the use of CAD from his own experience and data recorded (e.g. protocol analysis, design diaries) compared to attempting to do the same from other designers' recorded data. The aspects of process and press were not part of the main interest of this research except in that any software (press) or process could be used and data might incidentally emerge.

3.2.1 Qualitative and Quantitative in this Context

Researching within design activity would involve an attempt to interpret and describe a designer's thinking, acts and behaviours when using CAD from implicit forms to a more explicit and understandable structure. Qualitative approaches were considered for this research since Fischer described qualitative research as ‘a reflective, interpretive, descriptive, and usually reflexive effort to describe and understand actual instances of human action and experience from the perspective of the participants [designers]…… through a particular situation [designing in CAD]’ (2006: xvi).

While Berg notes that ‘qualitative research properly seeks answers to questions by examining various…..[design activity] settings and the individuals who….. [are involved in] these settings’ (1989: 6). In addition, the researcher is also allowed to ‘explore the human elements of a given topic, where specific methods are used to examine how individuals see and experience [designing in CAD e.g. creativity, creative behaviours]…….’ (Given, 2008: xxix)

In explaining the nature of qualitative research, Malterud (2001: 483) stated that ‘qualitative research methods involve the systematic collection, organisation, and interpretation of textual material derived from talk or observation’. In the wider context, Rowan and Huston notes that it is ‘designed to observe social interaction and understand the individual perspective, provides insight into what people’s experiences are, why they do, what they do…’ (1997: 1442).

According to Angrosino (2007) those involved in the qualitative research tend to explore and analyse data captured from: the people experiences, the ‘interactions and communications’ by the subjects within the observation settings, and the related documents (e.g. diaries, audio and/or video recordings). This is supported by Mack *et al* (2009: 1) who stated that qualitative research has the 'ability to provide complex textual descriptions of how people experience a given research issue. It provides information about the "human" side of an issue '. They also suggested that 'qualitative research is especially effective in obtaining….specific information about the ….opinions, behaviours …of particular populations [e.g. CADs' users]' (ibid: 1).

In the last stage of this study, a questionnaire survey was also undertaken to gather data from larger samples. Since the qualitative approaches, according to Morgan, lack potential for generalisation (2008: 798), the intention of implementing this quantitative approach is to possibly generalise the findings. This has been well explained by Patton who stated:

'The advantage of a quantitative approach is that it's possible to measure the reactions of a great many people to a limited set of questions, thus facilitating comparison and statistical aggregation of the data. This gives a broad, generalisable set of findings presented succinctly and parsimoniously. By contrast, qualitative methods typically produce a wealth of detailed information about a much smaller number of people and cases. This increases the depth of understanding of the cases and situations studied but reduces generalisability' (2002: 14)

The use of a quantitative method corresponding to qualitative techniques would establish a substantial body of evidence resulting to the triangulation of data (Ke, 2008). Hence, the following sections discuss the research methods undertaken and the rationale behind them.

3.3 Research Methods

This section will be focused on describing the research methods used in this research, and the reason why they were selected to be undertaken.

3.4 Case Studies

Since creativity is a very complicated subject, a case study approach was considered appropriate as it 'represents a disciplined mode of inquiry that can be organized around issues' (Smith and Strahan, 2004: 360). By definition, Blatter notes that 'a case study is a research approach in which one or a few instances of phenomena are studied in depth' (2008: 68). Case studies could provide descriptions of what CAD users, in particular industrial designer students do and say when using CAD during the act of designing.

When exploring new research areas, Flybvjerg suggested that qualitative approaches, such as case studies, are useful 'in the preliminary stages of an investigation to generate hypotheses' (ibid: 219). The information acquired from the case studies will contribute to the new understanding of the relationship between creativity, especially creative behaviours and the use of CAD in designing.

3.5 Interviews

In this study, participants were required to be involved in at least two phases of interview sessions, identified as preliminary (pre)-interview, and post-interview. The pre-interviews were undertaken before the participants' project commenced, and the post interview after the project completed. Interviews were undertaken in each case study organised in this study.

According to Brinkmann 'interviewing is a conversational practice where knowledge is produced through the interaction between an interviewer and an interviewee or a group of interviewees' (2008: 469). Similarly, Angrosino (2007: 39) described interview as 'a process of directing a conversation so as to collect information' from a participant. It is 'useful for getting the story [information] behind a participant's experiences' (McNamara, 2008), 'opinions, feelings, and knowledge' (Patton, 2002: 4). This would provide rich data that probably could not be acquired from other methods.

The researcher could use the interview sessions to 'pursue in-depth information around a topic' to get a better perspective of certain issues (Patton, 2002). In the interviews, participants were expected to provide 'meaningful, knowable, and able to made explicit' data for the research (National Science Foundation, 2009). Interviews gave the researcher rich information that was helpful to the research which usually existed in non-structured forms.

3.5.1 Preliminary (pre) Interviews

Before the participants engaged in their design projects, it was vital to have an overview of what they planned and anticipated in these projects. The pre-interviews were intended to provide information about the participants' background (e.g. CAD skills, perception of CAD roles in their designing activities) and how they intended to pursue their projects. The information would facilitate the researcher's understanding about the participants and their projects, and support the preparation of the data collection activities. These were scheduled with the participants based on their projection of how they were going to undertake their design projects.

The interviews were undertaken face to face between the researcher and the participant. The researcher posed questions with a pre-determined set of questions as guidelines to conduct the sessions. According to Morgan and Guevara, this is known as the question based approach where 'the expected content of the interview is outlined in terms of a series of questions the interviewer intends to ask' (2008: 469).

Brinkmann notes that this type of interview format would provide space for the participant to give 'more spontaneous descriptions and narratives' (2008: 470). Still, the researcher 'has the freedom to pursue the questions in a different order and allocate more time to some questions than to others depending on what is most appropriate for discussing…….with each individual participant' (Morgan and Guevara, 2008: 469).

These interviews were intended to seek the participant's perspective related to the used of CAD in their projects such as why they were going to use CAD; are there any other design tools that they are going to use in addition to CAD in the project; what they hoped to achieve from the use of CAD, etc. The listed questions were shown in Figure 3-3. According to Morgan and Guevara the prepared questions would allow the researcher to:

a) 'probe and follow-up questions that can elaborate on the basic set of questions', and
b) provide guidance whether 'a further probe or follow-up question can either extend the discussion of the current question or move the conversation toward the next question'. (2008: 469)

Loughborough University

Private & Confidential

D&T Bank

Pre Interview Questions Sheet

Questions

- What type of product you are going to design?
- Are you going to use computer while designing?

☐ Yes ☐ No

- If 'No'. Please give your reasons for not using computer?
- If "Yes". Are you going to use any design software in your design work?
- Have you been trained to use this software package?

☐ Yes ☐ No

- If 'Yes" please explain when and where you had received the training?
- If 'No' please explain how did you learn this software?
- What do you expect from the usage of the design software in your design work?
- What type of design modelling activity do you expect to undertake?
- What type of output do you hope to get from the use of the design software?
- In what stage of the design process is the most probably you will use the design software? Please explain Why?
- Are you going to use other design tools in addition of design software in your design work? Which?
- Is there any particular reason why you used the other tools?

Figure 3-3: Pre-interviews open ended questions

The participants' responses were recorded, and transcribed. The interview helped the researcher to profile the participants' projects, and gave initial information to the extent to which CAD software was to be involved in their project. In Case study 2, the researcher has switched role as interviewee, to check any ambiguity in the listed questions, and to improvise them if necessary. Participants in Case study 3 were interviewed using the improvised set as shown in Figure 3-4.

Private & Confidential

Pre Interview Questions Sheet

Questions

- What type of product you are going to design?
- Is there any possibility that a computer is going to be involved in any part of your designing?

  ☐ Yes ☐ No
- If 'No'. Please, can you explain further?
- If "Yes". Is there any particular software that you plan to use in your design project?
- Have you received any training to use the software?

  ☐ Yes ☐ No
- If 'Yes" please describe when and where you had received the training?
- If 'No' please describe how you learn to use the software?
- Please describe the type of output you anticipate from the use of the design software?
- Is there any particular time throughout the designing that you are most likely to use the design software? Please explain further?
- Are you going to use other design tools in addition of design software in your design work?
- Is there any particular reason why you would need to use other design tools?

Figure 3-4: Improvised pre-interview questions

3.5.2 Post-interviews

The post-interview is a venue for the researcher to clarify any incomplete and ambiguous data which may occur in the process of data collection, in particular design diaries. Angrosino (2007: 39) notes that the interview is also 'intended to probe for meaning, to explore nuances, to capture the grey areas'. Hence, in order to explore such matters, interviews subsequent to the data collection activity were undertaken.

According to Pedgley (1999: 118) post-interviews conducted following the completion of the design diaries aimed to:

a) explain the use of jargon or apparent strange or multiple use of vocabulary in entries;
b) elaborate on entries that were unintelligible to the researcher;
c) elaborate on episodes of designing that were of principal importance to the research (especially where the diary had captured insufficient evidence);

The post-interviews were planned to be undertaken in Case study 1, however, due to the lack of responses from the participants, and time constraints, they were unable to be executed. Only one of the participants returned the completed design diaries for analysis, but could not be reached for post-interview due to her completion of the course in Loughborough University. In Case study 2, the post-interview was not relevant or necessary to be undertaken as the participant was the researcher himself.

As for Case study 3, both participants participated in the post-interview session. The questions posed in the post-interviews were prepared based on a case-by-case situation developed to clarify prior data collected from the participants. An example of the post-interview questions is shown in Figure 3-5. The interviews were arranged after the participants submitted their whole completed design diaries, and when initial analysis had been undertaken of the diaries.

Post Interview For Design Diaries

Participant: MP01

Date	Questions	Notes
6/11/08	1) You've only spent about half an hour for this session and that achieved your task aim. Do you feel confidence using this software? 2) You suggest in this session that you produce idea which useful, sensible, and functional. But the activity was only create copy of an existing syringe. Can you please explain?	
30/11/08	1) Can you please explain, in what aspect the idea you come out in this session is useful? 2) 'Influence by inspiration'? 3) How does this session helped you to understand and determined future work? Can you please elaborate?	
1/12/08	1) In this session, you've mentioned that you found problems in your design whilst in CAD, but you need to 'reverting to sketches for faster exploration'. Could you please explain further, why you need to go back to sketches?	
23/12/08	1) Why do you suggest that your idea is something that 'unexpected' in this context? Is there any particular reason that you can share? 2) How this session has changed and improved your design compare to prior of this?	
27/12/08	1) It seems that it has been a slow process for this task, however	

Figure 3-5: Example of post-interviews questions (excerpt from MP01 post interview session)

3.6 Protocol Analysis Incorporating Video Recording

As previously discussed, the cognitive ability of human beings has and always will be utilised in design processes as they require one to be creatively involved with synthesising, and problem solving activity (Cross *et al*, 1996: 1). The intricacy of this 'design' task has generated 'stress on the rigour of the analysis of design processes, 'objective' observation and direct generalizability of the findings' (Dorst

& Dijkhuis, 1995: 262). They implied that to grasp in-depth understanding about this matter, 'logical analysis and contemplation of design' are necessary (ibid: 262). To consider an appropriate research approach, in this context, would involve seeking a method that allows useful data to be captured while designers were engaged with CAD for designing.

The enthusiasm to capture and accurately describe design activity 'in the way designers experience it (Dorst & Dijkhuis, 1995: 264) has seen an increase in the number of research projects using protocol analysis as the research methodology (e.g. Gero and McNeil, 1998; Suwa *et al*, 1998, Suwa and Tversky, 1997). On other occasions, Dorst (1995: 139) notes that 'the need for more detailed knowledge of design has put protocol analysis in the limelight as one of the ways to get close to the designer's thought processes (cognitive, problem solving, etc)'. Designers illustrate their design thinking through modelling (e.g. 2D sketching, 3D sketch modelling, CAD modelling) which established design outcomes as a result of such interactions. This was clearly stated by Roberts (1999: 36):

> 'A model [e.g. 2D sketching, 3D sketch modelling, CAD modelling] - represents cognitive modelling as active processes and functions which are within, related to, and derived from the design act.'

According to Hayes (1986: 352) protocol analysis is a method 'to justify the use of verbal reports as data, especially as data regarding thinking' as appear in designing (e.g. 2D sketching, 3D sketch modelling, CAD modelling). In a more straightforward statement, it is an approach that puts ‘think-aloud’ (e.g.Young, 2005; Ke, 2008) as a method to externalize one’s (e.g. designer) actual cognitive thinking. The designers were encouraged to share their design thinking as verbal descriptions while undertaking their designing acts. These would provide context to the acts they exhibited, and to the outcomes (e.g. sketches, physical models, CAD images) which emerged as a result of those actions. Shahriman (2008: 269) notes that protocol analysis is ‘a method of bringing out into the open some of the cognitive processes of designers’. The principle of this approach is to encourage people to speak out their thinking and feeling as they perform their activity.

The use of a video recorder to record the designing events in CAD was to allow access to the data for future reassessment or re-evaluation by the researcher whenever necessary. Similar types of data gathering approach known as Conversational Analysis (CA) was also suggested by Sosa (1999) as an alternative to various research approaches used in studying creativity (e.g. laboratory experiments, retrospective reports, protocol analysis). It emphasized a data gathering approach through ‘observation, recording, and interpretation of designers at work’ in real time and with non-artificial situations (ibid: 182). This approach is suggested when in studying creativity in design which he sees as involved with ‘the terribly mundane, communal, typical and recurrent activity’ (ibid). In this study, a combination of suggested approaches is applied where a number of CAD designing episodes were video recorded, concurrent verbalisation was encouraged, and the events were a real setting based on part of participants’ design project activities.

In this study, every participant was required to arrange a session in which approximately 20 minutes of their CAD activity was to be video recorded while they were encouraged to verbalise their thoughts. The video recorder was set up so that it provided a view of the computer or laptop screen. The ‘zoom in’ and ‘zoom out’ features were used whenever necessary to ensure the on-screen activity was clearly recorded. The 20 minutes recording was presumed sufficient to provide useful data for analysis. Accordingly, Trimingham (2007: 146) suggested that ‘the data collected during a 20 minute concurrent verbalisation and protocol analysis was more than sufficient to allow insight into a designer’s decision-making [author’s research interest]’. There are two types of raw data from the protocol analysis which are ‘verbal’ and ‘visual transcripts’ (Davies, 1999: 103). The data could be in the form of audio recorded verbalisation only (e.g. Ke, 2008), or could also be in the form of audio visual form (video recording) as in this study.

Participants were asked to suggest a session which they thought would mainly involve designing activity (e.g. ideas generation, decision-making, design probing, design evaluation). The reason was to avoid the selected session being involved with design documentation rather than true designing activity. In case studies 2 and 3, protocol analysis was not only carried out in at least one of the participants’ CAD activities, but also in a session of 2D sketching, and 3D sketch modelling.

In addition, on-screen CAD video recordings were also undertaken by the researcher in Case study 2, and by the participants' of Case study 3 which allowed them to provide the video data themselves. The aim was to provide the data in less obtrusive surroundings to the participants as they would choose the sessions that were going to be recorded. The researcher and the participants were provided a user license of CAMTASIA Studio, on-screen activity recording software. This software can be downloaded straightaway from the software provider website into their own personal computers or laptops where CAD software was accessible to them. The software has a recording feature that enables the on-screen CAD activity to be captured easily by the participants themselves. Subsequent to the recording, explanatory descriptions were needed to facilitate the data analysis. Three types of explanatory approach were undertaken which were:

- Video transcript – Case study 2 (the researcher)
- Guided explanation – Case study 3 (MP01)
- Retrospective verbalisation – Case study 3 (MP03)

The protocol analysis approach was also meant to complement the design diaries method which was also employed in the study. From his previous experience, Pedgley (1999: 290) claimed that the design diary approach had some limitations such as it might not be a real time recording method, and it could provide discrepancies of information between early and later entries. In this case, protocol analysis was undertaken to get real time data sources for the CAD activity analysis. The intentions were to identify a method to observe and identify any creative behaviour occurrences during the use of CAD in designing (RQ2), and to attempt to establish potential links between them (RQ3). The implementation of this approach would hopefully shed light on whether the protocol analysis would enable the creative behaviours to be distinguished by the frameworks during CAD use (RQ1), and when 2D sketching and 3D sketch modelling activities were undertaken (RQ4).

Despite its potential to provide 'close' descriptions of design activity which designers are immersed in (Dorst & Dijkhuis, 1995), it also causes concern that this approach 'may affect the design process in unpredictable ways' such as behaviour alteration, and possibly will provide inaccurate design behaviour descriptions (Davies, 1999: 115). Accordingly, Cross *et al* (1999: 2) identified three disadvantages that must be taken into consideration which are:

- the side-effects of the verbalization, such that it actually changes the subject's behaviour and their cognitive performance,
- what the subjects report may well be incomplete accounts of what their cognitive activity actually is,
- the subjects may, quite unintentionally, give irrelevant accounts, reporting parallel but independent thoughts to those that are actually being employed in the task

Nonetheless, the researcher agreed with Young (2005: 31) who was convinced that despite its limitation, this approach has its own strengths such as the ability to ‘enhance observational data’, ‘uncover usually covert cognitive process’, and ‘eliminate assumptions’ in the data analysis.

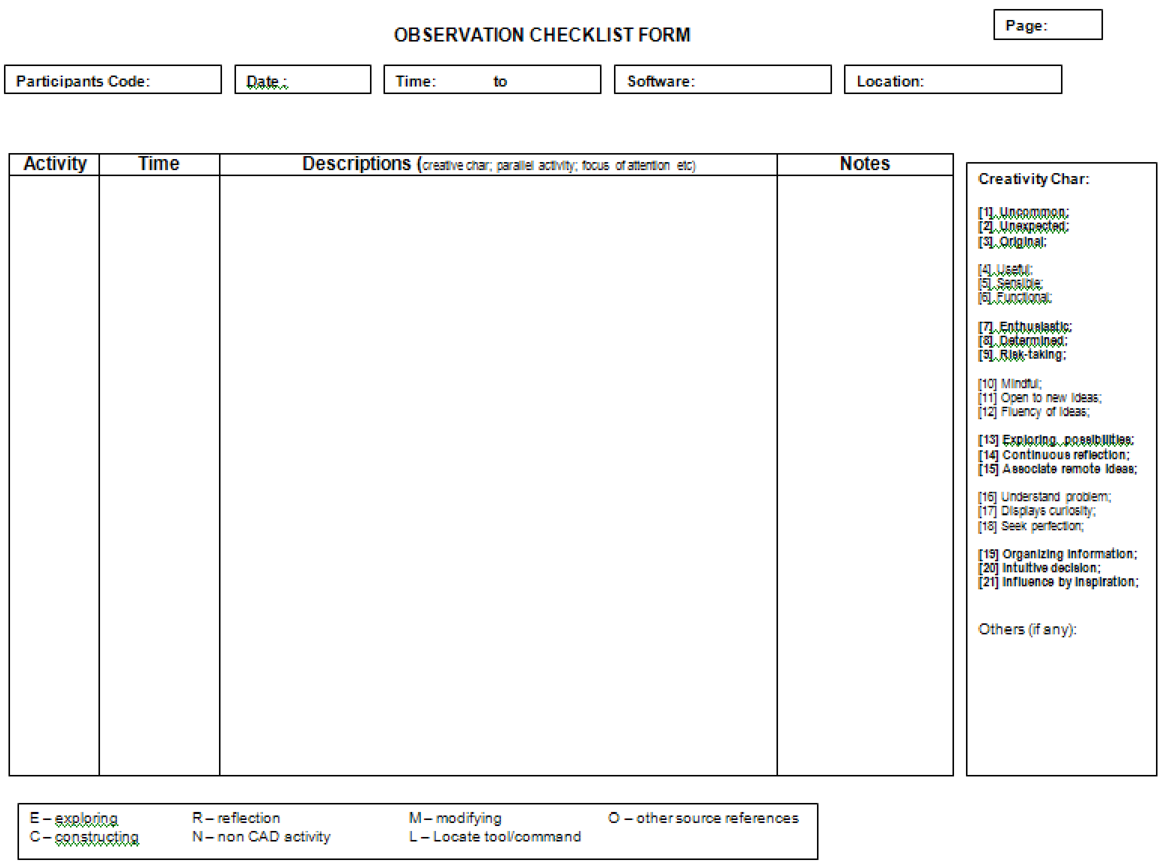
3.7 Observations

According to Angrosino (2007: 54) observation is ‘the act of noting a phenomenon, often with instruments, and recording it for scientific purposes’. In this context, the CAD designing by users was the focused event and the video recorder was being used as the recorder instrument to capture such activities and to attempt to identify creativity from it. Explicitly, McKechnie described observation as a research method that ‘involves collecting impression [of the designer]………using all of one’s senses, especially looking and listening, in a systematic and purposeful way to learn about a phenomenon of interest’ (2008: 573). While McQueen and Knussen (2002: 205) added that:

> ‘It [observation] can be used to establish what actually happens in various settings to generate hypotheses and theories, to illuminate findings or examine situations more closely, and to evaluate the impact of interventions’

Initially, observation was considered as one of the methods to be employed in this research and was trialled in Case study 1. It was vital to explore the capability of observations to generate useful data for the research study. The initial study had attempted to undertake two observation approaches in parallel, namely direct observation and video observation in order to compare their effectiveness.

In direct observation, the researcher will observe with minimum interruption and they will not be participating in the activity (Kawulich, 2005). This gave the researcher the opportunity to study the designing activity while designers were engaged with CAD designing and to record any significant event which emerged. From the data, the researcher would attempt to identify any behaviour that might link to creativity. The observation was guided using the observation checklist form as shown in Figure 3-6.


OBSERVATION CHECKLIST FORM

Page:

Participants Code: | Date : | Time: to | Software: | Location:

Activity	Time	Descriptions (creative char; parallel activity; focus of attention etc)	Notes

Creativity Char:

[1] Uncommon;
[2] Unexpected;
[3] Original;

[4] Useful;
[5] Sensible;
[6] Functional;

[7] Enthusiastic;
[8] Determined;
[9] Risk-taking;

[10] Mindful;
[11] Open to new ideas;
[12] Fluency of ideas;

[13] Exploring possibilities;
[14] Continuous reflection;
[15] Associate remote ideas;

[16] Understand problem;
[17] Displays curiosity;
[18] Seek perfection;

[19] Organizing information;
[20] Intuitive decision;
[21] Influence by inspiration;

Others (if any):

E – exploring R – reflection M – modifying O – other source references
C – constructing N – non CAD activity L – Locate tool/command

Figure 3-6: Observation checklist form

The CAD design event was categorised into seven codes as shown in Table 3-2 to allow the researcher to record the significant activity. However, the constraint of this approach was the inability of the researcher to make comprehensive concurrent analysis of the on-screen activity during the observation session. This could mean the researcher overlooking important events which could affect the research findings.

Table 3-2 CAD event activity coding

Code	Activity
E	Exploring
C	Constructing
R	Reflection
N	Non-CAD activity
M	Modifying
L	Locate tool/command
O	Other source references

Video recording enabled the researcher to capture important events that might have been more difficult to observe in real time. Video recorded data facilitated the micro analysis of each selected event (Paterson, Bottorf, and Hewat, 2003: 5). This approach enabled the researcher to take notes, and analyse the video-recorded data at a steady pace, due to its capability to execute 'frame-by-frame' video review. These made the analysis process more effective and the probability of capturing significant events was increased. The 'reverse' and 'forward' functions enabled the researcher go to specific episodes for further analysis or for data validation.

These two approaches were undertaken to check their ability to identify creative behaviours by capturing the occurrences of their descriptors. Hence, they were aimed to support data for RQ1, RQ2, and RQ3. It is also important for the researcher to understand the pros and cons of this type of approach. Thus, the advantages and disadvantages of this method are shown in Table 3-3.

Table 3-3: The advantages and disadvantages of observations

Advantages
Provide direct information about behaviour of individuals and groups
Permit evaluator to enter into and understand situation/context
Provide opportunities for identifying unanticipated outcomes
Exist in natural, unstructured, and flexible setting
Disadvantages
May affect behaviour of participants
Investigator has little control over situation
Selective perception of observer may distort data

(Excerpts from National Science Foundation, United States of America Website)

Experience from the initial study made the researcher realise the difficulty in undertaking a direct observation approach for this particular research, especially when dealing with on-screen CAD observation. The on-screen CAD activities were quite complicated to observe and understand if not supported with additional sources of information (e.g. verbalisation, video recording). Based on this situation, direct observation has been left out from the list of methods that were going to be used in the next study. Video recording seems to overlap with the protocol analysis approach, where both of them have the same principle in capturing data via video recording. The difference is only that in the video observations participants were not required to constantly verbalise their actions. Their commentaries were based on questions that were posed to them by the researcher. Thus, video observation like direct observation was also left out from the later study.

3.8 Design Diary

Since designing often takes an uncertain period of time before arriving at its attainment, a longitudinal data collection method such as a design diary appears to be appropriate. Frequent diary entries were vital to avoid difficulties in recalling past experiences which could be important to the study. Smith-Sullivan notes that 'diaries track participants' daily activities and objective experiences' (2008: 213). In this context, diaries would help the researcher to keep track, and gather as much information as possible from every CAD session participants anticipated throughout their design projects.

The design diaries also allowed the researcher to have hindsight about the designers' experiences each time they used CAD in designing. This is supported by McKernan (1996: 86) who suggested that keeping a diary 'forces one to reflect, describe and evaluate daily encounters'. Besides that, it can avoid or reduce the researcher from getting misleading information if solely relying on data from limited and 'simple snap shots of behaviour' (Wiseman *et al*, 2005: 395).

In undertaking this type of data gathering strategy, Pedgley (1999: 296) notes that a design diary study should consist of:

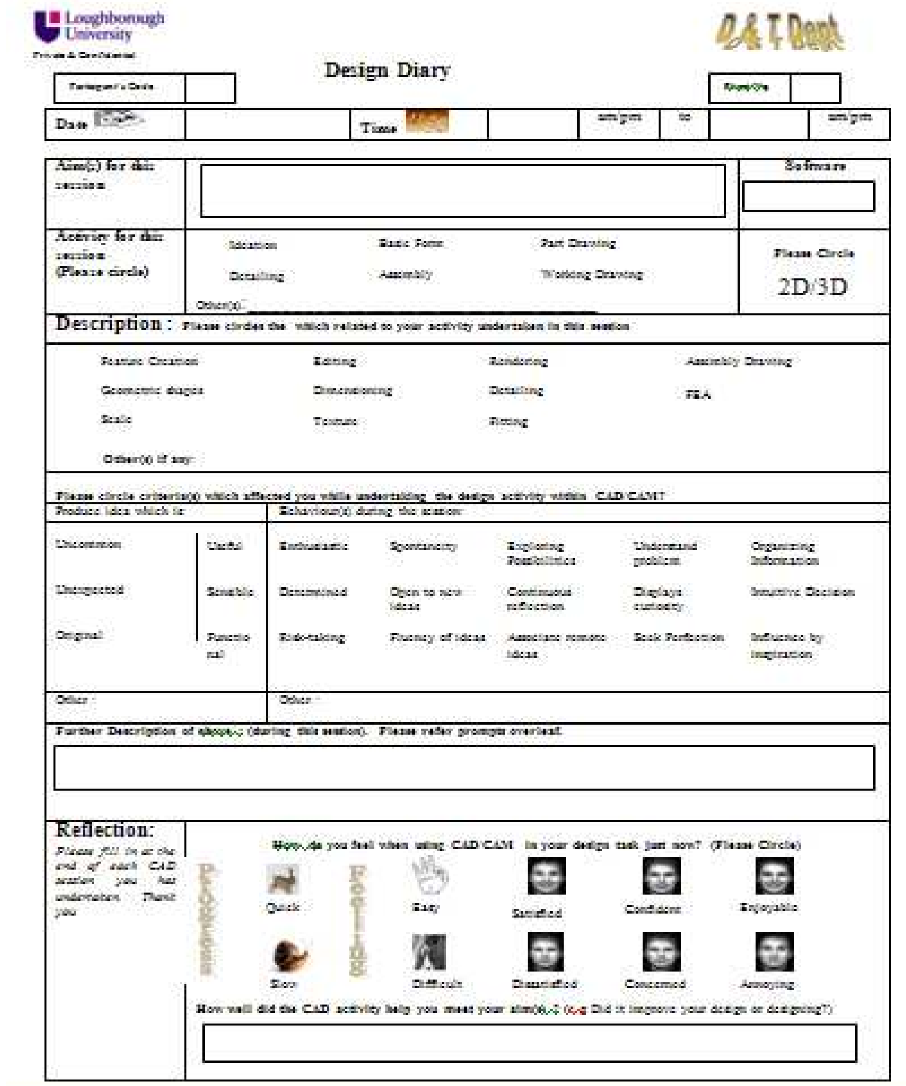
i) pre diary administration

ii) implementation of the design diary

iii) post diary interviews and data analysis

The researcher adopted Pedgley's generic approach to design diaries in this research as it has evidently proved effective. Thus, this method was undertaken in three case studies and aimed to provide supporting data for RQ1, RQ2, and RQ3.

In terms of its format, diaries could be of open-format or structured. Corti (1993), notes that open-format diaries provide flexibility to the participants 'to record activities and events in their own words'. However, for structured diaries participants' responses are restricted only to pre-categorised items. Participants in this study were provided with a combination of structure and open-format diaries as shown in Figure 3-7. It is a self-administered diary where the participants were required to fill in the diary entry by the end of every CAD session.


Design Diary

Date		Time		am/pm	to		am/pm

Aim(s) for this session | Software

Activity for this session (Please circle): Ideation, Basic Form, Part Drawing, Detailing, Assembly, Working Drawing, Other(s) | Please Circle 2D/3D

Description : Please circle the which related to your activity undertaken in this session

Feature Creation, Editing, Rendering, Assembly Drawing, Geometric shapes, Dimensioning, Detailing, FEA, Scale, Texture, Fitting, Other(s) if any:

Please circle criteria(s) which affected you while undertaking the design activity within CAD/CAM?

Produce idea which is: Uncommon, Useful, Unexpected, Sensible, Original, Functional, Other :

Behaviour(s) during the session: Enthusiastic, Spontaneity, Exploring Possibilities, Understand problem, Organizing Information, Determined, Open to new ideas, Continuous reflection, Displays curiosity, Intuitive Decision, Risk-taking, Fluency of ideas, Associate remote ideas, Seek Perfection, Influence by inspiration, Other :

Further Description of ideas (during this session). Please refer prompts overleaf.

Reflection: Please fill in at the end of each CAD session you has undertaken. Thank you

How do you feel when using CAD/CAM in your design task just now? (Please Circle)

Progress: Quick, Slow. Feeling: Easy, Difficult, Satisfied, Confident, Enjoyable, Dissatisfied, Concerned, Annoying

How well did the CAD activity help you meet your aim(s)? (e.g Did it improve your design or designing?)

Figure 3-7: Design diary format

Participants were given a briefing on how to administer the diary, and supplied with a sheet of guidelines on how to complete the diary entry as shown in Figure 3-8. The design diary sheets were given to the participants before they commenced the design project.

Loughborough University

D & T Dept

Design Diary

Entry Outlines

1. **Participant's Code**
   - The code which assign to you.

2. **Time**
   - The time you start the designing activity using CAD/CAM and the time you stop or finished.

3. **Aim(s)**
   - What will you use CAD/CAM for?
   - How will it help the designing?
   - What is/are your aim(s) for this particular CAD/CAM session?

4. **Types of software**
   - The type of design software you are using (e.g:ProE, AutoCAD etc)

5. **2D/3D**
   - You are going to use 2D or 3D in that particular session. If you use both of them alternately within the session, please circle both of them.

6. **Description**
   - Please circle information which related during that particular session.

7. **Further Description**
   - If you have anything which you believe useful to the research. Please do not hesitate to further describe them in this section.

   (Please Refer Prompts Overleaf)

8. **Reflection**
   - Your view/perception about CAD/CAM related with your design task after each session. Please circle the related item(s)
   - How well did CAD activity help you meet your aim(s)?

We are warmly appreciated for your precious time and effort.

Thank you very much

Aede Hatib Mustaamal
Research Student
Department of Design and Technology
Loughborough University
Loughborough
Leicestershire LE11 3TU

Room : Matthew Arnold Building, ZZ006
Telephone : 01509 228302
Email : A.H.MustaAmal @lboro.ac.uk

Figure 3-8: Design diary entry outlines

In using this method, Crosbie (2006: 8) however raised concern regarding the level of details and accuracy with the responses given by participants. Based on her experience, she identified some problems when using self-administered diaries such as:

a) diaries were partially completed,

b) less attention to details,

According to Wiseman *et al* (2005: 395) these problems might be the result of 'fatigue' symptoms where participants become less motivated to give detail, and complete responses. In dealing with such problems, post-interviews were conducted to clarify ambiguous or incomplete entries. This was also suggested by Crosbie (2006: 9) who stated that 'the most profitable way of employing self-administered activity diaries is some form of diary/interview method where the diary keeping period is followed by an interview asking detailed questions about the diary entries'.

3.9 Case Studies Research Methods Summary

In general the data gathering methods which employed in the case studies were shown in Figure 3-9.

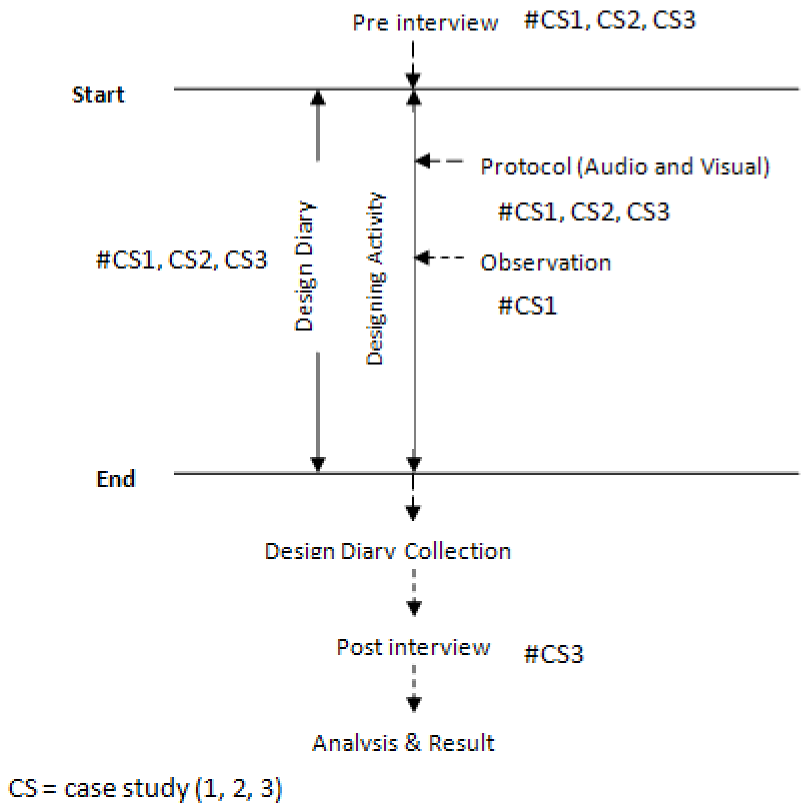


Figure 3-9 Case Studies Data Gathering Methods Summary Diagram

3.10 Case Studies Summary

In this study, three phases of case studies have been undertaken which involved the Design and Technology Department, Loughborough University postgraduates, and undergraduates including the researcher, himself. The brief information of these case studies including their objectives were shown in Table 3-4.

Table 3-4: Case studies and its objectives in the research programme

Case Study	Objectives
1	• To distinguish potential links between CAD and creativity • To identify potential data collection methods. • To gain insights into ways observing and distinguishing creativity characteristics whilst users are engaged with CAD.
2	• To replicate selected methods used in the initial study for reliability check. • To observe 2D sketching, and 3D physical modelling behaviours through the 'lens' of the Creative Behaviours Framework, and to establish comparative analysis possible association between them. • To look for creative behaviours linked to the products creative criteria.
3	• To replicate methods used in the prior study as evidence of reliability and validity. • To further establish possible associations between creative behaviours observed when using CAD with the creative characteristics of the products.

3.11 Research Samples – CAD Users: Industrial Design Students

In this study, samples were invited and recruited from among industrial designers who use CAD as part of their designing tools. In addition, they must also have good fundamental CAD background to avoid misleading findings influenced by their lack of CAD skill. In this context, samples were aimed at Design and Technology Department Loughborough University post-graduates, and undergraduate students. Candidates were invited to be involved through informal research presentation, and recruited on a voluntarily basis as participants. Students who agreed to become participants were requested to fill in a consent form (Appendix: 1)

This kind of sample recruitment is known as purposive sampling. Participants were carefully recruited to make sure the data collected was relevant (Palys, 2008). In selecting suitable samples, Berg (1989: 32) notes that 'researchers use their special knowledge or expertise about some groups to select subjects who represent this population'. The participants were invited and recruited based on these factors:

a) has CAD background,
b) has intention to use CAD in the project,

The number of participants depended on how many students were willing to be involved. However, a large sample size is not the main issue for the validity of the data and findings from case study based approaches. This was emphasized by Flyvbjerg that, 'the advantage of large samples is breadth, whereas their problem is one of depth. For the case study, the situation is the reverse.' (2006: 241).

Accordingly, Morgan notes that 'qualitative research emphasizes inductive theory building, subjective understanding, and detailed, holistic data, and these goals are often best met through intense investigations of small, systematically selected samples' (2008: 797). Further, he added that the most important thing is not how many samples were involved, but 'how well they serve the purposes of a specific study' (ibid: 797).

3.12 Questionnaire Survey

As stated before, this study attempted to incorporate qualitative with quantitative approaches. This, according to Silverman (2001: 35) would enable researchers 'to test and to revise their generalizations, removing nagging doubts about the accuracy of their impressions about the data'. Findings from the case studies which might be considered as isolated data could possibly be generalized through quantitative data (e.g. questionnaire survey). For those researchers who use qualitative data, Riley (1990: 131) notes that 'additional quantitative data that bears out your interpretation of your 'soft' study is very convincing'. In this context, the researcher has the opportunity to assess the significance of findings that were predetermined from the case studies to a wider proportion of CAD users.

Hence, the questionnaire survey has been considered to be implemented in the final stage of this study. Allison *et al* (1996: 69) notes that as a research tool, questionnaires have advantages in terms of 'accuracy, access to dispersed respondents and wide coverage in terms of topics and respondents'. In addition, a questionnaire 'allows greater uniformity in the way the questions are asked and thus ensures greater comparability in the responses' (Mouly, 1978: 189). However, Mouly (1978) also cautioned to those who use them to be aware of their drawbacks (e.g. non-return rates, inadequate answers, misunderstood questions). This was especially when the researcher attempted to obtain responses not only from CAD users in the UK (Design and Technology of Loughborough University undergraduates, postgraduates, and members of staff) but also in Malaysia (academics staff and students). Hence, two similar questionnaires were established to provide feedback through online-based and paper-based responses. The UK based respondents were chosen to provides larger sample in comparing the data established from the case studies which were from the same population. While data from Malaysian respondents were gathered for comparison.

In terms of the questionnaire formatting, Krosnick (1999) has discussed the pros and cons of using open-ended and closed-ended questionnaires. He notes that 'a closed-ended question can only be used effectively if its answer choices are comprehensive, and this is difficult to assure' (ibid: 544). For an open-ended questionnaire, one of its shortcomings is lack of viability when respondents are unable to explain themselves clearly, although the intentions of its use are to provide 'greater flexibility' as it 'allows the respondent more leeway in stating his position' (Mouly, 1978: 192). This was supported by Krosnick, although he also notes that 'open-ended questions seem to be more viable research tools than had seemed to be the case' (1999: 544).

In the context of this study, the researcher agreed with Mouly (1978: 192) who stated that 'as most of the problems to be covered in the social sciences are varied and complex, a combination of the two is generally better than the exclusive use of one'. Hence, the questionnaire was designed mainly in the form of closed-ended questions, while open-ended questions were also included to acquire respondents own points of view by further elaborating their responses.

The questionnaire consists of four sections which are:

a) demographic information,

   to acquire information about respondents and his/her CAD background (e.g. age, designation, CAD skill, use, and know how)

b) their CAD experiences,

   to understand respondents' perception about CAD, and how it facilitates their design and creative acts.

c) our research findings,

   to present some of the findings from the case studies, and to seek their feedback (e.g. is it possible that they came across similar experiences) from their own perspective.

d) creative behaviours model in wider applications,

   to explore the possibility for the Creative Behaviour Model to be applied in other settings (e.g. classroom activity)

From 56 questions, 53 of them were multiple choices, and 48 were using five-point Likert scale. This scale was suggested as it 'frequently elicits more valid responses, and is less frustrating to the respondent' (Mouly, 1978: 192). The Likert scale was not in the usual arrangement in the order of five equal intervals in the middle as 'neutral' or in this study 'DK' or 'Don't Know', but, it has been isolated to the right end of the row as shown in Figure 3-10. In the pilot run questionnaire one of the respondents commented that this strategy has made her more committed to give response between 1 and 4 (Strongly disagree to strongly agree) rather than just choose the midpoint (neutral or don't know) when she came across a question for which she was in an uncertain position.

Section 2: Your CAD experiences

With respect to your experience, and the Computer-aided Design (CAD) software which might currently be available to you, please indicate the extent to which you agree or disagree with the following statements:

Strongly Disagree : 1 2 3 4 : Strongly Agree

Don't know : 5

No	Item	SD 1	D 2	A 3	SA 4	DK 5
8.	I feel comfortable using CAD in designing	☐	☐	☐	☐	☐
9.	I consider CAD to be a designing tool.	☐	☐	☐	☐	☐

Figure 3-10: Five point Likert scale

Since the intention of this questionnaire was to provide a wider coverage of CAD user in especially in the UK and Malaysia, an online questionnaire survey was used to obtain quick feedback from Malaysian respondents. According to Wright (2005) using internet facilities is a 'fruitful area for conducting survey research'. He outlined the advantages, and the disadvantages of using online survey as shown in Table 3-5.

Table 3-5: The advantages and disadvantages of using online survey

Advantages	Disadvantages
• access to individuals in distant locations, • the ability to reach difficult contact participants, • the convenience of having automated data collection, which reduces researcher time and effort	• uncertainty over the validity of the data and sampling issues, and • concerns surrounding the design, implementation, and evaluation of an online survey

(ibid: excerpt from Wright 2005)

The questionnaire approach was sought to acquire data in supporting RQ1, RQ2, RQ3, and RQ5 as outlined in Chapter 1.

3.12.1 Triangulation

According to Rothbauer (2008: 892) the used of multiple research methods for 'data collection and data analysis' which aim to get the answer to the same research questions is known as triangulation (2008: 892). He further elaborated that triangulation is appropriate 'to render a fuller picture of research phenomena as well as to verify and validate the consistency and integrity of research findings' (Rothbauer, 2008: 894).

In this context, more than one research tool was used to provide information on CAD and creativity from different points of view. Hence, a few methods such as interviews, observations, protocol analysis, design diaries, and questionnaire were used in this study. Berg (1989) notes that much research generally used three methods to allow triangulation to be executed, and for this study, the researcher used five data gathering techniques for this purpose. This was shown in Table 3-6.

Research Question (RQ)	Interviews		Observations (CS1)	Protocol analysis (CS:1,2,3)	Design diaries (CS:1,2,3)	Questionnaire
	Pre (CS:1,2,3)	Post (CS:3)				
RQ1	*	*	*	*	*	*
RQ2	*	*	*	*	*	*
RQ3	*	*	*	*	*	*
RQ4				*	*	
RQ5						*

#CS = case study (1, 2, 3)

Table 3-6 Triangulating data from different research methods for each research question

The process of the triangulation can be divided into two stages named as ‘macro’ and ‘micro’ triangulations. The macro triangulation consists of three elements which are:

a) literature reviews
b) case studies
c) questionnaire

The macro triangulation aimed to provide evidence to the Creative Behaviours Framework validity as shown in Figure 3-11. The Creative Behaviours Framework established from literature reviews were published in journal and conferences to acquire feedback and comments from referees, and conference delegates. Case studies from small samples were also undertaken to generate data and establish evidence on the creative behaviours suggested from the literature reviews. Questionnaires aimed to provide responses from larger samples and to confirm data findings from case studies.

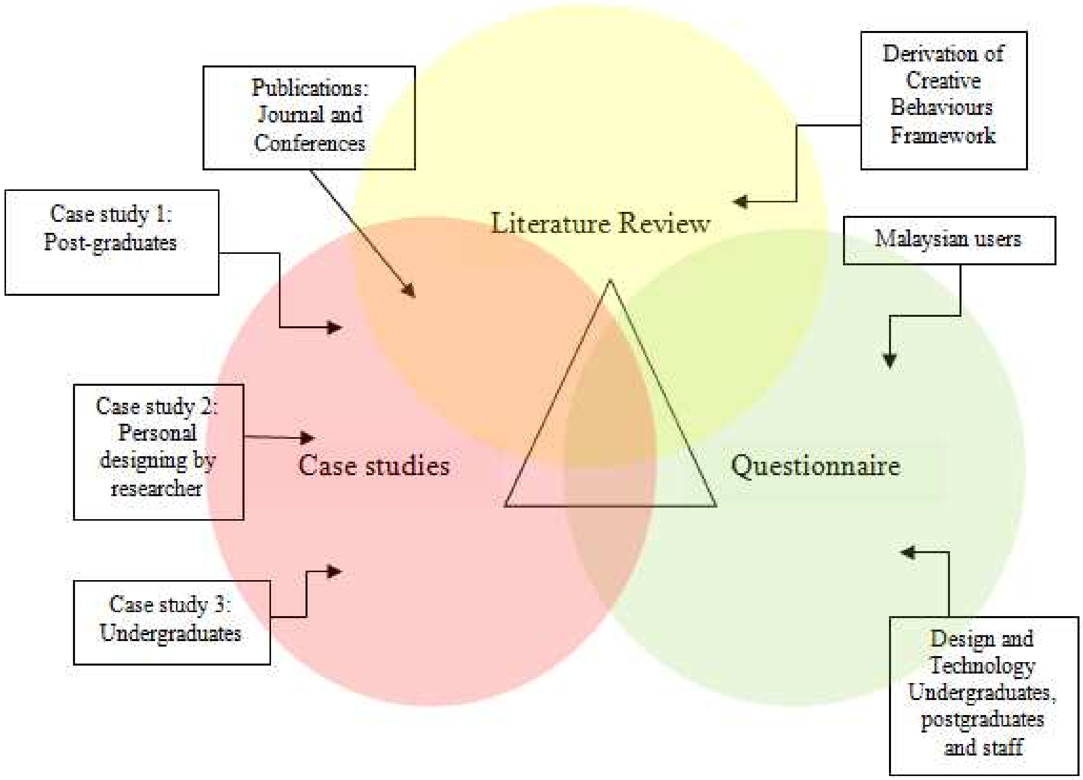


Figure 3-11: Macro triangulation

The micro triangulation in these three case studies used more than one data gathering approaches as shown in Figure 3-12. The creative behaviours in the framework were explored through the research methods and then comparisons were undertaken between the methods in the case studies. The verification of findings by carrying out multi methods in a number of case studies would increase the validity of the research (Miller, 2008). In addition, he stated that the reliability of research indicated through its ‘ dependability, consistency, and/or repeatability of a project’s data collection, interpretation, and/or analysis’ (ibid: 753).

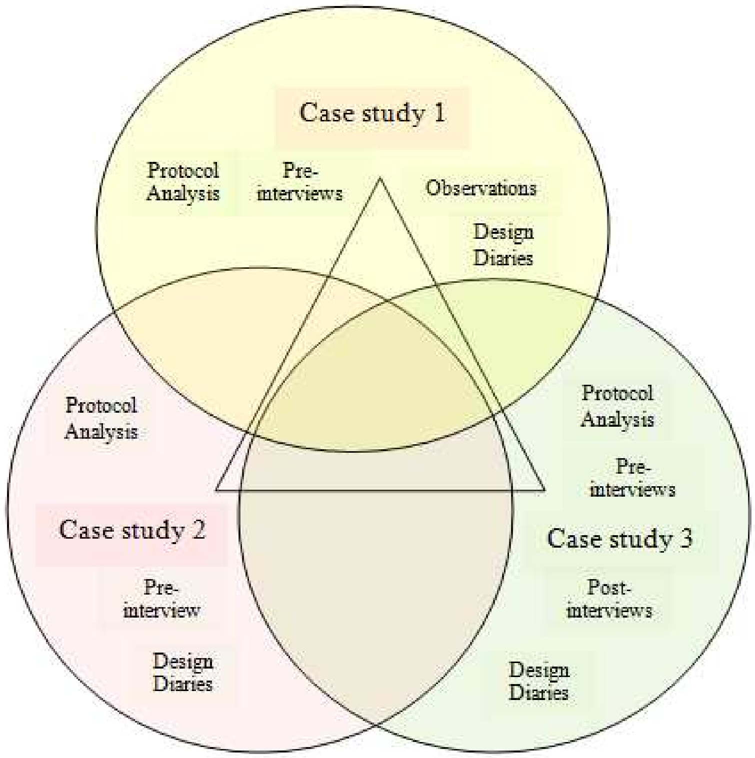


Figure 3-12: Micro triangulation

3.13 Chapter Summary

In brief, this section has summarised the research methods applied in the study, and the rationale for the chosen methods. The Creative Behaviours Framework is being used as a bridge between ‘CAD’ and ‘creativity’ in order to provide empirical data that can support analysis and discussion.

4 Chapter Four: Case Study One – Initial Study

4.1 Chapter Overview

This chapter discusses the initial study undertaken to explore the possible link between CAD and creativity. The research methods used in this study were designed, developed, and tested to try their ability to provide useful data for the research intent. Data analysis methods, and data findings are also discussed in this chapter.

4.2 Aim and Objectives

None of the literature reviewed previously in Chapter Two clearly suggest the evidence of the link between CAD and creativity. As having an effective instrument is essential to perceive the potential connections, an initial study was carried out with aims to explore and develop such instruments. It was also crucial to identify methods that enabled the researcher to develop an appropriate research instrument to collect significant data. Hence, the objectives of this case study were to distinguish potential links between CAD and creativity; to identify potential data collection methods; and to gain insights into ways of observing and distinguishing creativity behaviours whilst users are engaged with CAD.

4.3 Postgraduates' Design Projects

This study was initially conducted with four post-graduate students of the Design and Technology Department, Loughborough University, but later only three continued until the completion of all data collection activities. Three were Design and Technology Masters Programme students, and one was a PhD student.

The projects were based on their master's design project or research project as shown in Table 4-1. The data collection activities were only focused on the segments which involved the participants with use of CAD in designing.

Table 4-1: Participants' project

Participant	Project
P01	'Lap board for notebook/laptop'
P02	'Portable lighting with GPS tracer'
P03	'Multi-purpose bag'
P04	'Brace'

Since this was an exploratory study, a few data gathering approaches such as interviews, protocol analysis, observation, and design diaries were explored as shown in Table 4-2.

Table 4-2: Data gathering activities

Method	**Pre-interviews**	**(CAD design activity)**				**Post-interviews**
Participant		**Observations**		**Protocol Analysis**	**Design Diaries**	
		Direct	**Video**			
P01	*					
P02	*	*	*	*		
P03	*	*	*	*	*	
P04	*	*	*	*		

Three participants were involved in the protocol analysis in one of the CAD sessions they engaged in. All of the participants had the flexibility to choose a CAD session which they considered as dealing with designing activity. The sessions were arranged when and where the participants decided, and when CAD videoing was to be undertaken. The reason was to provide as non-obtrusive environment as possible by allowing them to work in their chosen settings. On-screen CAD activities were the main focus of data recorded for later analysis as shown in Figure 4-1.

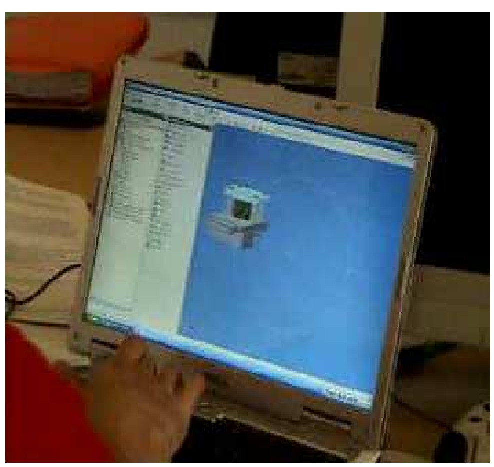


Figure 4-1: CAD activity by a participant

Participants were told to verbalise what they were doing for later analysis. However, only one participant confidently and consistently spoke out what he was doing without any problem. The other two participants seemed reluctant, and had difficulty explaining their actions concurrently despite continuous encouragement by the researcher.

4.4 Results

This section will present the data acquired from Case study 1:

4.4.1 Pre-interview

As stated in Chapter Two, the pre-interviews were intended to provide information about the participants' background and how they were going to complete their projects, especially with information that related to the use of CAD. The interviews had been recorded using a TEViON 512 Mb digital voice recorder and later transcribed. Four participants had been involved in the interviews and their responses were transcribed (full transcriptions can be referred in Annex 1). The participants in Case study 1 and 2 used English as a second language and the verbalisations from the interviews and protocol analysis entries in the design diaries and interview responses have been presented in the form that the data was gathered. Similarly for Case study 3, but these two participants used English as a first language. Each transcription consists of the participants' code, gender, and the interview texts as shown in Figure 4-2.

Preliminary Interview
ID Code: P03
Gender : Female

Q = Interviewer; P = Participant

Q	In this interview I would like to do some question regarding your master project,. So what type of product you're going to design in this…?
P	I'm going to design a […………..]
Q	A […………..]?
P	Yes
Q	Are you going to use computer while designing?
P	Err…I think I will introduce computer even like in the beginning of my designing….. Because I kind like to use a computer to generate some more rough ideas. I'm ought using Rhino to do that because quick and spare me a lot.
Q	So, Beside…. you just mention Rhino, are you going to use any other design software in your design work?
P	I think for the first several week I will use Rhino. And then, I'll doing like a 3DMax, because I'm using 3DMax for rendering. And I also may be will use 3DMax for animation. It's kind like a having a rotating product …

Figure 4-2: Pre-interview transcription format (Excerpt from P03 Pre-interview)

In analyzing the transcriptions, the researcher was grouping the statements by the respondents that showed as repeating ideas into coding themes. The Division of Instructional Innovation and Assessment, University of Texas suggested that coding enables one 'to organize large amounts of text and discover patterns that would be difficult to detect by just listening to a tape or reading a transcript'. From the pre-interview transcriptions, eight codes had been distinguished which are shown in Table 4-3:

Table 4-3: Pre-interviews thematic codes

Abreviation	Referring to
DST	design strategy anticipated
TOC	type of CAD proposed to be used
CFE	CAD feature expectation
CAE	Participants' CAD experience
RUC	reason to use CAD
CFT	where CAD fits
ODT	other design tools planning to use
RUO	reason to use other tools

Based on these codes, a thematic table for the pre-interview data was developed an example of the analysis is shown in Annex 2. The examples of participants' quotation based on the thematic codes established were as follow:

a) DST – design strategy anticipated

Respondents' statement on how they plan to undertake their design projects.

'P01:...if I sketch…first form, I will make CAD model of it and may be….create some view, some sketches, and so on , and….it's variation of things.'

'P03: Okay, at first I will do some sketches but just for me to have a general idea what I want to do. And then. I'm using Rhino [CAD software], for draft the modelling. It's like a … I don't care about size ….. I don't care about if the surface perfect. I just want to get general shape , and then If I decide to use the shape, I'll model it again and to make it really good.

b) TOC – type of CAD proposed to be used

The statements about the type of CAD software which participants intend to use in the design activity.

'P03: I think for the first several weeks I will use Rhino'

'P02: I will definitely use ProE as my tool for designing and then, may be I'm using the Alias for rendering, and Photoshop for presentation and rendering as well'

c) CFE – CAD feature expectation

Respondent's expectation of what they anticipated to obtain from the tools provided by the CAD software.

'P04: The expectation is term of first of all…wherever is….on the visual….on the actual … in the initial design stage that allow me to understand how things is going to fit together….'

'P01: I'm going to use Rhino……which is surface modeller because it's not…you not to had many constraint, so I can just change and doing things in more quickly and more fluently'

d) CAE – Participants' CAD experience

Background information about respondent's level of knowledge in CAD such as source of training, types of CAD software familiar with etc.

'P01: I've received…training in my previous course, in Mechanical Engineering, and some on this course, err….on the masters course.'

'P04: Yeah, I mean I've been trained formally using Unix Graphic when I used to work in an engineering company. And during the undergraduate degree study, I've use Solid Work, I taught myself Solid Work. And I taught myself Pro Engineer, and the few other. And almost every software I taught myself….. only being formally trained Uni-Graphic'

e) RUC – reason to use CAD

Respondent's views about CAD capabilities which become the reason to use them in the design activity.

‘P01: ...for the first stage it will easier for visualize and showing it to other people to get feedback, to get it more accurate visualization of it because I can’t sketch that good. But for manufacturing process it will allow me to see will this really worked in the real life. I will be able to analyze it’

P04: And it’s about being firm about the initial idea… the initial designing of the product. In terms of like visualization, its allow me to give the people ……. a looking at the project and understanding what’s going to look like when it’s finish ....’

f) CFT – where CAD fits

Respondent’s own perception about when they think CAD would be helpful in their design work.

‘P03: I think I will introduce computer [CAD] even like in the beginning of my designing [stage] .....’

‘P04: And basically, I’m using CAD from the start to finish’

g) ODT – other design tools planning to use

Statements which point out other design tools that respondent believed helpful in the design activity aside from CAD.

‘P01: I might doing some quick prototype… like basic prototype… some blue foam’

‘P03: Umm...the rapid prototyping is one of it ……and the blue foam.’

h) RUO – reason to use other

Respondent’s rationale about why they also used other tools in the design activity besides the CAD.

'P01: Just to evaluate the ergonomics .So, you just you can feel and evaluate the idea…and get understand the form'

'P04: Because I need check, it's actually going to work in term of the fact when something is picture out its feel about right. I mean…I made it in a CAD and I don't know if it's going to work…and making the prototype to check.'

4.4.2 Observation

As stated before, the observation data was provided from two types of data collection methods which were:

a) Direct observation

b) video observation

4.4.3 Direct Observation

During the direct observation sessions, the participants' activities were observed and important information was written down by the researcher as shown in Table 4-4. Simultaneously, the sessions were also recorded using a video recorder for video observation analyses.

Table 4-4: Direct observation data analysis (excerpt from P02)

Observation Data Analysis
(Direct observation)

Participant: P02
Date: 6/9/2007
Time:
Location: Participant's resident
Software: Pro Engineering

Time	Scene Description/Transcripts	Creativity characteristics	Rationale/Justification
10:21	View the product design image - intent to modify clip	[14] ; [18]	
10:24	Try to assemble the clip	[8]	
	Delete the clip part	[8]	
10:25	Make another attempt to assemble	[8] ; [7]	
10:30	Search for the strategy how to do it - try to identify relevant surface for assemble which can lead to 'fully constraint'	[19]	
	Still unable to achieve 'fully constraint'	[8] ; [7]	
10:40	Achieve 'fully constraint'		
	Removed the 'lense' from the assembly –will not part of RP		

From direct observation data findings as shown in Table 4-5, 49 Creative Behaviours occurrences were identified and recorded. Eleven descriptors were recognised to have occurred at least once during the CAD sessions.

Table 4-5: Frequency of Creative Behaviours descriptors occurrences from direct observations

Creative behaviour descriptor	P02	P03	P04	Total
sensible		2	4	6
enthusiastic	2	1		3
determined	4	2	2	8
risk-taking		3	4	7
open to new ideas		1	1	2
exploring possibilities		3		3
continuous reflection	1	2	1	4
display curiosity		1		1
seek perfection	1	4	5	10
organizing information		1		1
			Total	**45**

4.4.4 Video Observation

For the video observations, design sessions were recorded using the same approach that been used in protocol analysis. The videos data were reviewed and the outcomes were shown in Table 4-6. Refer to Annex 3 for a full version of video observation data analysis.

Table 4-6: Video observation data analysis (excerpt from)-P02

Observation Data Analysis
(Video observation)

Participant: P02 **Page: 1/2**
Date: 6/9/2007
Time:
Location:
Software: Pro Engineering Version

Time	Scene Description/Transcripts	Creative Behaviours descriptor	Rationale/Justification
0:01 – 1:25 (25 s)	Modifying 'clip' design – changing some dimensions	[5] ; [18]; [14] [20]	[5] – 'complete' or 'reliable' design needed to enable the assembly process. [18] – the graphic enable the designer to continuously evaluate [14] their design and encourage for seeking perfection. [20] - ((is the software encourage the designer to intuitively making certain decision e.g: what to change by changing certain dimension))
1:27 – 2:04 (37 s)	Viewing the 'clip' model from different angles	[14] ; [18]	[14] – check and virtually evaluating the 'clip' design. [18] – see for possible improvement or need to be improved. ((Generate enthusiastic [7] to the designer making sensible [5] part)).

The data analysis of video observation was able to identify 96 creative behaviours descriptor occurrences as shown in Table 4-7. Ten descriptors occurred at least once during CAD activity.

Table 4-7 : Frequency of Creative Behaviours descriptors occurrences from video observation

Creative Behaviour descriptor	P02	P03	P04	Total
sensible	1	1	6	8
enthusiastic		1	1	2
determined	1	6		7
risk-taking	2	2	3	7
open to new ideas		3		7
exploring possibilities	2	3	4	7
continuous reflection	5	5	5	15
understand problem			3	3
associate remote ideas		1		1
display curiosity		1	2	3
seek perfection	2	11	5	18
Organizing information			4	4
intuitive decision		2	1	3
			Total	**85**

4.4.5 Protocol Analysis

Protocol analyses were conducted with the aim of attaining in-depth information as to whether the use of CAD would encourage designers' creative behaviours. It was also desirable that the findings would insights which would lead to the development of research instruments to identify the relationship between CAD usage in designing and creative behaviours

The video analyses were carried out using WIN Amp software which was freely downloaded from the internet. The video clip reviewing was done several times based on two phases as follow:

a) Macro phase

The researcher scanned the video clip in order to identify any significant events that required further analysis. Note-taking was carried out using a designated form as shown in Figure 4-3. An example of a full protocol analysis can be found in Annex 4.

PROTOCOL ANALYSIS

ID code : P04
Date :16/06/07
Time : 2.00 ~ 2.20 pm

Pg: 1

Time (mins)	Activity					Cr. Char	Parallel activity	Focus of attention	Description
0.00 – 1.00	E								set aim for the task
1.01 – 2.00	E	C							
2.01 – 3.00	M	R				[illegible] cont' reflection; sensible			Match the component to complete model
3.01 – 4.00	R	N					sketching	prototype	Measurement check
4.01 – 5.00	N	C	R				sketching		
5.01 – 6.00	EL							Toolbars	-searching for 'sketch' tool -browse the toolbars
6.01 – 7.00	EL								
7.01 – 8.00	EL	C							
8.01 – 9.00	R	M	R	M	R	Sensible; con't reflection		prototype	- to affirm decision
9.01 – 10.00	N	C					measuring	prototype	
10.01 – 11.00	EL							Help feature	- how to turn off sketch grid
11.01 – 12.00	EL	M	R			Seek perfection; sensible			

E – exploring
C – constructing
M – modifying
R – reflection
N – non CAD activity
O – other source references
L – Locate tool/command

Creativity Char. :

Uncommon; Unexpected; Original; Useful; Sensible; Functional; Enthusiastic; Determined; Risk-taking; Mindful; Open to new ideas; Fluency of ideas; Exploring possibilities; Continuous reflection; Associate remote ideas; Understand problem; Displays curiosity; Seek perfection; Organizing information; Intuitive decision; Influence by inspiration;

Others:

Figure 4-3 Macro phase analysis (excerpt from protocol data analysis of P04)

b) Micro phase

Based on the macro phase analysis, in-depth reviews were carried out to detect any creative behaviours that occurred while using CAD. Segments of scenes were formed into video-clips and saved as files using Arcsoft Video Impression 2 software. A maximum of 20 slides and video clips were developed from every protocol analysis session for further analysis.

The result of the analysis were shown using Microsoft Power Point in the format as shown in Figure 4-4. An example of a PowerPoint to present the protocol analysis findings can be found in Annex 5.

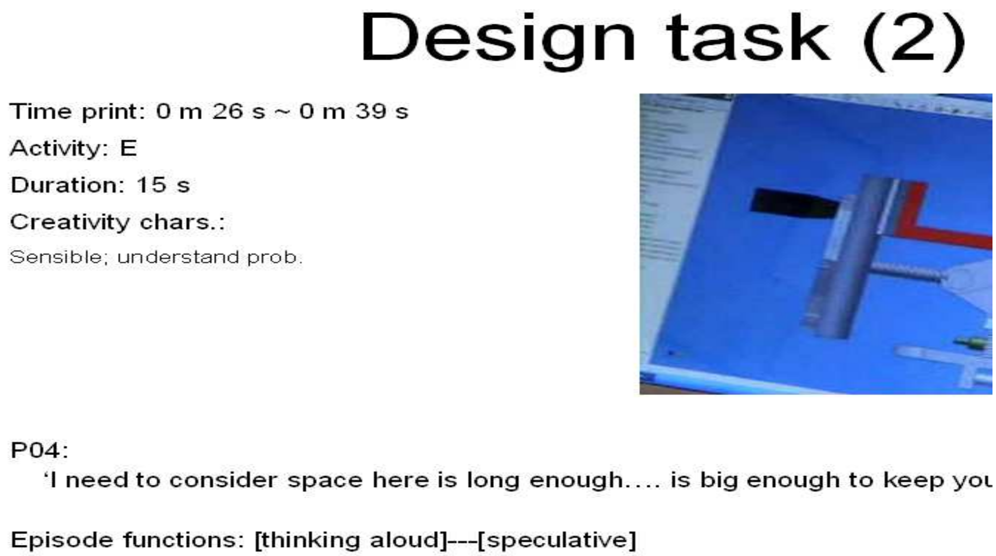


Figure 4-4: PowerPoint presentation of protocol analysis result (excerpt from P04)

From the protocol analyses, 122 creative behaviours occurrences were identified. Twelve descriptors have been identified a having frequent occurrences with at least one occurrence as shown in Table 4-8.

Table 4-8 Frequency of Creative Behaviours descriptor occurrences from protocol analysis

Creative Behaviours descriptor	P02	P03	P04	Total
sensible	9	8	6	23
functional	0	1	0	1
determined	2	1	0	3
risk-taking	5	7	3	15
fluency of ideas	3	0	2	5
exploring possibilities	4	6	4	14
continuous reflection	10	8	5	23
Understand problem	0	0	3	3
display curiosity	0	2	2	4
seek perfection	5	8	5	18
organizing information	4	2	4	10
intuitive decision	0	2	1	3
			Total	**122**

4.4.6 Design Diaries

The design diaries enabled the researcher to obtain information from the participants' CAD design activities throughout the design project phase.

Of the three participants who were involved, only one was able to hand over a completed diary. The design diaries were analyzed by recording the responses and written data into 'Design diary analysis' as shown in Figure 4-5. (See Annex 6 for an example of a full design diary data analysis).

Design diary Analysis

Participant: 03 Page: ☐

Date	Aim/Activity			Description				Cr categories			Further description	Reflection			
25/6/07	Design modelling			Feature creation	Geo. shape	Assy. Dwg	Dim.	1	2	3	Developed new design • Prepared for prototyping	Not satisfied, due to difficulty to model			
	ideation	Bas.Form	Prt.Dwg	Scale	Texture	Fitting	FEA	4	5	6		Quick	Easy	Confident	Enjoy
	Detailing	Assembly	W.Dwg	Editing	Render	Detailing		7	8			Slow	Difficult	concerned	Annoy
27/6/07	Detail modelling			Feature creation	Geo. shape	Assy. Dwg	Dim.	1	2	3	Developed part drwgs and assemble tehm • Produce basic shape	Satisfied with the work speed and outcome.			
	ideation	Bas.Form	Prt.Dwg	Scale	Texture	Fitting	FEA	4	5	6		Quick	Easy	Confident	Enjoy
	Detailing	Assembly	W.Dwg	Editing	Render	Detailing		7	8			Slow	Difficult	concerned	Annoy
7/7/07	Rendering – to seek any potential of modification/improvemnet			Feature creation	Geo. shape	Assy. Dwg	Dim.	1	2	3	Explore present design model for further improvement	Not satisfied with the time consumption			
	ideation	Bas.Form	Prt.Dwg	Scale	Texture	Fitting	FEA	4	5	6		Quick	Easy	Confident	Enjoy
	Detailing	Assembly	W.Dwg	Editing	Render	Detailing		7	8			Slow	Difficult	concerned	Annoy
11/7/07	Inspired (??)			Feature creation	Geo. shape	Assy. Dwg	Dim.	1	2	3	Got inspiration for new design ideas (??)	Unable to realize the shape in the mind into virtual			
	ideation	Bas.Form	Prt.Dwg	Scale	Texture	Fitting	FEA	4	5	6		Quick	Easy	Confident	Enjoy
	Detailing	Assembly	W.Dwg	Editing	Render	Detailing		7	8			Slow	Difficult	concerned	Annoy
15/7/07	Try to 'define' each parts properly (??)			Feature creation	Geo. shape	Assy. Dwg	Dim.	1	2	3	Facing difficulty to assemble the part (??)	Not satisfied with the outcome			
	ideation	Bas.Form	Prt.Dwg	Scale	Texture	Fitting	FEA	4	5	6		Quick	Easy	Confident	Enjoy
	Detailing	Assembly	W.Dwg	Editing	Render	Detailing		7	8			Slow	Difficult	concerned	Annoy
20/7/07	Component (??)			Feature creation	Geo. shape	Assy. Dwg	Dim.	1	2	3	Continue the attempt to assemble components/part drawings together	Still not happy with the computer (??)			
	ideation	Bas.Form	Prt.Dwg	Scale	Texture	Fitting	FEA	4	5	6		Quick	Easy	Confident	Enjoy
	Detailing	Assembly	W.Dwg	Editing	Render	Detailing		7	8			Slow	Difficult	concerned	Annoy
25/7/07	Assemble model			Feature creation	Geo. shape	Assy. Dwg	Dim.	1	2	3	Seek advice from the experts and have a go with the suggestion	Complete design drawing make the assembly process much easier.			
	ideation	Bas.Form	Prt.Dwg	Scale	Texture	Fitting	FEA	4	5	6		Quick	Easy	Confident	Enjoy
	Detailing	Assembly	W.Dwg	Editing	Render	Detailing		7	8			Slow	Difficult	concerned	Annoy

Figure 4-5 The design diaries analysis (excerpt from P03)

The design diary could be analysed quantitatively, and/or qualitatively as the format was a combination of closed and open-ended structure (refer Chapter 3). However, the participant gave very limited responses to the open-ended entries; consequently the reported data analysis would be mainly presented in quantitative format. In-depth data probing through post-interview was not able to be undertaken as the participant had already completed her course, and could no longer be contacted.

The data provided was based on eleven CAD sessions recorded by the participant throughout the design project. Some of the data findings from the design diary were presented as follow:

a) CAD design related activity engaged

This item was intended to provide information types of CAD design related activity the participant had undertaken in each CAD session. The frequency of each activity involved in the design project was shown in Table 4-9.

Table 4-9: Frequency of design related CAD activity engaged by participant (P03)

Activity	Frequency
Ideation	1
Detailing	1
Basic form	1
Assembly	8
Part drawing	2
Working drawing	0

Figure 4-6 shows the percentage of CAD activity engaged in by the participant. The data clearly demonstrated that assembly was the most frequent activity embarked on by the participant when using CAD in the design project. The participant used CAD mostly for assembly tasks accounting for 61% of overall usage; followed by part drawing development at 15%. CAD was used evenly for design work which related to ideation, detailing, and creating basic form at 8% for each of them. However, there was no evidence of CAD being used for developing working drawings in this design project.

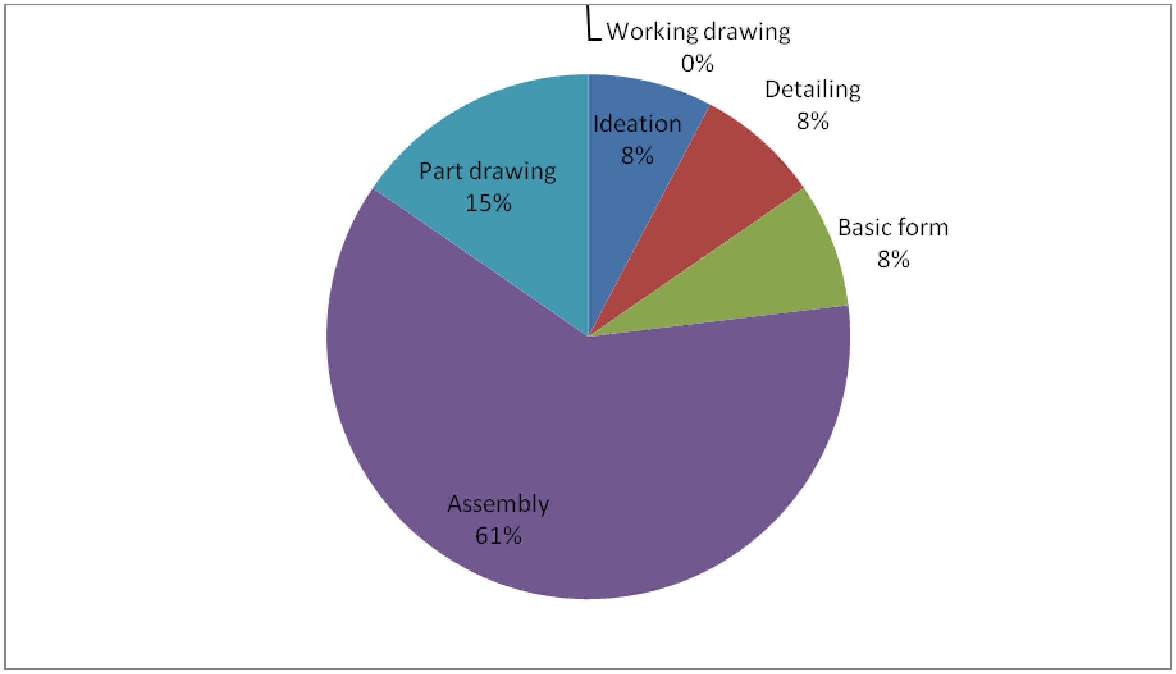


Figure 4-6: Percentage of design related CAD activity engaged in by participant (P03)

b) CAD activity description

This section attempted to encourage the participant to further describe the CAD activity in a structured way. Table 4-10 shows the frequency of CAD activity description which was executed by the participant in the project.

Table 4-10: Frequency of CAD activity described undertaken

CAD activity description	Frequency
Feature creation	1
Scale	2
Editing	5
Geometric Shape	3
Texture	3
Rendering	10
Assembly drawing	7
Fitting	3
Detailing	7
Dimension	2
FEA	0

Further analysis was carried out and the data were presented in percentages as shown in Figure 4-7. Rendering was recorded as the most frequent activity from all the CAD sessions involved with 23% of the overall activities recorded. This was followed by assembly drawing development (7%), and design detailing (7%). However, there was a small percentage of feature creation tasks involved with only 2%, but none at all for Finite Element Analysis (FEA).

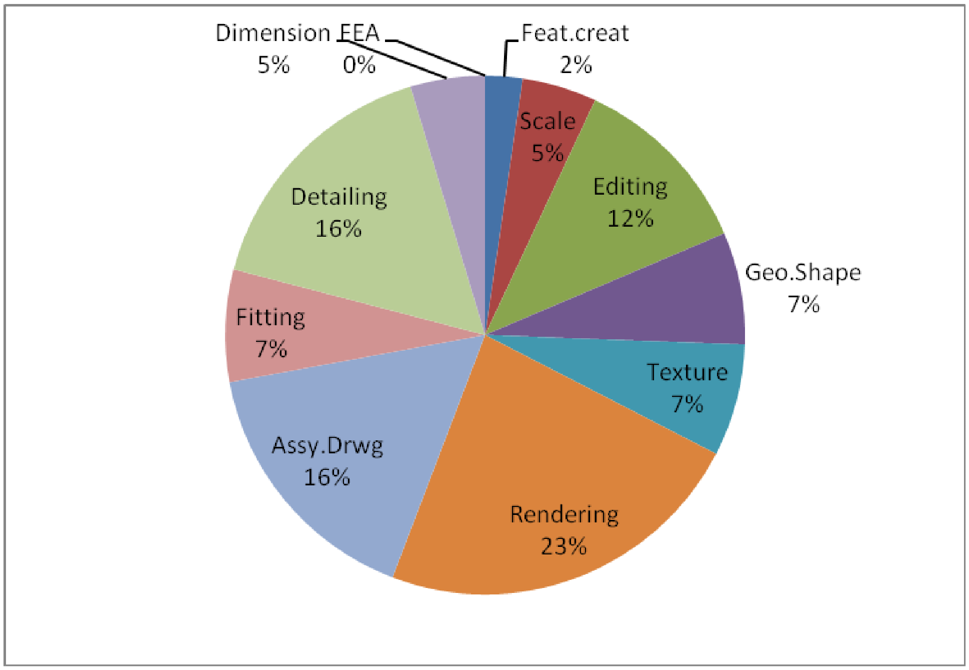


Figure 4-7: Percentage of types of CAD activity engaged in by participant (P03)

c) creative behaviours occurrences

In the design diaries method, the participant was encouraged to self observe and identify the creative behaviours based on descriptors listed in the sheet. The participant was also encouraged to record other descriptors of creative behaviour detected during the CAD sessions. The descriptors identified would then cluster under each group of creative behaviour. The findings were later tabulated as shown in Table 4-11. In total, 46 occurrences of creative behaviours were documented.

Table 4-11: The frequency of Creative Behaviours occurrences

Creative Behaviour	Frequency
Novelty	0
Appropriateness	11
Motivation	11
Fluency	5
Flexibility	2
Sensitivity	11
Insightfulness	6
Total	46

From Figure 4-8, it was indicated that appropriateness and motivation were equally the highest percentage of creative behaviours identified by the participant when using CAD. Then it was followed by sensitivity with 24% of occurrences. No occurrences of novelty and its descriptors were reported.

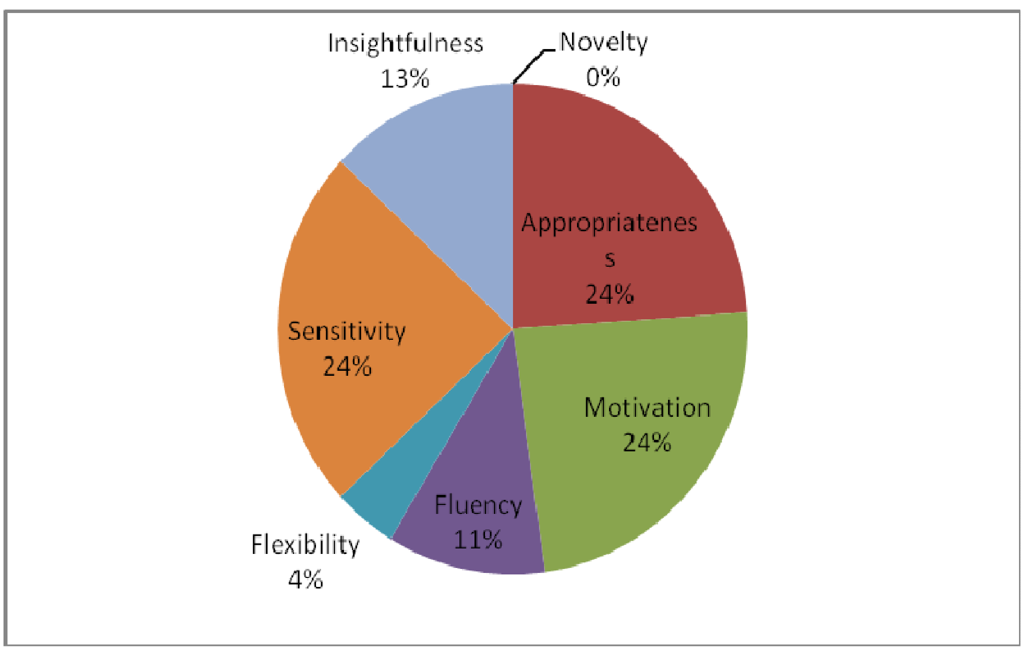


Figure 4-8: The percentage of Creative Behaviours occurrences

d) CAD usage reflection

At the end of each design diary page, the participant was required to give feedback about the CAD design session that had been carried out. The participant could provide her responses descriptively and by selecting the relevant options listed. The participant's feelings about the use of CAD in the design work can be presented by the percentages that shown in Figure 4-9.

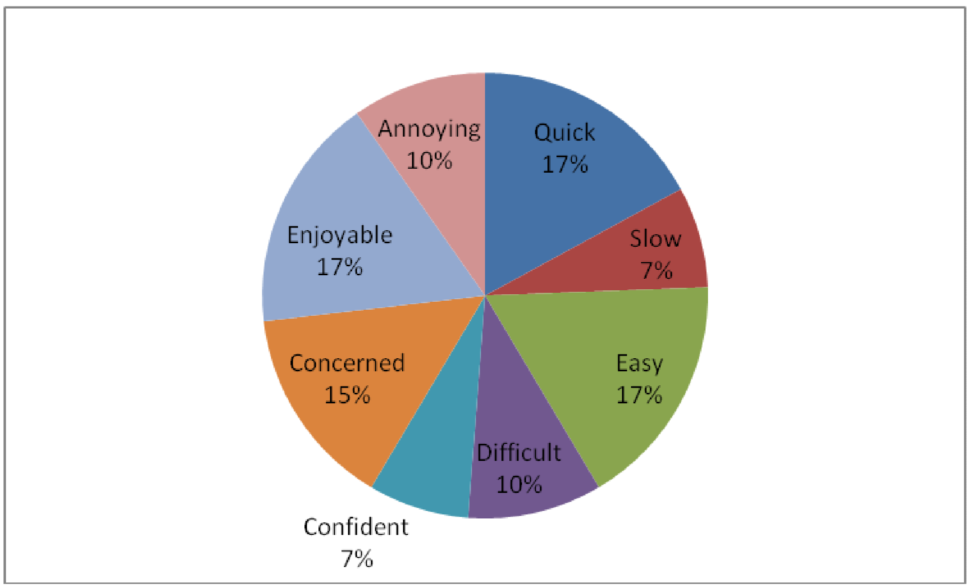


Figure 4-9: Participant's feedback of CAD usage in the design activity

The participant felt that CAD is a useful tool in facilitating her design work which is obviously demonstrated from the responses given. The findings show that CAD made the design work easy (17%), enjoyable (17%), and quick (17%). This is shown by her feedback in the reflection section such as 'very well in terms of speed & result' which referred to

CAD modelling for parts and developed basic shape. The participant also feels that the 'render' facility in CAD is helpful in making design decisions. On the other hand, the participant also displays her apprehension when using CAD as illustrated in Figure 4-10.

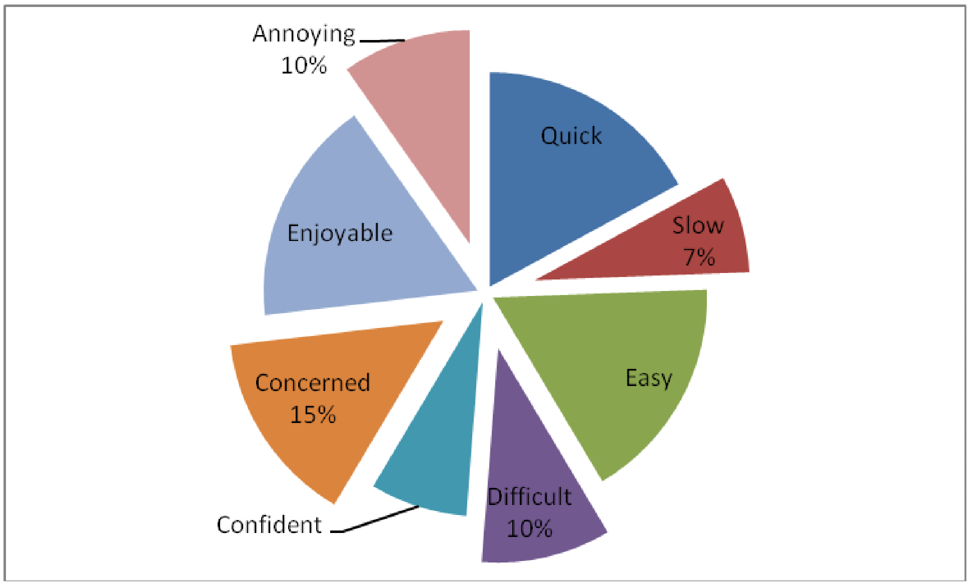


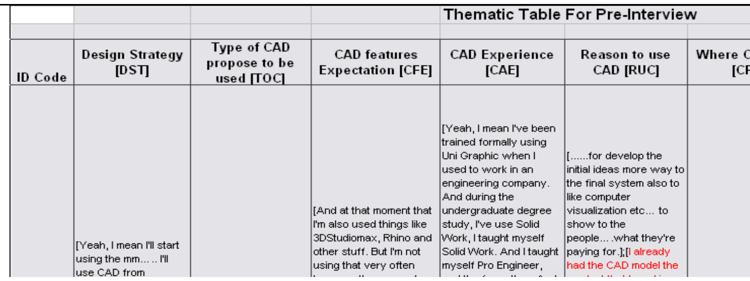
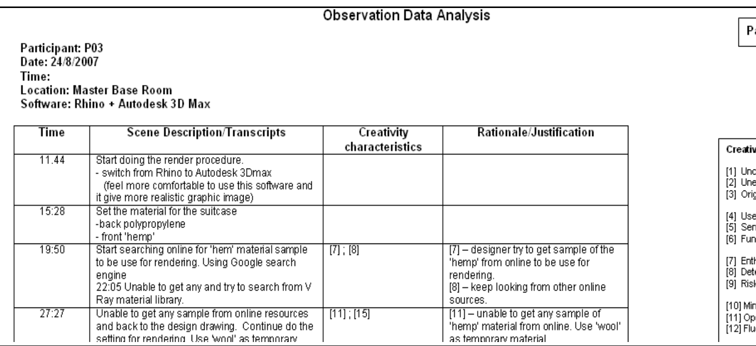
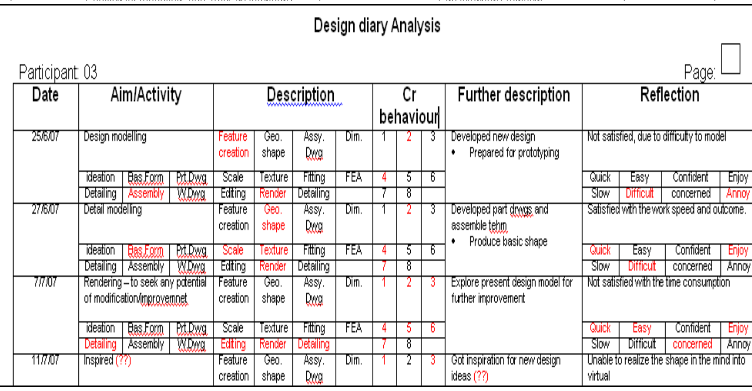
Figure 4-10: Participant's apprehension when using CAD in designing

.

4.5 Chapter Summary

This section reported the data analysis method and findings for Case study 1. Table 4-12 is a summary of data analysis methods executed in the case study.

Table 4-12: Data Analysis Methods Summary

Data collection method	Analysis method	Sample
Interviews	Transcribed, and grouped repeated ideas into coding themes.	
Protocol Analysis	Video clips were analysed and presented in PowerPoint format.	
Observations	CAD design activities were observed and video recorded. Video data were analysed to complement the direct observations analysis. (e.g: Paterson *et al*, *2003*)	
Design Diaries	Data were analysed by identifying the frequency for each creative behaviour responded by the participant.	

All the data findings acquired in the case study was presented in Table 4-13.

Table 4-13: Result data summary from Case study 1

Creative behaviours	Creative behaviours descriptors	Protocol Analysis	Video Observation	Direct Observation	Design Diaries	Total
Novelty	uncommon	0	0	0	0	**0**
	unexpected	0	0	0	0	**0**
	original	0	0	0	0	**0**
Appropriateness	useful	0	0	0	4	**4**
	sensible	23	8	6	0	**37**
	functional	1	0	0	7	**8**
Motivation	enthusiastic	1	2	3	3	**9**
	determined	3	7	8	6	**24**
	risk-taking	15	7	7	2	**31**
Fluency	spontaneity	0	0	0	0	**0**
	open to new ideas	2	3	2	2	**9**
	fluency of ideas	5	2	0	3	**10**
Flexibility	exploring possibilities	14	9	3	1	**27**
	continuous reflection	23	15	4	0	**42**
	associate remote ideas	0	1	0	1	**2**
Sensitivity	understand problem	3	3	0	3	**9**
	display curiosity	4	3	1	3	**11**
	seek perfection	18	18	10	5	**51**
Insightfulness	organizing information	10	4	1	2	**17**
	intuitive decision	0	3	0	0	**3**
	influence by inspiration	0	0	0	4	**4**
	Total	**122**	**85**	**45**	**46**	**298**

5 Chapter Five: Case Study Two – Personal Designing Exercise

5.1 Chapter Overview

This chapter reported the personal designing exercise executed by the researcher in an attempt to seek any link between creative behaviours and the product's creative characteristics. Similar methods were applied and any necessary improvement or changes made was also discussed. In addition, the Creative Behaviours Framework robustness was assessed by using it in identifying such behaviours in 2D sketching and 3D sketch modelling activities. The results were also presented in this chapter.

5.2 Aim and Objectives

This case study was initiated by the researcher as a consequence to the results findings in the initial study where the characteristic of novelty was unable to be identified. Understanding the complexity in studying the design process as discussed in the interim conclusion (refer Chapter Two), the researcher attempted to seek the link between creative behaviours to the product characteristics by going through the design process himself.

Subsequent to a key question arising from a conference presentation's feedback, the 2D sketching and 3D sketch modelling were also included in the data gathering activities. The rationale was to explore whether the creative behaviours characteristics observed in CAD activities could also identified in 2D sketching and 3D sketch modelling through the 'lens' of the Creative Behaviours Framework. Thus, the objectives of the case study were to:

- look for creative behaviours which linked to a products' creative characteristics,
- replicate selected methods used in the initial study for a reliability check,
- observe 2D sketching and 3D sketch modelling behaviours through the 'lens of the Creative Behaviours Framework'.
- compare the Creative Behaviours Framework with previous descriptions of 2D sketches and 3D sketch modelling identified from the literature review.

5.3 Personal Designing Exercise

The personal designing research was inspired from Pedgley's PhD practice led-research which reported on a case study of acoustic polymer guitar design. Pedgley (2007: 463) described practice-led research as 'a mode of enquiry in which design practice is used to create an evidence base for something demonstrated or found out'. In an attempt to explore CAD's relationship with creative behaviours and creative characteristics of a product recognised, this type of approach seemed plausible. By undertaking his own design exercise, the researcher would potentially discover the unstated knowledge in the designing process that is possibly difficult to apprehend by observing others' design acts. The practice led-research, according to Pedgley, allows researchers to 'elicit and communicate new knowledge and theory originating from their own design practices' (2007: 466).

Subsequent to a discussion with Prof. Eddie Norman, a design project related to developing an alternative music therapy instrument was considered. Music is a vital element in 'the therapeutic process and the music is the means of interaction through which the therapeutic relationship develops' (Norman, unpublished). An informal discussion was also arranged with Liz Norman, a professional music therapist (www.soundconnection.org.uk) to get a better understanding of any underlying issues in this area. A few issues were highlighted associated with the equipment and instruments available to music therapists (e.g. storage, transportation, set-up time consuming, multi-sensory). These aspects were considered in developing a conceptual design of the alternative music therapy instrument in this case study.

Similar data gathering approaches such as protocol analysis and design diaries were used. A pre-interview session was carried out to confirm themes that emerged in the prior case study findings and to suggest further improvement of this method where needed. In this session, Prof. Eddie Norman took the role of interviewer with the researcher as interviewee.

An adjustment to the method was made in terms of the way to record the CAD designing session where CAMTASIA, an on-screen video recording instrument was used. This would allow one-man operation of the data capturing process without the need for other person to carry out the video recording of the CAD session. The data gathering activities involved are shown in Table 5-1.

Table 5-1: Data gathering activities in Case study 2

Activity / **Method (Instrument)**	Pre-Design	2D Sketching	3D Sketch Modelling	CAD
Pre-interview	* (Audio recorder)			
Protocol analysis		* (Video recorder)	* (Video recorder)	* (On-screen video-CAMTASIA)
Design diaries				* (Design diary sheets)

In this study, the researcher has played the role of designer, and at the same time recording the data for the analysis. Protocol analysis was undertaken for a session of 2D sketching, 3D sketch modelling, and also CAD activity. Similar procedures were used to video record the 2D sketching, and 3D sketch modelling. The camera was aimed at the working area, and set for recording before the activities began.

Figure 5-1: 3D modelling by researcher

However, this is not the case for on-screen CAD recording, where the camera cannot automatically zoom in and zoom out to suit the computer screen view. Hence, CAMTASIA was used to accommodate this matter. The CAD session was on-screen recorded without verbalisation and was retrospectively transcribed to put the video in context, and for analysis purposes. Design diary entries were also filled in each time CAD was used to record the emergence of creative behaviours. The video data were analysed using Transana, a type of qualitative analysis software for video and audio data.

5.4 Results

Data findings were presented as follows.

5.4.1 Pre-Interviews

The audio recorded data was transcribed using Transana before being analysed (see Annex 7 for an example of the transcription). The analysis was based on the eight themes established from prior case study, while at the same time seeking other themes that might emerge. The findings are shown as follow:

a) DST – design strategy anticipated

'...maybe I'll start a little bit using sketching'

' And maybe, I'll keep going back and forth between sketch and CAD.'

b) TOC – type of CAD proposed to be used

'Basically in this stage I'm going to use ProE but for example during the process of designing if I find out that I need other type of software so I might consider to use them. But, in this stage I'm going to use ... predominantly ProE'

c) CFE – CAD feature expectation

'ProE, because this is 3D designing software, maybe it…I believe that it is much easier for me to visualize and to see how it looks whether ... it suits …my intention'

d) CAE – Participants' CAD experience

'...for ProE I don't have any formal training. But previously I've used AutoCAD and basically …the nature of the software is the same. But,

although, in term of the features is quite different, but I think I can manage in using ProE.'

e) RUC – reason to use CAD

'Basically, I hope that by using the software I could easily or could visualize much easier the part of the design that I'm trying to establish and which is some time is quite difficult to visualize when you do it in 2D form.'

'.....I hope I could established the 3D graphical model which is I hope it is as realistic as I can because it is very important in terms of ... whether it is reliable or not for production later on.'

'...and one other thing is in terms of aesthetic value'

'I'm trying to use more CAD in terms ....of evaluating or analyzing the design.'

f) CFT – where CAD fits

'...the beginning of the design process which is I don't have any structured ideas ... what it is the form ... the shape ... what is the type of product I'm going to design. So, maybe I'll start a little bit using sketching but when I seen…. I could visualize the form even if it is semi structured, so I'll try to use CAD for the evaluation. And maybe, I'll keep go back and forth between sketch and CAD'

g) ODT – other design tools planning to use

'I think it depends on … what type of product that …I'm going to design'

'…from blue foam, clay, and so on'

h) RUO – reason to use other

'….if for example, in certain circumstances that I need to develop 3D modelling which is from blue foam, clay, and so on. So I'm going to use that type of modelling technique.'

5.4.2 Protocol Analysis – 2D Sketching

In the early stage of the design process, the researcher used sketching in the seeking and exploration of initial ideas. Figure 5-2 shows the sketching session that was video recorded for data capture process.

Figure 5-2: Sketching activity by the researcher

The video file was then embedded into the Transana database for transcribing. The software has features that enable audio and video data to be transcribed concurrently while observing and/or listening the recording as shown in Figure 5-3.

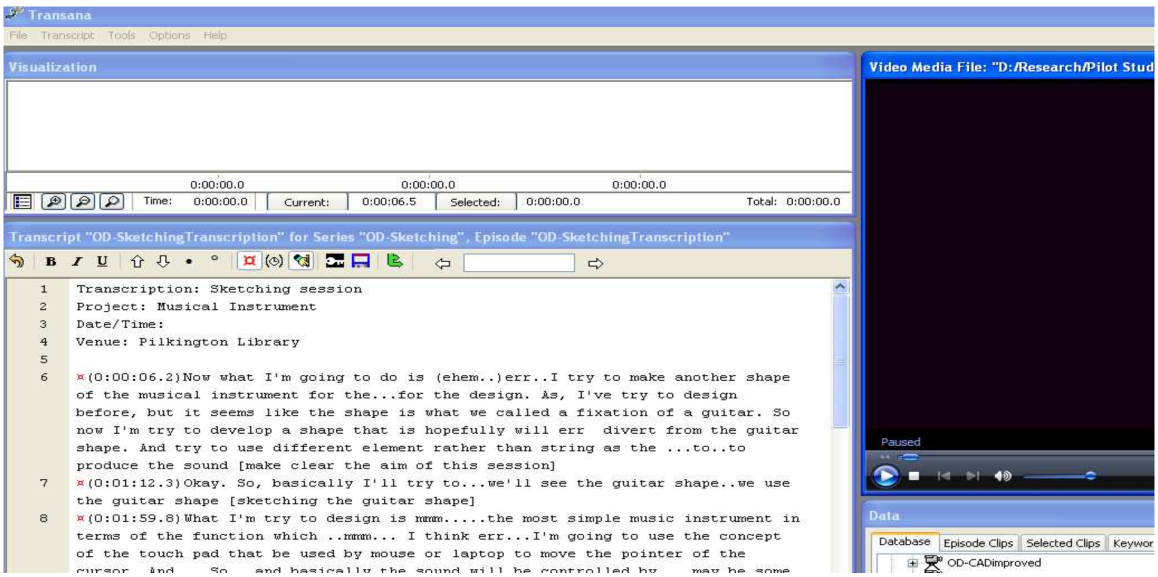


Figure 5-3: Transcribing in Transana Software

Time codes can be put into the text of the transcript that can be very useful for synchronizing a transcript with the audio and video especially with a longer recording. This is very useful in facilitating the data analysis and links findings with the exact time these occurred in the video clips. An example of the transcription is shown in Figure 5-4.

Transcription: Sketching session
Project: Musical Instrument
Date/Time:3/9/2008
Venue: Pilkington Library

¤<6240> (0:00:06.2) Now what I'm going to do is (ehem..) err..I try to make another shape of the musical instrument for the...for the design. As, I've try to design before, but it seems like the shape is what we called a fixation of a guitar. So now I'm trying to develop a shape that is hopefully will err…. divert from the guitar shape. And try to use different element rather than string as the ...to…to produce the sound [making clear the aim of this session]

Figure 5-4: 2D Sketching video session transcriptions (excerpt from R01-Personal Designing Exercise

Apart from the Transana software introduced as the analysis tool, the researcher used a similar approach to that embarked on during the initial study (Case study 1). The video data were analysed to identify 2D sketching behaviours previously identified in the literature review (see Chapter Two), and later observed through the 'lens' of the Creative Behaviours Framework using the descriptors' indicator.

The examples of behaviours identified from the 2D sketching data analysis are displayed in Table 5-3. From the act exhibited, the researcher tried to capture the significant events in the 2D sketching behaviours' description. When any particular behaviour was observed, the category and its description were recorded. The transcription was also referred to seek possible texts that might provide further support of the finding. In the example, the subject was observed from the video clip to initiate idea generation by taking a guitar concept and shape as the initial design shape to start the exploration. The subject was interpreted to display experimental behaviour where he was involved in the process of concept generation.

Table 5-3: Example of behaviours identified excerpt from the 2D Sketching data analysis.

Time (Start~End)	2D Sketching Behaviours (description)	Observation	Verbalisation (Text)
(0:02:00.5) ~ (0:03:51.8)	Experimental • Concept generation	Initiating the thinking with guitar shape	*'Okay. So, basically I'll try to[develop]...we'll see the guitar shape…we use the guitar shape[as the starting point]' [sketching the guitar shape]*
	Restructuring • Subtraction, • Embedding in other components	• take out the headstock from the original sketching • adopt in the 'touch-pad' concept on laptop to this instrument	*'So now I'm try to develop a shape that is hopefully will err… divert from the guitar shape'* *'I think err...I'm going to use the concept of the touch pad that be used by mouse or laptop'*

In the analysis, eight behaviours have been identified from the 2D sketching session as shown in Table 5-4.

Table 5-4: 2D sketching behaviours identified in the sketching session in the personal designing exercise

2D Sketching Behaviours	Occurrences
Restructuring	2
Vertical Transformation	3
Reflective	2
Experimental	1
Total	**8**

Subsequent to the 2D sketching behaviours analysis, the same events were later re-analysed using the Creative Behaviours Framework. A similar analysis approach was undertaken and the example of the data analysis findings is shown in Table 5-5.

Table 5-5: Example of Creative Behaviours identified excerpt from the 2D sketching data analysis

Time (Start~End)	Creative Behaviours (descriptor)	Observation	Verbalisation (Text)
(0:02:00.5) ~ (0:03:51.8)	Novelty • Uncommon	using touch pad is uncommon in knowledge of designer	*'It will have the concept like a guitar but the difference is, it's not going to use any string...it's not going to use any string but it's going to be using the touchpad'*
	Flexibility • Assoc. Remote Ideas	use the [concept of] touch pad on computer to this instrument	*'I'm going to use the concept of the touch pad that be used by mouse or laptop to move the pointer of the cursor....and basically the sound will be controlled by... may be some sort of the button and you just have to scratched or to move your hand around this surface'*

The analysis has identified seven creative behaviours descriptors as shown in Table 5-6. These findings indicated that three creative behaviours were recognized including appropriateness, flexibility, and insightfulness. The flexibility behaviours were the most frequent.

Table 5-6: Creative Behaviours identified in the 3D sketch modelling session in the personal designing exercise

Creative Behaviours	Creative Behaviours Descriptor	Occurrences
Novelty	uncommon	1
Appropriateness	sensible	1
Flexibility	exploring possibilities	2
	continuous reflection	2
	associate remote ideas	1
Insightfulness	organizing information	1
	Total	8

5.4.3 Protocol Analysis – 3D Sketch Modelling

Similar data capture and data analysis were undertaken on the 3D modelling engaged in by the researcher. In the initial stage of developing the shape of the musical instrument, plasticine, a clay type modelling material has was used. The session was the early stage of designing to generate possible musical instrument shapes that could be ergonomically held by the user. Plasticine was used because of its characteristics which are moldable and flexible in forming shapes.

Subsequent to the video transcribing, the analysis was undertaken to observe the 3D sketch modelling activity in an attempt to identify any significant behaviour as listed and discussed in the literature review chapter. The example of the 3D sketch modelling behaviours that were identified in the session is shown in Table 5-7.

Table 5-7: Example of behaviours identified from the excerpt of the 3D sketch modelling data analysis

Time (Start~End)	**3D Sketch Modelling Behaviours (description)**	**Observation**	**Verbalisation (Text)**
(0:05:58.1) ~ (0:06:15.1)	SOT • Feel • See	demo the 'instrument'/incomplete model and try to see and feel when holding it	*I need to get some idea..to err..to start create the shape that..err tht going to be comfortably..and practically you know..err..for the user.*
(0:09:52.3) ~ (0:10:27.6)	CMAI • con't improvement	trying to make the shape feel and look better	*'I just need to make it a little bit nice.'*

Seven 3D sketch modelling behaviours were identified as shown in Table 5-8 from the 'Continuous modifications and improvements' and the 'Sense of Touch'. However, none from the 'Adding and subtracting act' behaviour were observed.

Table 5-8: 3D sketch modelling behaviours identified in the physical modelling session

3D Sketch Modelling Behaviours	**Occurrences**
Adding and Substracting Act (ADSA)	0
Continuous Modifications and Improvements (CMAI)	3
Sense of Touch (SOT)	4
Total	7

The video data was then re-analysed to observe and identify any creative behaviours that emerged during the 3D sketch modelling activity. Table 5-9 presents an example of such findings.

Table 5-9: Example of Creative Behaviours identified excerpt from the 3D sketch modelling data analysis

<table>
<tr><th>Time
(Start~End)</th><th>Creative Behaviours
(descriptor)</th><th>Observation</th><th>Verbalisation
(Text)</th></tr>
<tr><td rowspan="2">(0:05:58.1)
~
(0:06:15.1)</td><td>Appropriate
• Useful</td><td>demo the 'instrument'/incomplete model and try to see and feel when holding it</td><td>'..the instrument should be err..comfortably hold and at the same time we can err..scratch to..to what...to make the sounding'</td></tr>
<tr><td>Flexibility
• Con't reflection</td><td>-as above-</td><td>'... it should have some sort like a..a slope or something to...so it can easily err....hold'</td></tr>
<tr><td>(0:09:52.3)
~
(0:10:27.6)</td><td>Sensitivity
• Seek perfection</td><td>trying to make the shape feel and look better</td><td>'A little bit more [curve]..because it's quite difficult ..err..if you can't see it..you can't feel it.'</td></tr>
</table>

In total, fifteen occurrences of descriptors were recorded and these indicated the emergence of six creative behaviours in the 3D sketch modelling session as shown in Table 5-10.

Table 5-10: Creative Behaviours identified in the 3D sketch modelling session in the personal designing exercise

Creative Behaviours	**Creative Behaviours Descriptor**	**3D Sketch Modelling**
Appropriateness	sensible	1
	functional	1
Motivation	enthusiastic	2
	determined	3
Fluency	fluency of ideas	1
Flexibility	continuous reflection	3
Sensitivity	seek perfection	3
Insightfulness	influence by inspiration	1
	Total	**15**

5.5 Relative Findings Analysis Betweens 2D Sketching and 3D Sketch Modelling With Creative Behaviours Framework

In this section, the researcher attempted to explore possible relationships between behaviours identified through 2D sketching and 3D sketch modelling with those that recognized when using the Creative Behaviours Framework. The links would hopefully provide substantial evidence that the Creative Behaviours Framework is capable and efficient in identifying creative behaviours in design activity. As a consequence, the findings from the CAD observations hopefully could be associated with creativity as the 2D sketching and 3D sketch modelling are widely accepted as a creative tool.

Data obtained from the 2D sketching behaviours framework and Creative Behaviours Framework were re-analysed to seek any relationship between them. The analysis shows that at least a number of behaviours from both frameworks exhibit links between them. The examples of the data can be seen in Table 5-11.

Table 5-11: Observed behaviours relationship between 2D sketching and Creative Behaviours Framework

Start End time (Hrs:mins:secs)	**2D Sketching Behaviours framework**	**Creative Behaviours Framework**
(0:02:00.5) ~ (0:03:51.8)	Restructuring (Embedding in other components) #adopt in the 'touch-pad' concept on laptop to this instrument	Flexibility (Assoc. Remote Ideas) #use the touch pad on computer to this instrument
(0:09:00.3) ~ (0:11:04.2)	VT (refined version) #the shape slightly change;	Exploring possibilities #playing around with the existing ideas

Similar attempts were undertaken between 3D sketching behaviours and Creative Behaviours. The same trend of findings was shown as displayed in Table 5-12.

Table 5-12: Observed behaviours relationship between 3D sketch and Creative Behaviours Framework

Start from End time (Hrs:mins:secs)	**3D Sketch Modelling Behaviours framework**	**Creative Behaviours Framework**
(0:04:59.7) ~ (0:05:41.7)	Sense Of Touch (making form) #suggesting the shape based on the way probably user will hold the instrument	Fluency (spontaneity) #no particular sketches or model
(0:05:58.1) ~ (0:06:15.1)	Sense Of Touch (feel; see) #demo the 'instrument'/incomplete model and try to see and feel when holding it	Appropriate (Useful) # need some sort of curve surfaces in order the instrument to be able hold or comfortable grip by user whilst playing the instrument
		Flexibility (Con't reflection) #see and feel the bottom shape

5.5.1 Protocol Analysis – CAD

It is also the interest of the researcher from this personal designing exercise to check the reliability of the data collection approach in capturing any creative behaviours emerging whilst CAD use in designing. A CAD session by the researcher (Figure 5-5) was on-screen recorded using CAMTASIA.

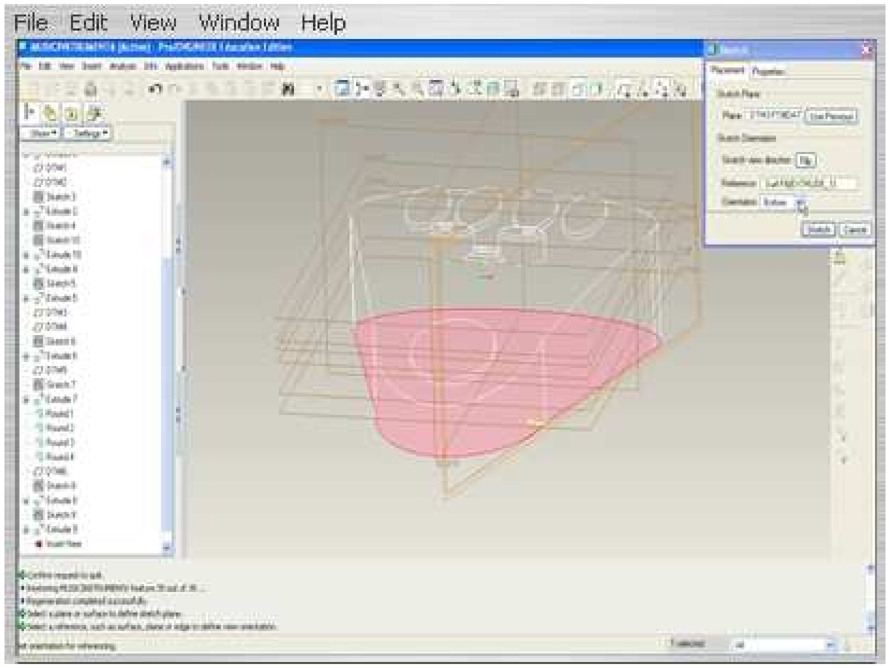


Figure 5-5: A CAD activity session

Subsequently, a video transcription was established to explain the video content prior to the analysis as shown in Figure 5-6.

#This is not a verbal transcriptions of CAD design as when the event take place, I was in the research room ZZ006 Matthew Arnold Building. Besides, myself, there were others individual from the Commercialization studio staff as verbalisation will disturbed others#

#In this event, I was tried to develop feature buttons for volume control and power switch for the musical instrument#

¤<0>(0:00:00.0)I continue my previous work to develop the features button for the musical instrument.

¤<83624>(0:01:23.6)I tried to create curve surface for the button using Extrusion/protrusion feature. ¤<92759>(0:01:32.8)I sketch the the curve line to get the curve surface. ¤<103583>(0:01:43.6)Through the extrusion 'simulation', I could view and assessed the possible subsequent outcome. ¤<150364>(0:02:30.4) I think I need to 'verify' the output if I proceed with the action ¤<151839>(0:02:31.8)and review the model to see how it's look like. ¤<161824>(0:02:41.8)I feel it's okay and decided to confirm the action.

Establishing 'High' and 'Low' symbol:

¤<236603>(0:03:56.6)Now, I intend to established the 'High' and 'Low' volume symbol

Figure 5-6: CAD activity video transcription excerpt

The video transcription was a substitute approach to the concurrent verbalisation that was unable to be executed because the session was undertaken in a shared working space. The researcher felt uncomfortable verbalising his CAD act in this situation as this might disturb others who were also in the room at that time.

The video data and the video transcription were analysed and some of the examples of the findings are shown in Table 5-13.

Table 5-13: Example of Creative Behaviours identified excerpt from a CAD activity data analysis

<table>
<tr><th>Time
(Start~End)</th><th>Creative Behaviours
(descriptor)</th><th>Video Transcription (Text)</th></tr>
<tr><td rowspan="4">(0:11:02.3)
~
(0:12:14.9)</td><td>Flexibility
(Con't reflection)</td><td>'From the model tree-track back the development of LED light bulb. To see whether any modification can be done to the heights and if it will make it look nicer'</td></tr>
<tr><td>Sensitivity
(Seek perfection)</td><td>'I modified the height of the object, might change the height of the LED light bulbs and make the appearance much better'</td></tr>
<tr><td>Risk Taking</td><td>'Just make assumption of the suitable height. Have a-go, why not.</td></tr>
<tr><td>Determined</td><td>'I still can make further changes if needed.'</td></tr>
</table>

From the analysis, twenty nine descriptor occurrences were captured which indicated the emergence of six creative behaviours as shown in Table 5-14. None of descriptors identified had any link with novelty behaviour.

Table 5-14: Creative Behaviours identified in a CAD activity in Personal Designing Exercise

Creative Behaviours	Creative Behaviours Descriptor	CAD
Novelty		0
Appropriateness	sensible	2
Motivation	determined	3
	risk-taking	4
Fluency	Spontaneity	3
Flexibility	exploring possibilities	4
	continuous reflection	7
Sensitivity	seek perfection	4
Insightfulness	intuitive decision	1
	influence by inspiration	1
	Total	**29**

5.5.2 Design Diaries

As in the prior case study, the researcher was also completing the design diary sheet every time he engaged in CAD activity. By filling in the diaries himself, the researcher would acquire a better understanding of how this method could provide significant information on the design project, especially when related to CAD usage. The researcher could also use this opportunity to identify any problems with the design diary format and make necessary improvements for the next case study.

The data provided was based on thirteen CAD sessions recorded throughout the design project. Some of the data findings from the design diaries are presented as follows:

a) CAD design related activity engaged

This item was intended to provide information of CAD design related activity undertaken by the participant in each CAD session. The frequency of each activity involved in the design project is shown in Table 5-15.

Table 5-15: Frequency of design related CAD activity engaged in by the researcher

Activity	Frequency
Ideation	9
Detailing	4
Basic form	11
Assembly	0
Part drawing	0
Working drawing	0

Figure 5-7 shows the percentage of CAD activity engaged in by the participant. The data clearly demonstrated that basic form was the most frequent activity embarked on by the researcher when using CAD in the design project. CAD was mostly used for basic form in 46% of the overall usage, followed by ideation, 37%, and for design detailing, 17%. However, there was no record of CAD being used for developing working drawing, part drawing, and assembly in this design project. This was due to the design activities were involved until to a conceptual design of the music instrument in the form of 3D CAD image. Hence, those activities were not involved in this particular design project.

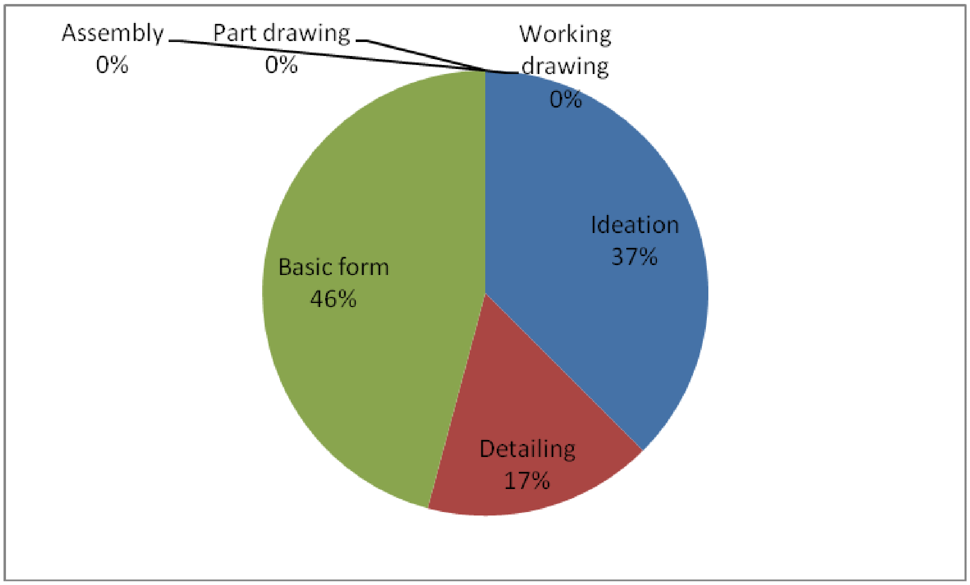


Figure 5-7: Percentage of design related CAD activity engaged in by participant (P03)

b) CAD activity description

In this section, there were some changes and additional activity descriptions to provide more specific selection to the designer. This is shown in Table 5-16.

Table 5-16: Altered and added description of activity in the design diary

Originally	Altered to	Added
Detailing	Elaborating	-
Fitting	Assembly & Fit	-
-	-	Simulation/Test

Table 5-17 shows the frequency of CAD activity descriptions which were executed by the researcher in the project.

Table 5-17: Frequency of CAD activity undertaken

CAD activity description	Frequency
Feature creation	9
Geometric Shape	2
Scale	0
Editing	2
Dimensioning	0
Texture	0
Rendering	1
Elaborating	2
Assembly & Fit	0
Assembly drawing	0
FEA	0
Simulation/Test	0

Further analysis was carried out and the data were presented as percentages as shown in Figure 5-8. Feature creation was recorded as the most frequent activity engaged in from all the CAD sessions involved, which cover 23% of the overall activities recorded. This was followed by editing (13%) and elaborating (13%). The data also showed that 13% of CAD activity was used by the researcher to develop geometric shapes in the design process and 6% for rendering the final design product.

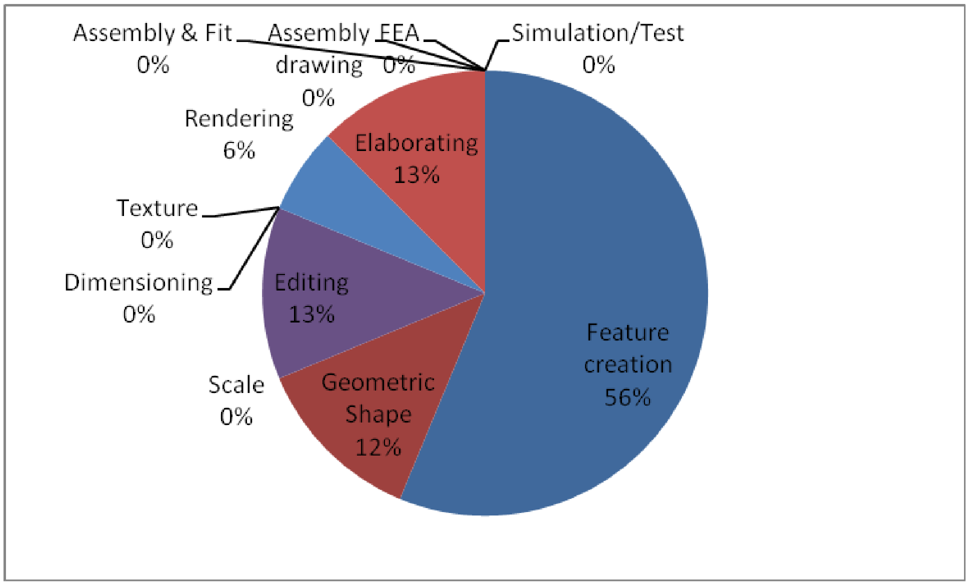


Figure 5-8: Percentage of types of CAD activity engaged in by the researcher

c) Creative Behaviours occurrences

This section presents the creative behaviours recorded by the researcher. The findings are tabulated as shown in Table 5-18. In total, 46 occurrences of creative behaviours were documented in the diaries.

Table 5-18: The frequency of Creative Behaviours occurrences

Creative Behaviours	**Frequency**
Novelty	2
Appropriateness	2
Motivation	19
Fluency	8
Flexibility	12
Sensitivity	1
Insightfulness	2
Total	46

From Figure 5-9, it was indicated that motivation (41%) was the highest percentage of creative behaviours identified by the researcher when using CAD. This was followed by flexibility with 26% and fluency with 18% of occurrences. Interestingly, there was 5% of novelty which had not been distinguished in the prior case study.

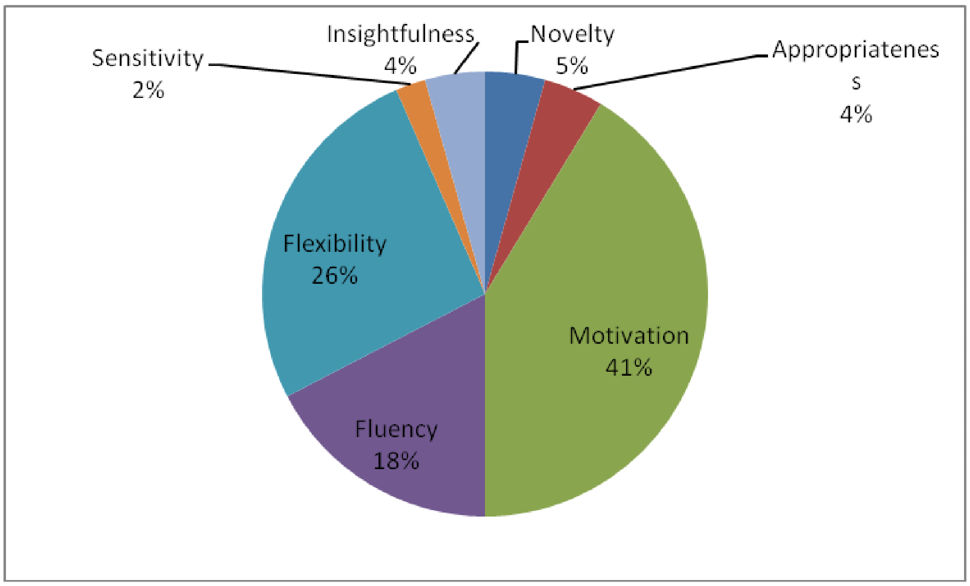


Figure 5-9: The percentage of Creative Behaviours occurrences

The researcher has distinguished the emergence of the novelty behaviour in two of CAD sessions as follow:

- Unexpected musical instrument form

  '*suggest unexpected form-elaboration from sketching*' (28th November 2008 diary entry) as shown in Figure 5-10.

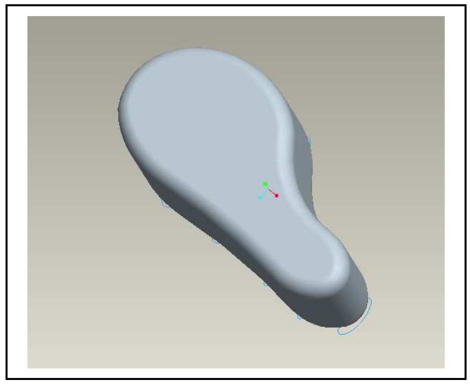


Figure 5-10: Unexpected basic form in a CAD session

- Unexpected '*speaker holes pattern'* (1st December 2008 diary entry) as shown in Figure 5-11.

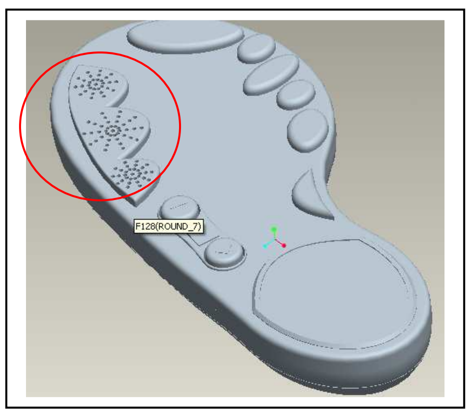


Figure 5-11: Speaker holes pattern (first design edition)

d) CAD usage reflection

At the end of the design diary sheets, the researcher provided reflection about his feelings in using the CAD for the particular session. The researcher's feedback presented as percentages is shown in Figure 5-12.

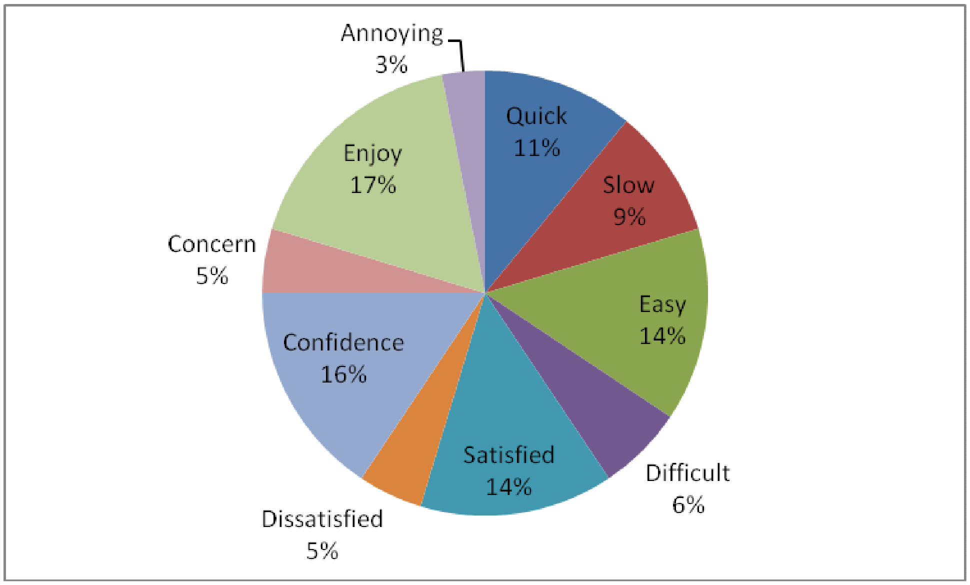


Figure 5-12: Participant's feedback of the CAD usage in the design activity

The findings demonstrated higher percentages to the positive aspects (enjoy, confidence, satisfied, easy, and quick) compared to the negative aspects (annoying, concern, dissatisfied, difficult, and slow). Overall, the researcher's reflections were almost consistent with the feedback from P03, a participant from Case study 1. Both findings demonstrated higher percentages in these items: enjoy, quick, and easy.

5.6 Seeking Possible Links between Creative Product Characteristics and Creative Behaviours

One of the case study objectives was to establish possible links between the use of CAD and the emergence of product's creative characteristics. This was attempted by seeking respondents' feedback (e.g. music therapist, industrial designer, and engineer) based on a conceptual product design in the form of a 3D CAD image as shown in Figure 5-13.

Figure 5-13: 3D CAD image of the music instrument design

Colours and materials were added for rendering purposes. The rendering process was undertaken using ALIAS Image Studio software and one of the images was chosen to be used in the product descriptions sheet as shown in Figure 5.14.

Figure 5-14: 3D CAD image rendered using ALIAS Image Studio

Four respondents had agreed to give feedback and sent back their responses. Each respondent was given a set of product description and feedback form to be filled (see Appendix 2 – Example of a respondent feedback). The product description consists of written information and images about the product as shown in Figure 5-15.

Figure 5-15: Product design description

Based on their own perspective, each respondent was required to highlight any innovative aspect of the design concept presented. The responses were filled in on the feedback form attached as shown in Figure 5-16.

Feedback form

It would be most appreciated if you could give some feedback about this product conceptual design:

1) Are any aspects of the design innovative in your view?

2) If so which aspect(s)?

Thank you for your response, comments, and suggestions.

Best regards,

Aede H Musta'amal
Research Student
Design & Technology Department
Loughborough University
edahm@lboro.ac.uk

Figure 5-16: Feedback form

In identifying the creative characteristics of the product design, the researcher not only based this on respondents' feedback but also suggested his own criteria. From the feedback, the researcher searched for evidence that could provide links between the use of CAD and the product's creative aspects. Three of the creative aspects had been found to have such links as shown in Table 5-19. Subsequently, from the diaries' entries, all the creative behaviours which were identified and reported in the related sessions were established.

Table 5-19: Creative characteristics of product and its link with the Creative Behaviours

Product's creative characteristic	**Link to CAD activity**	**Creative Behaviours reported**
#'Interchangeable function for left and right handed person' (R00) #'The left and right handed button is also innovative' (R03)	**Design diary entry**: *#15/12/08-'Create 'L' and 'R' musical instrument function'* *'Straight away sketch and extrude the form ideation . See the visual and try a few other forms'*	Motivation Fluency Flexibility Insightfulness
#.'…creating a handheld device as a music therapy is quite innovative (assuming that creating music at any time is indeed providing therapeutic effect)' (R02) #'an alternative methods given to provide better hand held music instrument design to be chosen here' (R03)	**Design diary entry:** 1#14/10/08- *Musical instrument shape* *'exploring possible form for the musical instrument. Try to get new shape'* *Reflection: 'Basically, I've manage to develop the initial shape. Whether it's going to be sensible or not, we'll see.'*	Appropriateness Motivation Fluency Flexibility Insightfulness
	Design diary entry: 2#1/12/08- *Developing new shape for the music instrument* *Try to create a new form of musical instrument shape . Make some attempt with sketching and extrusion/protrusion to have some visualization.* *Reflection: 'At last! I 'have a go' to a shape for further development'*	Motivation Fluency Flexibility
#'People used to play piano, the idea keep the linking'(R04)	**Design diary entry:** *#2/12/08-Look into more detail to the 'touch pad' and button*	Fluency Flexibility Motivation

Notes: R – respondent

5.7 Chapter Summary

This chapter was mainly reporting Case study 2, a personal designing exercise conducted by the researcher himself. The findings have been presented in a similar format as the initial study to provide better understanding that the selected methods undertaken were reliable for this research.

Based on the data presented, it can be seen that the Creative Behaviours Framework can feasibly be used to observe and identify creative behaviours not only in CAD activities but also in other design approaches particularly in 2D sketching, and 3D sketch modelling (e.g. plasticine modelling). The summary of the results is shown in Table 5-20. In total, 97 creative behaviour descriptors were identified in this case study, and 75 occurrences were captured in CAD activities.

Table 5-20: Results summary from Creative Behaviours Framework analysis

Creative Behaviours	**Creative Behaviours Descriptor**	**2D Sketching**	**3D Sketch modelling**	**CAD**		**Total**
				Protocol	**Design Diaries**	
Novelty	uncommon	0	0	0	0	0
	unexpected	0	0	0	2	2
	original	0	0	0	0	0
Appropriateness	useful	0	0	0	1	1
	sensible	1	1	2	1	5
	functional	0	1	0	0	1
Motivation	enthusiastic	0	2	0	4	6
	determined	0	3	3	8	14
	risk-taking	0	0	4	7	11
Fluency	Spontaneity	0	0	3	3	6
	open to new ideas	0	0	0	5	5
	fluency of ideas	0	1	0	0	1
Flexibility	exploring possibilities	2	0	4	8	14
	continuous reflection	2	3	0	4	16
	associate remote ideas	1	0	0	0	1
Sensitivity	understand problem	0	0	0	0	0
	display curiosity	0	0	0	0	0
	seek perfection	0	3	4	1	8
Insightfulness	organizing information	1	0	0	0	1
	intuitive decision	0	0	1	2	3
	influence by inspiration	0	1	1	0	2
	Total	**7**	**15**	**29**	**46**	**97**

Comparative analysis to seek association between behaviours identified through 2D sketching and 3D sketch modelling frameworks with the Creative Behaviours Framework were also presented.

This chapter also reported the attempt to establish the link between creative behaviours and the product's creative characteristics. In summary, the steps and the links can be displayed as shown in Figure 5-17.

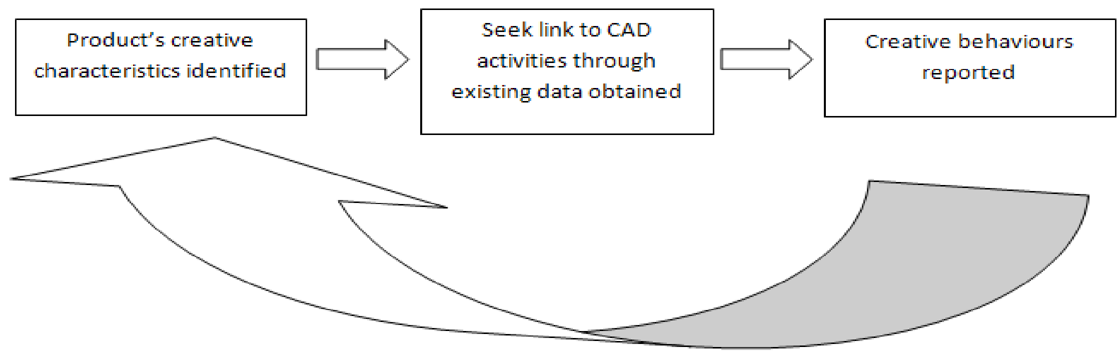


Figure 5-17: Linking creative behaviours and the products' creative characteristics

6 Chapter Six: Case Study Three – Undergraduate Finalist Design Projects

6.1 Chapter Overview

This chapter reports the case study with undergraduate finalists who were undertaking their final year design project. The finalised methods that were applied in Case studies 1 and two were replicated in this study and the findings are presented.

6.2 Aim and objectives

This case study was undertaken to provide evidence of the reliability and validity of methods used in the study. The research methods are reported and data findings are also presented. Further attempts to discover possible associations between creative behaviours observed when using CAD and the creative characteristics of the design outputs were also executed.

6.3 Undergraduate Finalists Design Projects

In this case study, three final year undergraduate students gave their consent to be the research participants. They were assigned alphanumeric pseudonyms (e.g. MP01 for Main Participant 01). However, only two participants remained involved until the completion of their design projects. These two undergraduate participants were undertaking projects related to a self-administered vaccination pack for people in remote areas and a new concept for a musical instrument. The project information is shown in Table 6-1.

Table 6-1: Participants' project information

Participant	Project
MP01	'Self administered vaccination pack'
MP02	'Heart rate monitor'
MP03	'Alternative music instrument'

The data collection activities included interviews, protocol analysis, and design diaries. The details are shown in Table 6-2.

Table 6-2: Data gathering activities

Data collection method	Activity	Equipment/tool
Interviews	Pre-design; post-design	Digital audio recorder
Protocol analysis	2D sketching; 3D sketch modelling	Digital Video Recorder
	CAD	Digital video recorder and CAMTASIA on-screen video recorder
Design diaries	CAD	Design diaries sheets

In this study, protocol analysis was undertaken to gather data when participants were engaged with 2D sketching, 3D sketch modelling, and CAD activities. After pre-arranging the design activities to be video recorded, the researcher arranged the venue for sessions to take place. Participants were requested and reminded to undertake the designing activities for about 20 minutes. During the designing tasks, participants were encouraged to keep verbalising their thoughts and actions concurrently. The researcher would prompt a question every time participants were silent, to encourage them to keep verbalising. However these give concerns to some researchers as an obtrusive approach, and might provide inaccurate interpretation of events.

Consequently, in order to provide multiple sources of data, participants were requested to produce their own CAD video recording without the researcher present. Accordingly, each participant was provided with CAMTASIA on-screen video recording software with a user license to be installed in their own computer. Participants were requested to at least produce a video recording of their own CAD activity using the software. Both participants were unable to provide concurrent verbalization whilst recording the CAD activities, and consequently the researcher required them to undertake retrospective verbalisation or interview to clarify the video events. MP01 preferred to undertake retrospective interview, while MP03 provided an audio verbalisation of the on-screen recorded video. Participants were also provided with design diary sheets and required to fill in the diary entries at the end of their CAD sessions.

6.4 Results

This section will present data findings from the case study.

6.4.1 Pre-interview

Three pre-interviews were undertaken and audio recorded for analysis. The analysis was based on eight codes established from the Case study 1 initial findings. The emergence of new themes would be included and assigned under new codes. From the analysis, two new codes (CDB – CAD drawback, and RCD – reason for CAD drawback) were assigned in addition to the prior eight codes as shown in Table 6-3.

Table 6-3: Pre-interviews thematic codes

Abreviation	Referring to
DST	design strategy anticipated
TOC	type of CAD proposed to be used
CFE	CAD feature expectation
CAE	Participants' CAD experience
RUC	reason to use CAD
CFT	where CAD fits
ODT	other design tools planning to use
RUO	reason to use other tools
CDB	CAD drawback
RCD	Reason for CAD drawback

Examples of participants' quotation based on the thematic codes are as follow:

a) DST – design strategy anticipated

'*So usually at that point [photoshop] just as an extension of the sketch I've done....then I use ProEngineer as...an extension ... confirming the process before I made it in a 3D model...' (MP03).*

b) TOC – type of CAD proposed to be used

'*I mean ProEngineer mainly for modelling...and maybe...ALIAS for rendering' (MP03)*

'...ProE' (MP01)

c) CFE – CAD feature expectation

'...this [design] has more solid geometry and the testing hopefully I can use to test [whether] the mechanism works...[through] simulation or something' (MP01)

'...well you see it is useful to me in that using ProEngineer I can make a model which first and foremost lets me…visualize my idea…my concept in 3D.' (MP03)

d) CAE – Participants' CAD experience

'Every year I've got in... a course... I've done ProE and coming on this year so...that's the only training I had but obviously the lessons are enough…' (MP01)

'All those softwares...Photoshop Ilustrator...ProEngineer...ALIAS...we have been given in the support in all these on over the years' (MP03)

e) RUC – reason to use CAD

'...probably going to do rapid manufacture.... the part...the device...so the whole thing has to be modelled in 3D CAD to produce it.' (MP01)

'I'll just need to show the accuracy for the manufacture…That's it I think...and also for rendering as well' (MP03)

f) CFT – where CAD fits

'Yes, probably all of it [design stages]' (MP01)

'…using computer software…after I had an initial idea in my head and then I've made a sketch of that... [CAD modelling] sort of confirms that.' (MP03)

g) ODT – other design tools planning to use

' *I've done a few mock up too like foam' (MP01)*

'I want to basically use this as a template and then put on some MDF in order to then mark out the 2D points and cut around with a bandsaw and get it [physical model]...nicely' (MP03)

h) RUO – reason to use other

'I like a physical model...so that's why I did the modelling of my syringe already' (MP01)

i) CDB – CAD drawback

'Hard to get one it to look like...it can compromise the design...so the product dosen't look like you imagine it would look in the first place.' (MP01)

j) RCD – Reason to CAD drawback

'...possibly my skill from not knowing how to create it in the first place' (MP01)

6.4.2 Protocol Analysis – 2D Sketching

An appointment was made with each participant before a video session of 2D sketching activity was executed. A room was booked to provide conducive working space for participants to undertake their sketching activity while being video recorded by the researcher.

The analysis approach executed in the Case study 2 was replicated in this study. The video data were analysed using Transana and the examples of behaviours identified from the 2D sketching data analysis is displayed in Table 6-4.

Table 6-4: Examples of behaviours identified excerpt from the 2D sketching data analysis of MP01 and MP03

Time (Start~End)	**2D Sketching behaviours (description)**	**Observation**	**Verbalisation (Text)**
(0:07:41.2) ~ (0:08:23.1)	Reflective (thinking);		*'I do a sort of small sketches like you can see here…just repeating the same thing over and over to help kind of...It kind of fixes it into your mind...or you do it a lot of times so you keep re-thinking it'(MP03)*
(0:08:00.9) ~ (0:08:20.3)	Vertical Transformation (Elaboration of ideas)	trying to make more organic shape	*'make it... a little bit more interesting than a syringe body as it at the moment... put some styling to that' (MP01)*

From the analysis, 64 occurrences of 2D sketching behaviours were identified in the sketching session undertaken by MP01 and 29 occurrences by MP03. 7 out of 8 behaviours listed in the 2D sketching behaviours framework were recognised in this study. These are presented in Table 6-5.

Table 6-5: 2D sketching behaviour occurrences

2D Sketching Behaviours	**Occurrences**		**Total**
	MP01	MP03	
Combining		1	1
Restructuring	9		9
Lateral Transformation	14	1	15
Vertical Transformation	15	13	28
Part by Part Dwg			0
Non Part by Part Dwg	6		6
Reflective	7	11	18
Experimental	13	3	16
Total	64	29	93

Subsequent to the 2D sketching behaviours analysis, the same events were later re-analysed in the perspective of the Creative Behaviours Framework. The example of the data analysis findings is shown in Table 6-6.

Table 6-6: Example of creative behaviours identified excerpt from the 2D sketching data analysis of MP01 and MP03

Time (Start~End)	2D Sketching behaviours (description)	Observation	Verbalisation (Text)
(0:07:41.2) ~ (0:08:23.1)	Continuous reflection	Re-sketch the same idea	*'I do a sort of small sketches like you can see here..just repeating the same thing over and over to helps kind of..It kind of fix it into your mind…or you do it a lot of time so keep re-thinking it'(MP03)*
	Determined	Firmness in doing things	
(0:08:00.9) ~ (0:08:20.3)	Open to new ideas		*'make it... a little bit more interesting than a syringe body as it at the moment... put a styling of that' (MP01)*
	Exploring possibilities	trying to make more organic shape	*'don't want to make just ...a boring medical device. I want to make it a litlle bit nicer' (MP01)*
	Spontaneity	spontaneous free sketching to make the shape more interesting and stylish	*-none-*

In total, 83 occurrences of creative behaviours were recorded where 52 were captured in a 2D sketching session undertaken by MP01 and 31 were identified in a session by MP03. From seven categories of Creative Behaviours, six emerged in these sessions except the novelty behaviour category as shown in Table 6-7.

Table 6-7: Creative behaviours identified in the 2D sketching sessions undertaken by MP01 and MP03

Creative Behaviour	Creative Behaviour Descriptor	2D sketching		Total
		MP01	MP03	
Novelty		0	0	0
Appropriateness	useful	2	0	2
	sensible	2	3	5
	functional	0	1	1
Motivation	determined	3	5	8
	risk-taking	2	1	3
Fluency	Spontaneity	6	1	7
	open to new ideas	12	0	12
	fluency of ideas	1	0	1
Flexibility	exploring possibilities	11	3	14
	continuous reflection	5	9	14
Sensitivity	understand problem	2	2	4
	display curiosity	3	3	6
	seek perfection	1	0	1
Insightfulness	organizing information	1	1	2
	intuitive decision	1	2	3
	Total	**52**	**31**	**83**

6.4.3 Protocol Analysis – 3D Sketch Modelling

Data gathering in 3D sketch modelling involved clay modelling using plasticene by MP01 to develop a potential shape for the self administered immunisation pack. MP03 built a physical model of the initial idea for a musical instrument using wood in one of his workshop activities that was recorded for data capturing. Participants were requested to verbalise their activities, however, since MP03's modelling session was in a workshop with noisy surroundings, retrospective verbalisation was an option. MP03 was given a copy of the video data and asked to verbalise it for analysis. Based on the video data and an audio file of MP03 retrospective verbalisation, the analysis was undertaken.

The examples of the 3D sketch modelling behaviours that were identified in those sessions are shown in Table 6-8.

Table 6-8: Example of behaviours identified excerpt from the 3D sketch modelling data analysis of MP01 and MP03

Time (Start~End)	**3D Sketch Modelling Behaviours (description)**	**Observation**	**Verbalisation (Text)**
(0:01:05.6) ~ (0:02:10.9)	Adding and subtracting act (ADSA): Shape, cut out	Start making the syringe casing shape-triangular shape	*‘I'm trying to make a triangular shape’(MP01)*
(0:01:35.2) ~ (0:01:49.5)	Sense of touch (SOT): See	seeing what a design look like	*'Back from the bandsaw, cut two edges, one of them...you see if it fits around the centre... ‘(MP03)*

From the analysis, 40 occurrences of 3D sketch modelling behaviours were identified where 25 were from the MP01 session and 15 from the MP03 session. All of three behaviours listed in the framework emerged and were identified in these sessions as shown in Table 6-9.

Table 6-9: 3D sketch modelling behaviours identified in one of physical modelling sessions undertaken by MP01 and MP03

3D Sketch Modelling Behaviours	**Occurrences**		**Total**
	MP01	MP03	
Adding and Subtracting Act (ADSA)	12	7	19
Continuous Modifications and Improvements (CMAI)	5	2	7
Sense of Touch (SOT)	8	6	14
Total	25	15	40

The video data was then re-analysed to observe and identify any creative behaviours that emerged during the 3D sketch modelling activity. Table 6-7 presents an example of such findings.

Table 6-10: Example of Creative Behaviours identified excerpt from the 3D sketch modelling data analysis

Time (Start~End)	**Creative Behaviours (description)**	**Observation**	**Verbalisation (Text)**
(0:01:05.6) ~ (0:02:10.9)	Open to new ideas	Triangle shape as a design alternative	*'I'm trying to make a triangular shape' (MP01)*
	Exploring possibilities	allow other approach which problems may be solved	*'...to try something different from cylindrical'(MP01)*
(0:01:35.2) ~ (0:01:49.5)	Continuous reflection	-	*'Back from the band saw, cut two edges, one of them...you see if it fits around the centre...centre peg a bit easier...but a fact of comparing second one there...you can see... it's just slot in alongside....'(MP03)*

When the same videos were analysed from the perspective of the Creative Behaviours Framework, 32 occurrences have been captured, with 19 identified from the MP01 and 13 recognised from the MP03. This is shown in Table 6-11 where six creative behaviours emerged in these sessions except novelty behaviour.

Table 6-11: Creative Behaviours identified in the 3D sketch modelling sessions undertaken by MP01 and MP03

Creative Behaviours	**Design Activity**	**3D Sketch Modelling**		**Total**
	Participant	**MP01**	**MP03**	
	Descriptor			
Novelty		0	0	0
Appropriateness	useful	0	1	1
	functional	0	1	1
Motivation	enthusiastic	1	0	1
	determined	1	0	1
	risk-taking	3	2	5
Fluency	Spontaneity	3	0	3
	open to new ideas	1	1	2
Flexibility	exploring possibilities	3	1	4
	continuous reflection	3	5	8
Sensitivity	seek perfection	3	1	4
Insightfulness	organizing information			0
	intuitive decision	1	1	2
	Total	**19**	**13**	**32**

6.5 Relative Findings Analysis between 2D Sketching and 3D Sketch Modelling With Creative Behaviours Framework

Data were re-analysed to seek potential relationships between 2D Sketching Behaviours framework and Creative Behaviours Framework observed in 2D sketching activities. Some example excerpts from the MP01 and MP03 data findings are shown in Table 6-12. Besides presenting findings based on the researcher observations and interpretations, supporting evidences from participants' verbalisation were also provided if there were any.

Table 6-12: Observed behaviours relationship between 2D sketching and Creative Behaviours Framework – MP01 and MP03

Participant	Start End time (Hrs:mins:secs)	2D Sketching behaviour framework	Creative behaviour framework (CAD)	Verbalisation
MP01	(0:03:12.0) ~ (0:03:37.5)	LT (different form of solution)	Open to new ideas #try to imagine different form it could take	
		Restructuring (Modification of different form)	Exploring Possibilities #sketch cylindrical shape	
	(0:08:00.9) ~ (0:08:20.3)	**VT (Elaboration of ideas)**	Open to new ideas	'make it.. a little bit more interesting than a syringe body as it at the moment. (not clear) put a styling of that'
			Exploring Possibilities #trying to make more organic shape -	'don't want to make just a...a boring medical device. I want to make it a litlle bit nicer
MP03	(0:07:00.3) ~ (0:07:34.2)	**Reflective (thinking)**	Continuous Reflection	
			Display curiosity #speculate things-how the mechanisms going to work	
	(0:07:41.2) ~ (0:08:23.1)	Reflective (thinking)	Continuous Reflection # re-sketch the same idea	

A similar procedure was undertaken on 3D sketch modelling data and examples of the findings are shown in Table 6-13.

Table 6-13: Observed behaviours relationship between 3D sketch modelling and Creative Behaviours Framework

Participant	**Start End time (Hrs:mins:secs)**	**3D Sketch Modelling Behaviours framework**	**Creative Behaviours Framework (CAD)**	**Verbalisation**
MP01	(0:01:05.6) ~ (0:03:32.5)	Adding and substraction:Shape , Cut out-#start making the syringe casing shape-triangular shape	Open to new ideas # 'I'm trying to make a triangular shape'- as design alternative	
			Exploring Possibilities #...to try something different from cylindrical'- allow other approach which problems may be solved	
	(0:14:19.5) ~ (0:15:52.3)	Sense of touch: See, Evaluate	Continuous Reflection	'Only that one doesn't look very interesting'
MP03	(0:01:27.8) ~ (0:03:18.4)	Adding and substraction:draw	Risk-taking # make a marking to cut the material (tube)- have a go	'just going to see what happened if I remove a bit of material.'
			Intuitive decision # make a guess to how much need to be cut -	'It's quite ...loose obviously at the moment is nothing really marked out accurately...kind of just basically trying to get whole thing moving and working'
	(0:00:06.3) ~ (0:00:16.9)	Sense of touch :Evaluate #seeing what a design look like.	Continuous Reflection	'I've just come back cutting up one of them at the band saw....I've only have cut...a one half of one of them...I'm just going to line up that edge with this second one there'

6.6 Protocol Analysis – CAD

CAD data gathering activities were undertaken by pre-arrangement with participants who were allocated a suitable time for that purpose. At the same time they were also requested to record at least one of their CAD activities using CAMTASIA.

Then, the video data and the video transcriptions were analysed and some of the examples of the findings are shown in Table 6-15. The data were presented based on time of event and creative behaviours identified including the observation and verbalisation text if any.

Table 6-14: Example of Creative Behaviours identified excerpt from CAD data analysis

Participant	**Time (Start~End)**	**Creative Behaviours (description)**	**Observation**	**Verbalisation (Text)**
MP01	(0:23:28.3) ~ (0:26:01.1)	Motivation (Determined)	Look confidence	
		Motivation (Risk-taking)	Have a go with the slot creation	*'I don't have any measurement yet...Just to test the thing'*
		Flexibility (Continuous reflection)	Preview the current output	*'It here...like an indent for a finger as well as the button. It's the idea..obviously sizes needed finding'*
	(0:25:10.3) ~ (0:26:01.1)	Insightfulness (Organising information)	preview the current CAD model, and plasticene model image	
MP03	(0:04:55.9) ~ (0:07:08.1)	Fluency (Spontaneity)	haven't planned like this before	*'Which I haven't planned to do…it's just…I kind need that one...'*
		Appropriateness (Sensible)		
		Motivation (Risk taking)	have a go-to find the best dimension and position	*'..this is the best..kind of place to put them both when I look at...'*
		Flexibility (Exploring Possibilities)	playing with ideas-play around with the dimension to see what it looks like	

In total, 110 Creative Behaviours occurrences were identified and the detail is shown in Table 6-15.

Table 6-15: Creative Behaviours identified in MP01 and MP03 CAD activities

Creative Behaviours	Design Activity	CAD				Total
	Participant	MP01		MP03		
	Descriptor	CADvid	CADcam	CADvid	CADcam	
Novelty		0	0	0	0	0
Appropriateness	useful	1	0	1	0	2
	sensible	0	2	1	0	3
	functional	1	0	0	0	1
Motivation	enthusiastic	0	0	0	1	1
	determined	3	2	2	0	7
	risk-taking	5	3	5	3	16
Fluency	Spontaneity	0	2	1	1	4
	open to new ideas	3	1	2	1	7
	fluency of ideas	0	0	0	1	1
Flexibility	exploring possibilities	4	3	5	3	15
	continuous reflection	7	7	11	2	27
	associate remote ideas	0	1	0	0	1
Sensitivity	understand problem	0	0	1	0	1
	display curiosity	0	0	1	0	1
	seek perfection	4	6	5	3	18
Insightfulness	organizing information	2	0	0	0	2
	intuitive decision	3	0	0	0	3
	Total	**33**	**27**	**35**	**15**	**110**

6.6.1 Design Diaries

Each participant was given a set of design diary sheets to be completed until the end of their projects. The completed design diaries were submitted to the researcher for analysis. Post-interviews were undertaken to confirm and validate data established from design diaries analysis. In this section, data findings from design diaries are presented. The data were based on 12 CAD sessions by MP01, and 23 sessions by MP03. These data were presented based on individual participant and followed by clustered figures as shown:

a) CAD design related activity engaged

In this section an activity item, 'assembly' has been substituted with 'simulation/test' to provide an option for participants to choose if they were carrying out any activity under this category. The category would supply better information and link with any item in the 'description' section.

The types of CAD design related activity undertaken by participants in each CAD session are shown in Table 6-16 and Table 6-17.

Table 6-16: Frequency of design related CAD activity engaged in by MP01

Activity	**Frequency**
Ideation	3
Basic form	7
Part drawing	1
Detailing	9
Simulation/Test	0
Working Drawing	1

Table 6-17: Frequency of design related CAD activity engaged in by MP03

Activity	**Frequency**
Ideation	3
Basic form	7
Part drawing	4
Detailing	2
Simulation/Test	1
Working Drawing	0

Figure 6-1 displays the percentage of CAD activity engaged in by MP01. The data indicated that CAD predominantly has been used to develop design ideas where 43% of MP01 CAD usage involved 'detailing' items. Next were 'basic form' creation, 33% and 'ideation' at 14%. However, 'part drawing' and 'working drawing' involved only 5% each from the overall CAD usage by MP01. No record shows 'simulation' or 'test' such as Finite Element Analysis during any of the MP01's CAD activity.

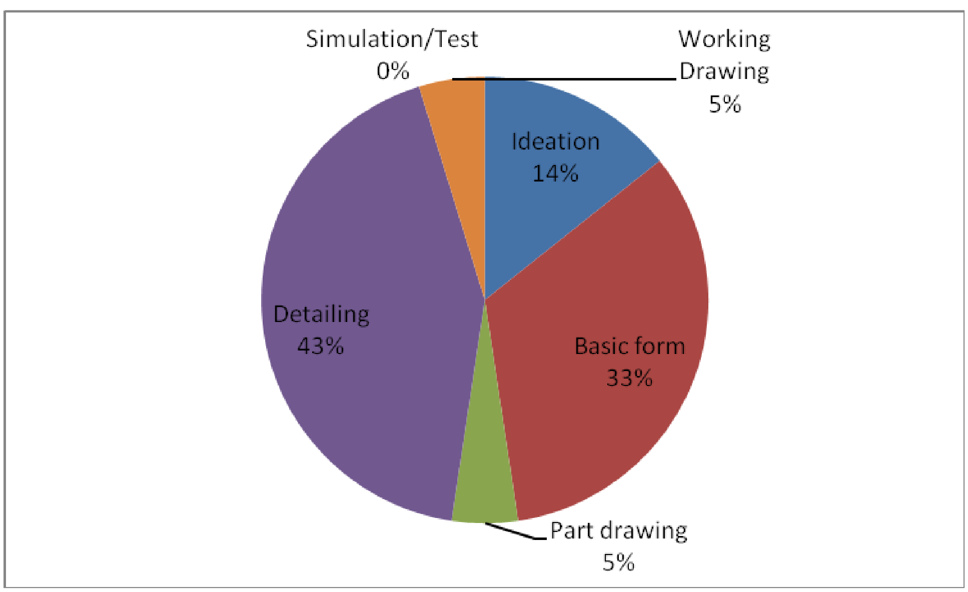


Figure 6-1: Percentage of design related CAD activity engaged in by MP01

A different scenario had been displayed by MP03 based on the data as shown in Figure 6-2. Unlike MP01, this participant reported that 41% of his CAD activities in the project related to 'basic form' creation activities, and only 12% involved 'detailing'. MP03 used CAD a little bit more for ideas generation with 18% on 'ideation'.

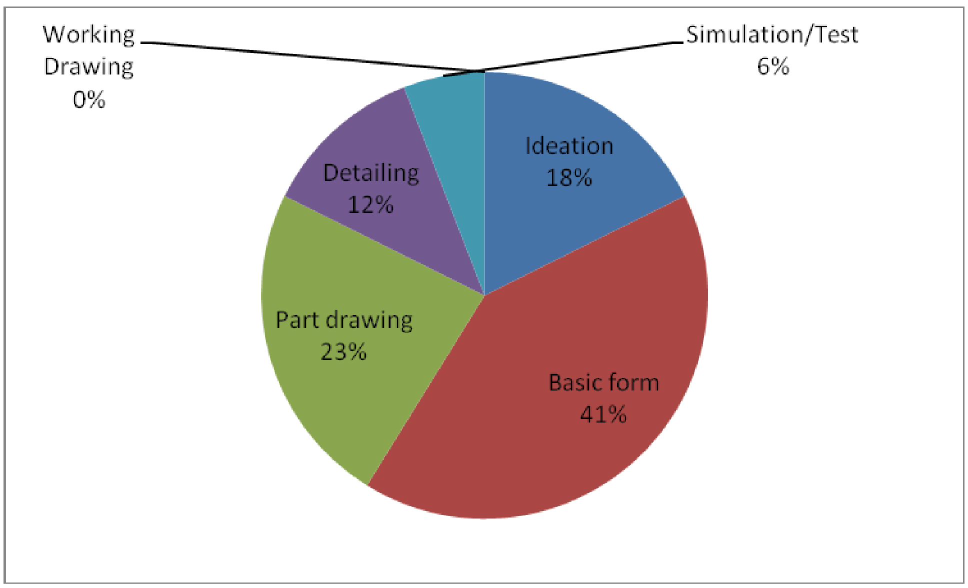


Figure 6-2: Percentage of design related CAD activity engaged in by MP03

When both data were clustered (Figure 6-3), the trend indicated that 'basic form' was the most frequent reason for CAD use with 37% throughout the design projects. It can also be seen that participants used CAD in developing their product's design with 29% involved design 'detailing', and even in the ideas generating phase with 16% in 'ideation'.

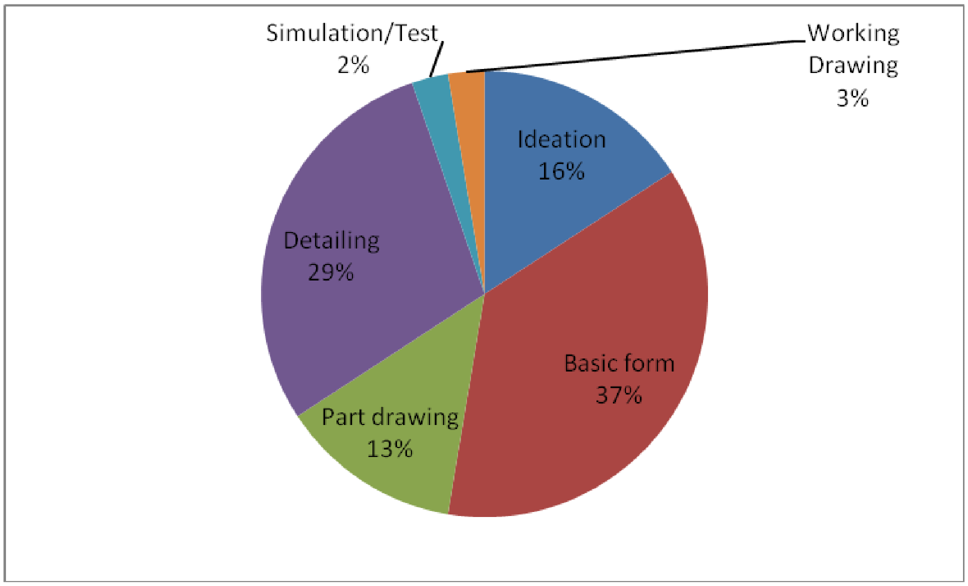


Figure 6-3: Percentage of design related CAD activity engaged in by participants when data clustered

b) CAD activity description

In this section Finite Element Analysis 'FEA' and 'simulation/test' were combined under a category known as 'analysis'. The changes would prevent confusion to participants as these two categories show redundancy of meaning and could be misleading. Table 6-18 shows the frequency of CAD activity which executed by MP01, and Table 6-19 by MP03.

Table 6-18: Frequency of CAD activity described undertaken by MP01

CAD activity description	Frequency
Feature creation	7
Edit	7
Render	0
Assembly drawing	2
Geometric shape	6
Dimensioning	6
Elaborating	0
Analysis	1
Scale	3
Text	0
Assembly and Fitting	9

Table 6-19: Frequency of CAD activity described undertaken by MP03

CAD activity description	Frequency
Feature creation	1
Edit	1
Render	7
Assembly drawing	2
Geometric shape	15
Dimensioning	4
Elaborating	0
Analysis	0
Scale	0
Text	0
Assembly and Fitting	5

From Figure 6-4, it can be seen that 'assembly and fitting' was the highest proportion of acts undertaken by MP01 when using CAD with 22%. It was followed by 'feature creation', 17%, design editing, 17%, creating 'geometric shape', 15% and 'dimensioning' design drawing covering 15% from overall CAD activities involved. Other activities reported were between 7% and 2% and are 'scale', established 'assembly drawing', and doing design 'analysis'.

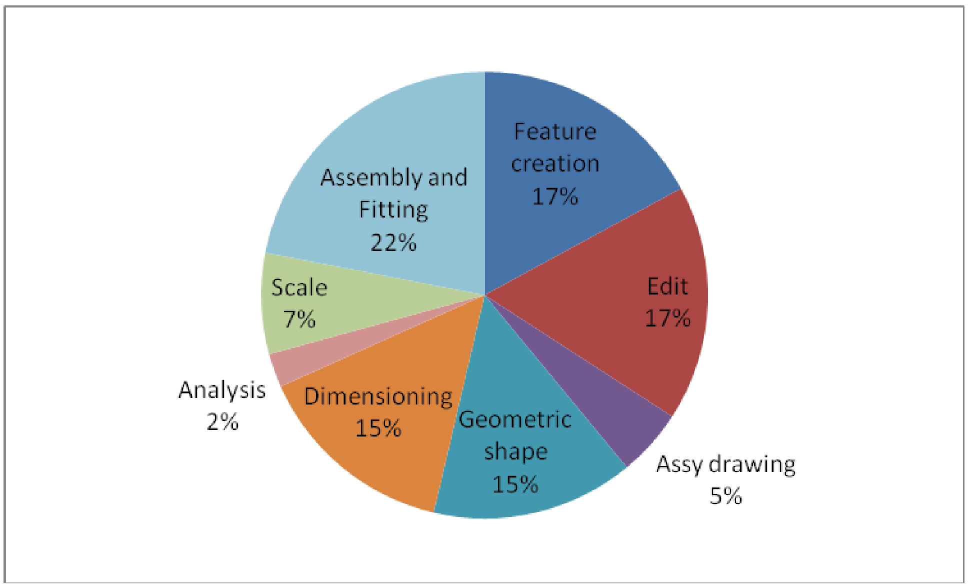


Figure 6-4: Percentage of types of CAD activity engaged in by MP01

Referring to Figure 6-5, it was significantly shown that MP01 used CAD to create 'geometric shape' for his music instrument design. It covers 43% from overall CAD usage that he engaged with. Interestingly, MP01 reported using CAD to render his design model by 20% which was the second most frequent activity after 'geometric shape'.

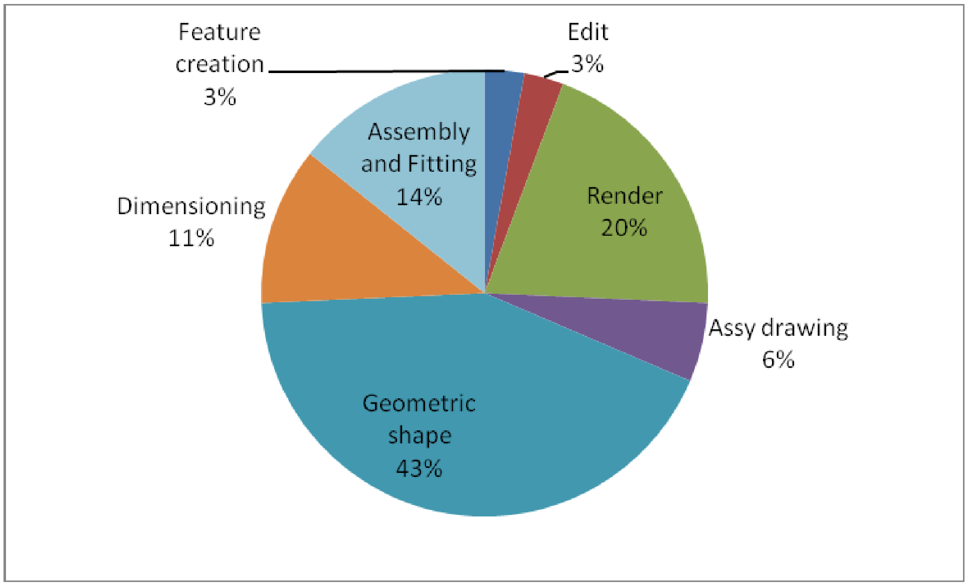


Figure 6-5: Percentage of types of CAD activity engaged in by MP03

Following is Figure 6-5 where data was clustered from MP01 and MP03.

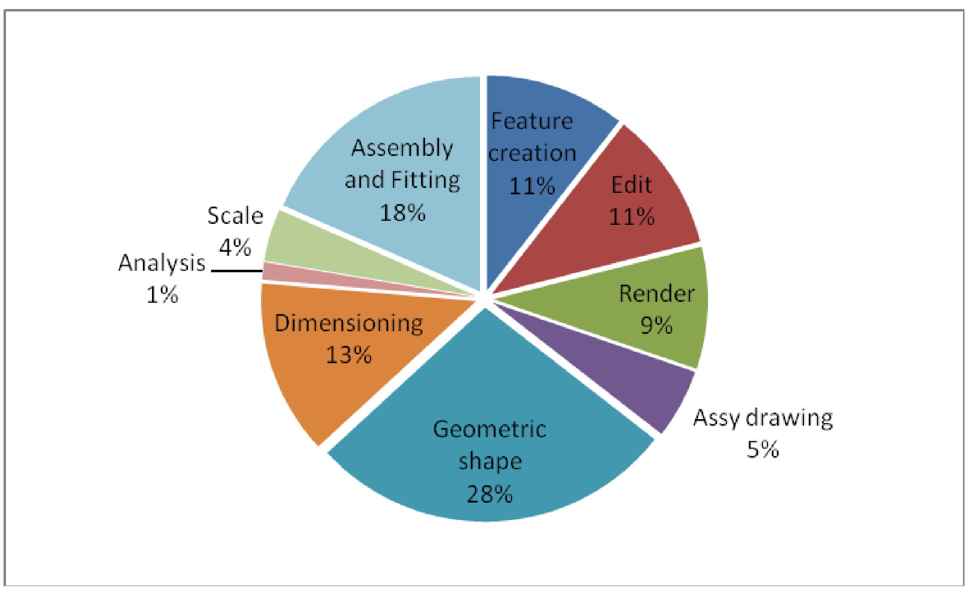


Figure 6-6: Percentage of design related CAD activity engaged in by participants when data clustered

c) Creative Behaviours occurrences

This section presented the creative behaviour occurrences recorded by participants, MP01 and MP03. The findings were tabulated as shown in Table 6-20 and Table 6-21.

In 23 CAD sessions MP01 has identified 50 creative behaviour occurrences. Novelty behaviour was recorded in one of the sessions.

Table 6-20: The frequency of creative behaviours occurrences by MP01

Creative Behaviours	Frequency
Novelty	1
Appropriateness	13
Motivation	3
Fluency	7
Flexibility	9
Sensitivity	10
Insightfulness	7
Total	50

While MP03 has undertaken 23 CAD sessions, nearly double compared to MP01. From all those sessions, 75 emergences of creative behaviours were reported with 10 of them under novelty category.

Table 6-21: The frequency of creative behaviours occurrences by MP03

Creative behaviour	Frequency
Novelty	10
Appropriateness	12
Motivation	16
Fluency	10
Flexibility	8
Sensitivity	9
Insightfulness	10
Total	75

The design diaries of MP01 indicated that 'appropriateness' was the most significant from all seven creative behaviours categories. Data findings in Figure 6-7 shows that 26% of the creative behaviours identified were 'appropriateness', followed by 'sensitivity' 20%. The lowest percentage of all was novelty with only 2%, of occurrences. However, this provides further evidence of a link between the novelty category of behaviour and CAD usage in designing. In describing this occurrence, MP01's related diary entry stated:

> '*New ideas were generated for mechanism for mechanics and reduction of parts-dual use parts*' (MP01- Diary entry dated 23 December 2008)

This was later emphasized by the participant in the post-interview which affirmed:

> *'it change...what...my original idea was because CAD highlighted that you could do it easier...it was an improvement of the design...that was*

unexpected [novelty descriptor] *because I thought I had...mechanism design and then found it...that an easy way to do it.'* (MP01, post-interview)

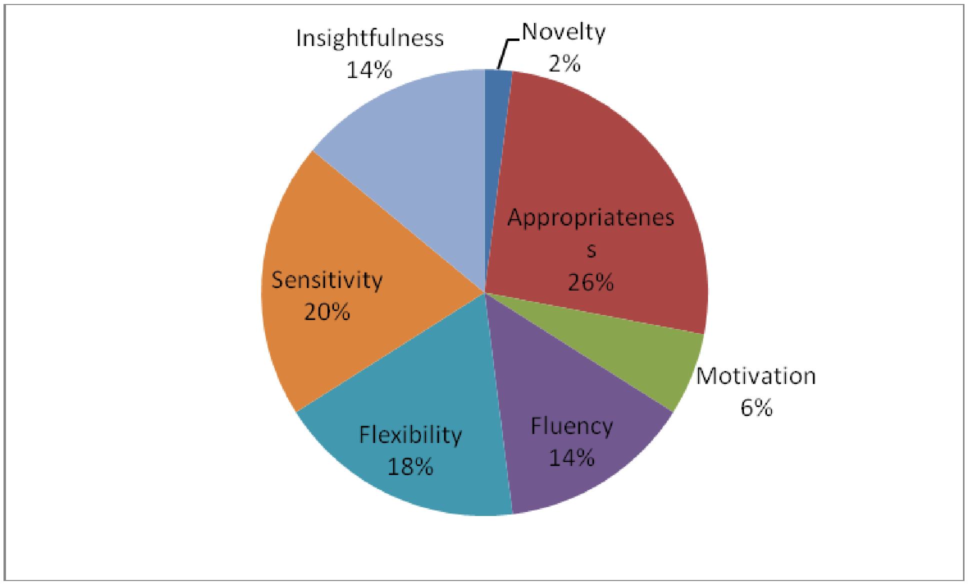


Figure 6-7: The percentage of creative behaviours occurrences by MP01

The pie chart in Figure 6-8 showed that CAD promotes participant MP03's motivation in undertaking his design work. It covers 21% of creative behaviours. The data also suggested the possible link between CAD usage and participants' consideration of 'appropriateness'. Interestingly, MP03 reported a high percentage of novelty occurrences with 14% which was far higher than identified by MP01.

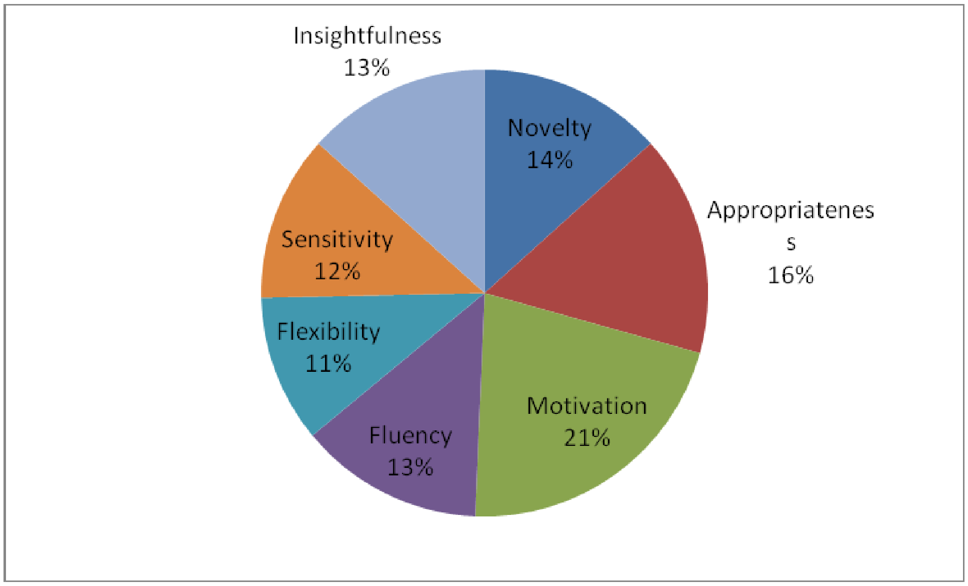


Figure 6-8: The percentage of creative behaviours occurrences by MP03

Subsequently, data from both participants were clustered and presented in Figure 6-9. It shows that the highest percentage category was 'appropriateness' with 20% and the lowest was 'novelty' with 9% of overall occurrences.

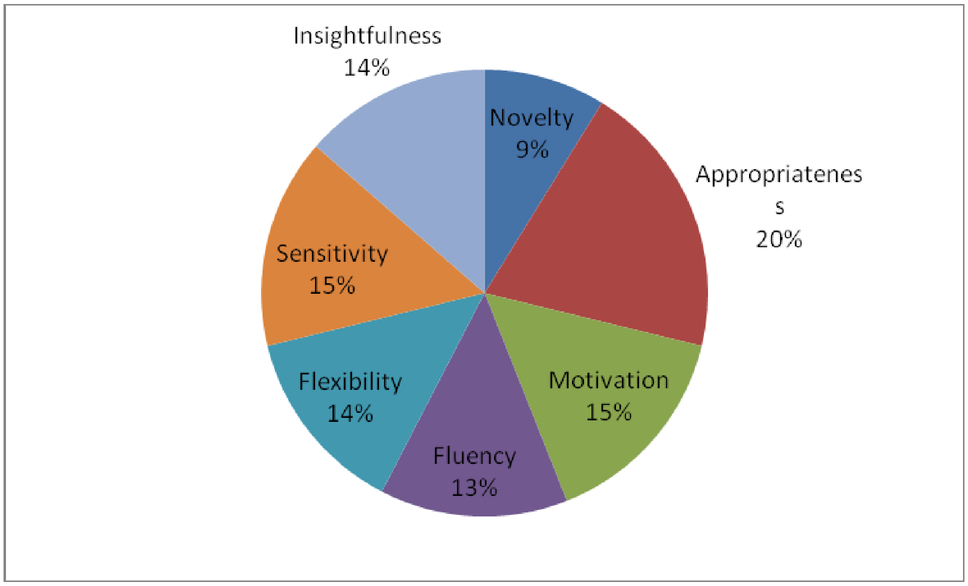


Figure 6-9: The percentage of creative behaviours occurrences by MP01 and MP03

d) CAD usage reflection

Figure 6-10 and Figure 6-11 display reflections of participants' feelings about using CAD in their design projects. Feedback was presented by percentage as follow.

MP01 has shown mixed feelings about her CAD use in the design project. The participant in general feels 'satisfied' every time using CAD with 9% feedback. She felt 'confidence' (14%) when using CAD and believed it made her design work a lot more 'easy' (23%). However, she thought that CAD made her progress 'slow' (23%) and sometimes felt 'annoying' (11%).

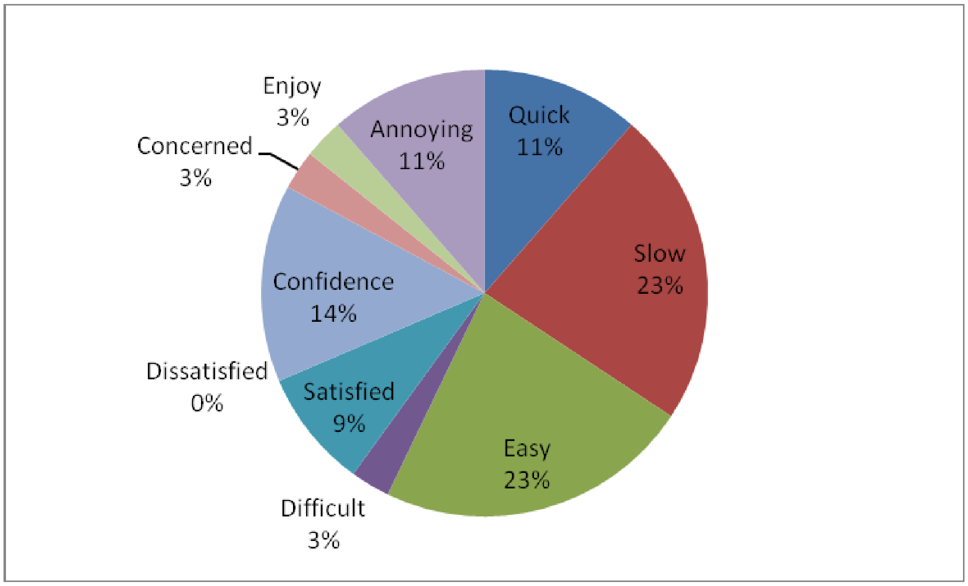


Figure 6-10: MP01 feedback of the CAD usage in the design activity

Overall, MP03 also felt ‘satisfied’ (27%) when using CAD in his designing. 19% of his feedback showed that CAD made his designing activities ‘easy’ (19%), although he believed it made his design progress ‘slow’ (18%). The participant enjoyed most of his CAD designing sessions and there was no feedback indicating that he felt it ‘annoying’ (0%) in any of the sessions. However, he has a balanced feeling between ‘confidence’ (7%) and ‘concerned’ (7%) when using CAD in this project.

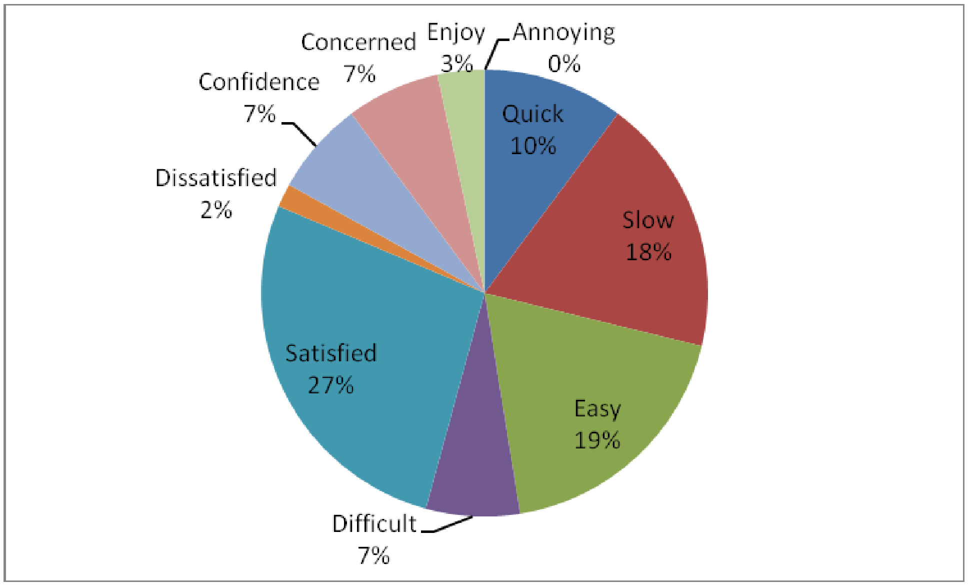


Figure 6-11: MP03 feedback of the CAD usage in the design activity

When data were clustered, the following pie chart was established as shown in Figure 6-12. The data clearly illustrates that participants felt 'satisfied' (20%) when using CAD in their projects and reported that CAD made their designing task 'easy' (20%). They had similar views that CAD made their designing work 'slow' (20%), although, the data indicated that participants felt 'confidence' (10%) and 'enjoy' (3%) their CAD sessions.

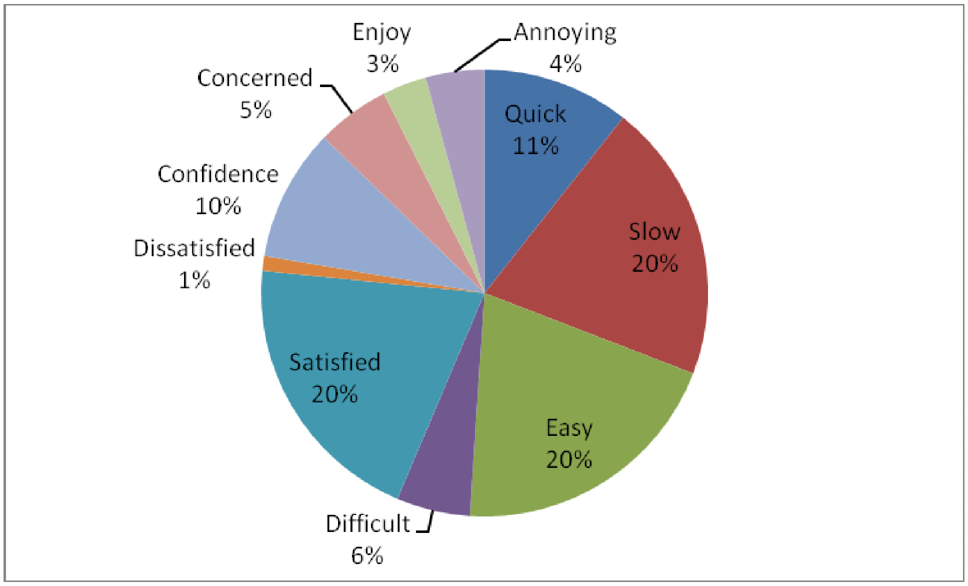
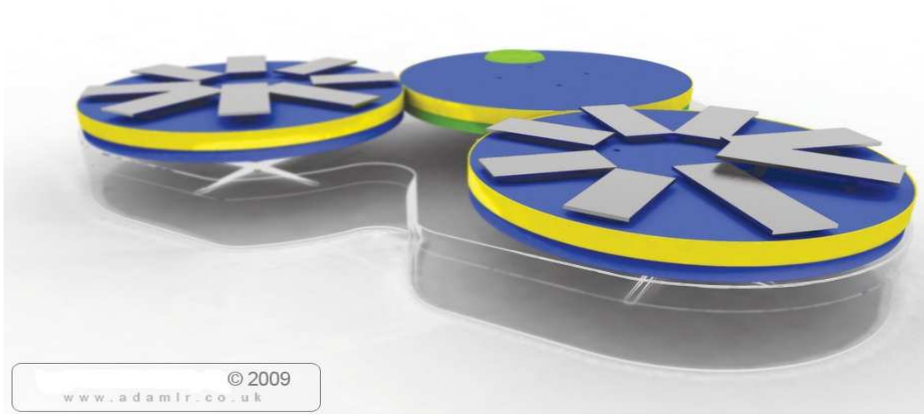


Figure 6-12: MP03 feedback of the CAD usage in the design activity

6.7 Seeking Possible Links between Creative Product Characteristics and Creative Behaviours

The attempt to seek such links began after the completion of the participants' design projects and submission of their design diaries. In providing the creative product characteristics, their project advisors were contacted to obtain their feedback. The advisors were reached face to face or through emails, and feedback forms were sent through email. The feedback form required the advisors to suggest any innovative aspect of the product design from their perspectives. An example of the feedback form is shown in Figure 6-13.



It is most appreciated if you could give some feedback about any innovative aspect of this product design:

Product Aspect	Innovative Aspect (if any)	Comment
Form		
Colour		
Material		
Functional		
Other (if any)		

Figure 6-13: Feedback form for MP03's design project

From the feedback, the researcher went through all the data obtained such as video data, design diaries, including transcriptions of verbalisation and post-interviews to seek any indication that could lead to the establishment of links between product design creative characteristics observed and the use of CAD. The analysis established evidences that could link the creative aspects identified to the use of CAD in designing. The findings will be presented based on each project as follows.

6.7.1 'Self Vaccination Administration Device'

Subsequent to the email sent to the MP01's final project advisor, the feedback form has been filled in and returned to the researcher. The advisor has highlighted three innovative aspects in the context of its form, colour selection, and functionality from the product design. Based on the aspects, the researcher attempted to track back its link with the CAD usage during designing from all the data previously obtained and the findings are shown in Table 6-22.

Table 6-22: MP01 product's creative characteristics and its links with the creative behaviours

Creative Characteristics	**Link to CAD activity**	**Creative Behaviours reported**
'Allow single handed uses' • Enabled self vaccination	CAMTASIA On-screen videoing (0:06:57.7)'...I have two handles...I managed to design it in the end to only have one handle...in the one slider...but at one point I had two or more handles...to activate the whole device' (0:08:13.1)	Sensitivity Motivation Flexibility Appropriateness
Bright Yellow • High visibility/bio-hazard	No link could be distinguished	
Moulded springs and clips to enable single use • All featured designed into moulding for low cost simplicity	Design Diary entry (23/12/08) #Creating mechanism for vaccine device # New ideas were generated for mechanism for mechanics & reduction of parts- dual use parts. Fitting together & supports created & refined. This then supported by the post-interview for the design diary entry: '…it change...what...my original idea was because CAD highlighted that you could do it easier...it was an improvement of the design...that was unexpected because I thought I had...mechanism design and then found it...that an easy way to do it.' (MP01-Post-interview)	Novelty Appropriateness Flexibility Sensitivity Insightfulness

However, the researcher was unable to find from the established data any indication that could provide a link between the 'colour selection' with the participant's CAD activities.

6.7.2 'Alternative Music Instrument'

The feedback from MP03's advisor indicated five creative characteristics from the 'alternative music instrument' designed. A similar approach as in the 'self vaccination administration device' was executed to seek links between the product's creative characteristics and CAD usage. The findings shown in Table 6-23 display such links.

Table 6-23: MP03 product's creative characteristics and its links with the creative behaviours

Creative Characteristics	Link to CAD activity	Creative Behaviours reported
Combining the functions of a case for transportation and a base for the instrument when in use.	No link could be distinguished	
The use of transparent material for the case.	No link could be distinguished	
The interlocking of the three wheels is key to the function of the design.	Post Interview: Design diary entry for 26/11/09 '…innovation piece...three...spinning discs...turning discs which you know kind the main original thing about the project probably. And so that was I'm trying to capture in CAD.' 'So that's what I'm trying to capture...the original idea that I had in my head...I'm trying to catch that in 3D CAD'	Novelty Appropriateness Motivation Fluency Insightfulness
The operation of the instrument allows participation by people with limited ability	Post Interview: Design diary entry for 27/11/08 'I just want to externalise it...in ProEngineer...Cause that was based on some users feedback which was one autistic child like this circle spinning disc...' 'I think you have two other people doing that...you get like...one person will doing that here...and two other people right on side'	Novelty Motivation Fluency Flexibility
Rotating the driver wheel via an inserted disk	Post Interview: Design diary entry for 27/11/08 'And the turning disc and then this kind spinning somehow…be like some kind mechanical noise out …..you hit this notes as they spin...'	

6.8 Chapter Summary

This chapter presents data findings from Case study 3, involving two undergraduate finalists design project. Overall, the analysis has shown results consistent with prior case studies. The findings indicated that methods used in this research were reliable.

The summary of the results from the case study are shown in Table 6-24. The data analysis had captured 395 creative behaviour occurrences from the data gathering activities. From the total, 280 were the occurrences that related to the CAD activities which were recorded and analysed.

Table 6-24: Summary of the results for Case study 3

Creative Behaviour	Design Activity	2D sketching		3D sketch modelling		CAD				Design Diaries		Total
	Participant					MP01		MP03				
	Creative Descriptor	MP01	MP03	MP01	MP03	CADvid	CADcam	CADvid	CADcam	MP01	MP03	
Novelty	uncommon										1	1
	unexpected									1	3	4
	original										6	6
Appropriateness	useful	2			1	1		1		9	2	16
	sensible	2	3				2	1		2	12	22
	functional		1		1	1				10	2	15
Motivation	enthusiastic			1					1		6	8
	determined	3	5	1		3	2	2		3	19	38
	risk-taking	2	1	3	2	5	3	5	3			24
Fluency	Spontaneity	6	1	3			2	1	1	2	2	18
	open to new ideas	12		1	1	3	1	2	1	2	10	33
	fluency of ideas	1							1	2	2	6
Flexibility	exploring possibilities	11	3	3	1	4	3	5	3	8	10	51
	continuous reflection	5	9	3	5	7	7	11	2		6	55
	associate remote ideas						1					1
Sensitivity	understand problem	2	2					1		7		12
	display curiosity	3	3					1			3	10
	seek perfection	1		3	1	4	6	5	3	5	12	40
Insightfulness	organizing information	1	1			2				5	7	16
	intuitive decision	1	2	1	1	3				1	8	17
	influence by inspiration									1	1	2
	Total	**52**	**31**	**19**	**13**	**33**	**27**	**35**	**15**	**58**	**112**	**395**

The link between the CAD usage and the creative behaviours was also established by tracking back the product's creative characteristics suggested by students' project advisors through the existing data collected.

7 Chapter Seven: Questionnaire

7.1 Chapter Overview

Following the case studies, a questionnaire survey was undertaken with a larger sample to provide a comparison of findings between these two approaches. Two forms of questionnaire were involved; the online-based and the paper-based questionnaires. The findings from the online questionnaire (Malaysian respondents) and paper questionnaire (Design and Technology Department, Loughborough University) are reported.

7.2 The Questionnaire Survey Background

As stated in the research methodology chapter, the questionnaire surveys were undertaken to compare the data acquired from a small number of participants in the case studies with a larger population. In this context, the population refers to CAD users, in particular, students (undergraduates and postgraduates) of the Design and Technology Department of Loughborough University and CAD users from Malaysia. In the case studies, the researcher explores the creativity aspects relating to CAD users in a 'real life' situation where the researcher has little control over the events. It means that the participants chose what task they are going to do with CAD, when and where they were going to do it. The questionnaire surveys would allow the researcher to acquire feedback based on the case studies findings from other CAD users on whether they have similar experiences when using the software.

A questionnaire was established and some findings from Case study 1 were included. The detail about the questionnaire has been described in the Chapter Three: Research Methodology. The questionnaire was distributed to a total of five research students and research associates for piloting. Overall feedback was that the questionnaire was easily understood and simple to complete. There were only minor amendments suggested before this questionnaire was uploaded into the online questionnaire database.

Items relating to the Creative Behaviours Framework were included in the 'CAD experiences' and 'Our research findings' sections, although there were two items referring specifically to the research findings.

7.3 Online Questionnaire

The piloted questionnaire was uploaded to Bristol Online Surveys (BOS) which was the online questionnaire platform provided by Loughborough University for its staff and students. After opening a user account, the researcher developed the online questionnaire by referring to self-learning online resources that were supplied by the service provider. A questionnaire survey entitled 'CAD and its relationship with creativity in designing' was created (url:http//www.survey.lboro.ac.uk/cadcreativity').

The online questionnaire allowed the researcher to broaden the sample by obtaining responses from CAD users in Malaysian higher education institutions. Respondents from Malaysia were chosen since this research was funded by the Malaysian Government under the Ministry of Higher Education sponsorship program and in return the involvement would provide findings in the context of Malaysian CAD users. A number of potential respondents were contacted through online communication media such as email, Facebook and Yahoo Messenger. These respondents were then requested to spread the information about the online questionnaire to their colleagues and students at their own institution (e.g. Universiti Teknologi Malaysia (UTM), Universiti Malaysia Kelantan (UMK), Universiti Malaya (UM), Politeknik Johor Bahru, Politeknik Kota Bharu).

The questionnaire was opened for access from 24th August 2009 until 24th February 2010. However, only ten respondents completed the online questionnaire. Although this was considered to be a small response, this feedback was useful in providing data which allowed comparison to be made with the UK CAD users' responses. The data were automatically analysed by the database (in terms of frequency and percentage) and presented online. The researcher transferred the data into Microsoft Excel in order to produce charts to report the data. The data will be presented in four sub-sections which consist of:

a) users' 'demographic information';

b) users' 'CAD experiences' (perception of CAD roles, and the Creative Behaviours emergence);

c) feedback on the case study 'research findings' feedback;

d) feedback on the potential of 'Creative Behaviours Framework in wider applications'.

7.3.1 Information about the Respondents

7 items were included to record information about the respondents. The information requested concerned the respondents' age, role, years of CAD use, skill level, source of CAD knowledge, types of CAD frequently used, and recent use of CAD. The results were shown in Figure 7-1 to 7-7.

All the respondents are aged between 20 to 49 years old with 9 of them aged above 30 years old (see Figure 7-1). All of them were lecturers, except one who was a student. Only one considered him or herself as a designer (see Figure 7-2). In terms number of years in using CAD, most of the respondents have used the software for more than five years (see Figure 7-3). Most of the respondents also considered themselves as 'intermediate' users (see Figure 7-4) with 2 of them expert users.

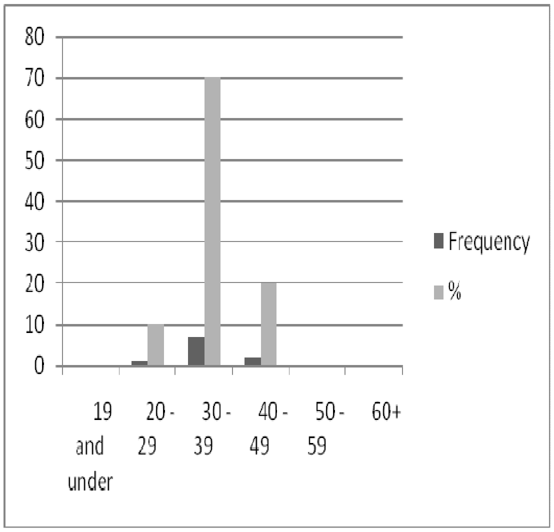


Figure 7-1: Respondents' age

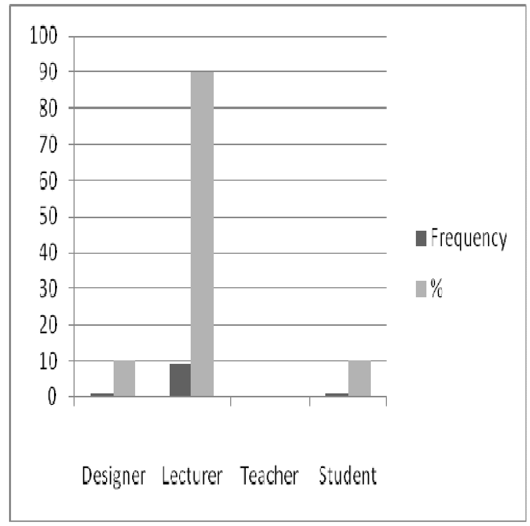


Figure 7-2: Respondents' role

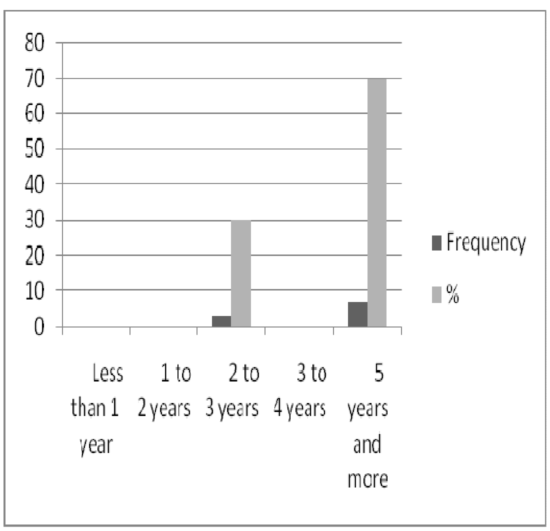


Figure 7-3: Number of years has using CAD

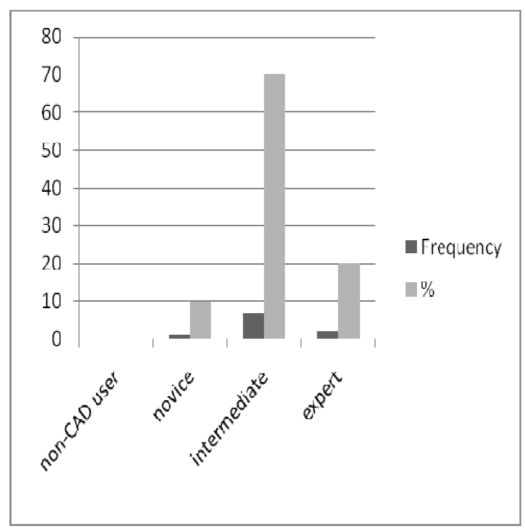


Figure 7-4: CAD user skill level

The findings in Figure 7-5 indicated that the CAD knowledge was mostly acquired from undergraduate courses and through self-learning. Figure 7-6 displays the type of software frequently used by respondents; most of them use AutoCAD. The data also indicated that all of the respondents have been using CAD between one week and six months ago. Overall, 6 respondents had used CAD less than four weeks before giving feedback to the online questionnaire. Hence, these can be considered as reliable responses since the events happened quite recently.

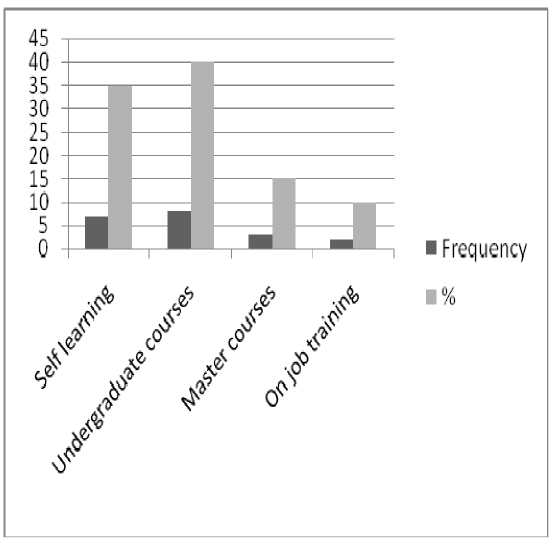


Figure 7-5: Sources of CAD knowledge acquired

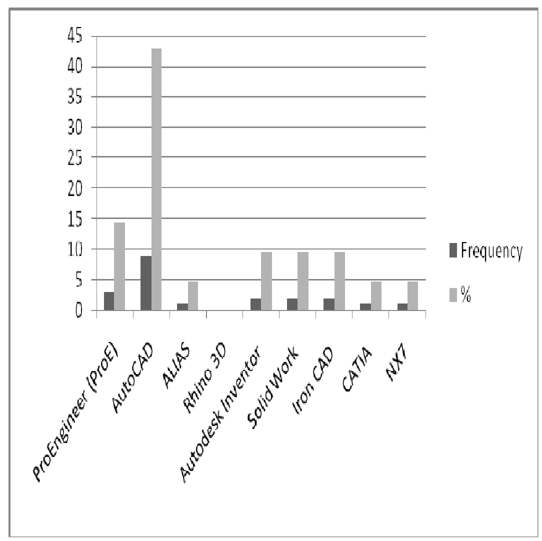


Figure 7-6: Types of CAD software frequently used

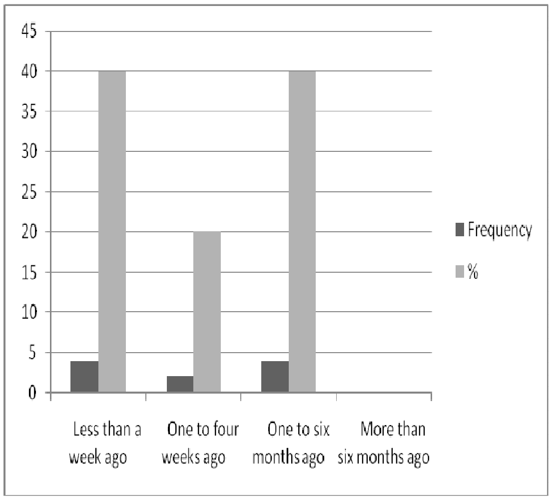


Figure 7-7: Respondents recent use of CAD

7.3.2 Feedback on Respondents' CAD Experiences

This section will report respondents feedback related to their perception and experiences with CAD. The items were developed based on data acquired from the case study (in particular, case study 1). Some of the items were included to check the respondents' feedback consistency. In such cases, the data will be presented simultaneously to provide comparison between responses. The feedback was categorised into three groups including 'Agree', 'Disagree', and 'Don't Know'.

a) Are they comfortable and keen to use CAD in designing work?

   2 items were included to explore whether respondents feel comfortable when using CAD and keen to use the software in designing work. The responses in Figure 7-8 and 7-9 indicated that all respondents agree they were comfortable and keen to use CAD in designing.

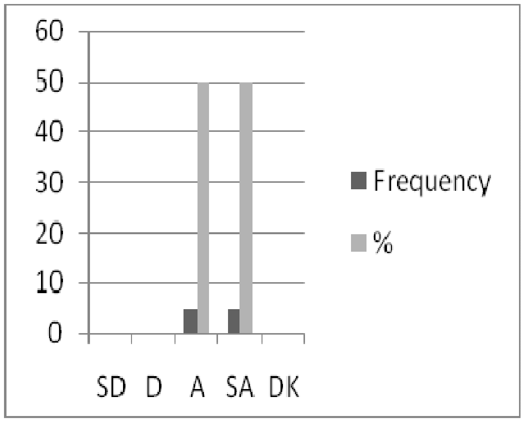


Figure 7-8: Feel comfortable in using CAD

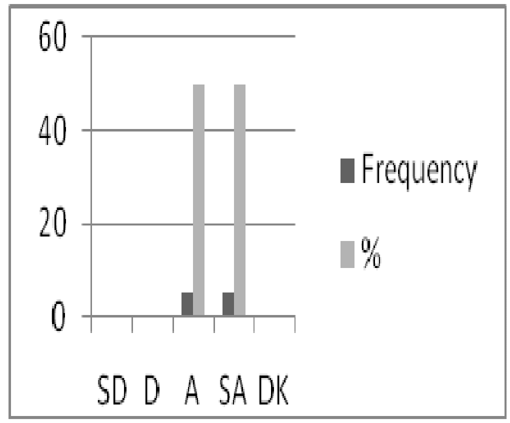


Figure 7-9: Keen to design using CAD

b) Perception of CAD role in designing.

2 items were included to explore respondents' perception of CAD role in designing that shown in Figure 7-10 and 7-11. The findings indicated that all respondents perceived CAD as a designing tool where 7 were responded to Strongly Agree (see Figure 7-10). In Figure 7-11, most of respondents disagree that they only used CAD as a presentational tool and only a small number of them agree to the statement. These data indicated that most respondents considered CAD as a designing tool rather than only as a presentational tool.

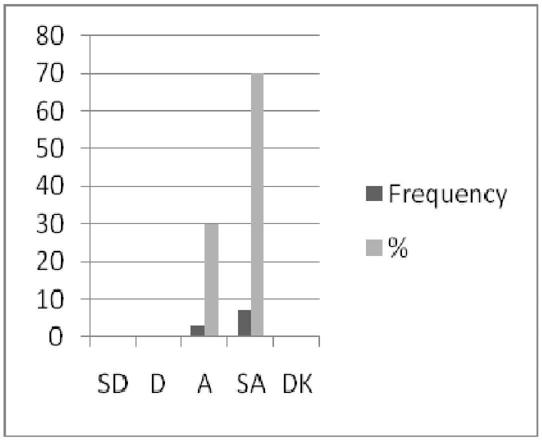


Figure 7-10: Use CAD as a designing tool

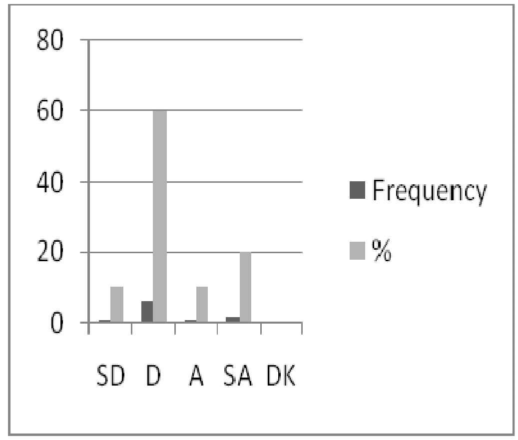


Figure 7-11: Use CAD only as a presentational tool

c) When they are normally using CAD?

3 items were included to explore when the respondents will normally use CAD in designing, and responses are presented in Figure 7-12 to 7-14. Most respondents agree that they used CAD from the initial stage through the final phase of design, and when generating design concepts. However, most respondents disagree that CAD was used in the concept generation process to seek potential design concepts.

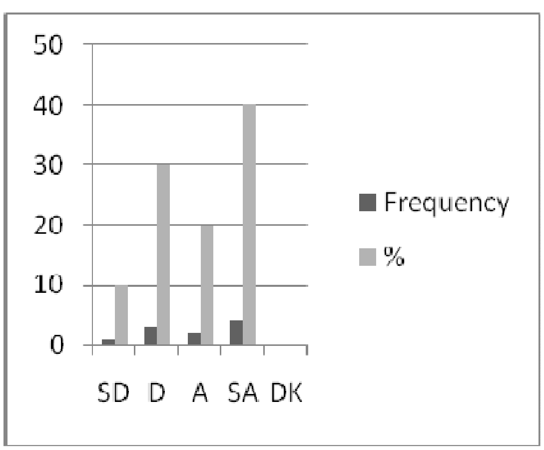


Figure 7-12: Use CAD from initial stage through the final phase of

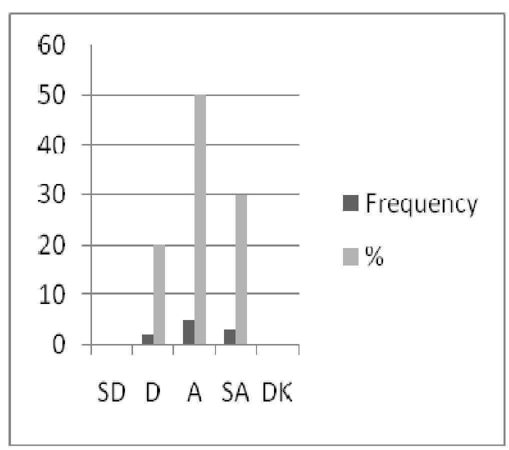


Figure 7-13: Use CAD to generate design concepts

design

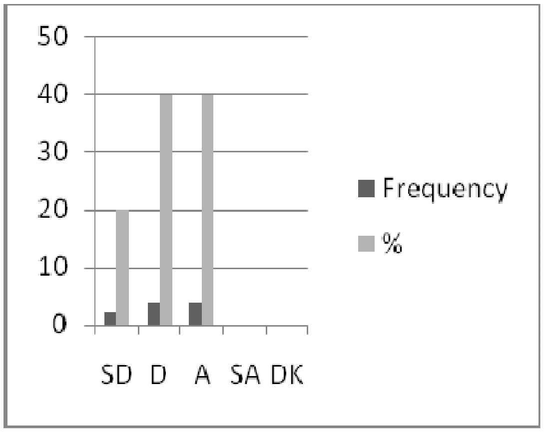


Figure 7-14: Use CAD in the brainstorming process

d) Does CAD facilitate the externalisation of ideas?

4 items were included to explore whether CAD does facilitate the externalisation of ideas and the responses are presented in Figure 7-15 to 7-18. Most of the respondents disagree that CAD allowed them to express their ideas efficiently (see Figure 7-15), but opposite responses were given to the statement that CAD allows the respondent to externalise their ideas effectively where most of them agree (see Figure 7-16). The findings from Figure 7-17 show that all respondents agree that CAD allowed them to model their design ideas accurately with a ratio 1:1, between Agree and Strongly Agree. In Figure 7-18, most respondents agree that CAD allowed them to visualize what is in their mind closer to reality and only small number of them were disagreed. Overall, most respondents agree that CAD did facilitate them to externalise their design ideas efficiently.

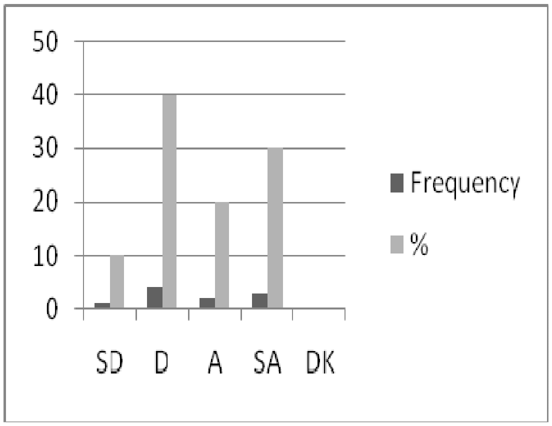


Figure 7-15: CAD allows respondents to express their ideas efficiently

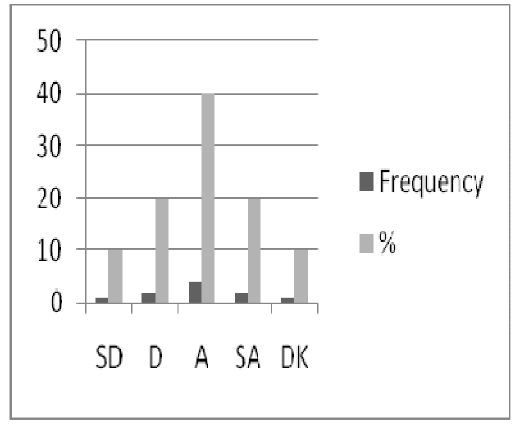


Figure 7-16: CAD allows respondents to externalise their ideas effectively

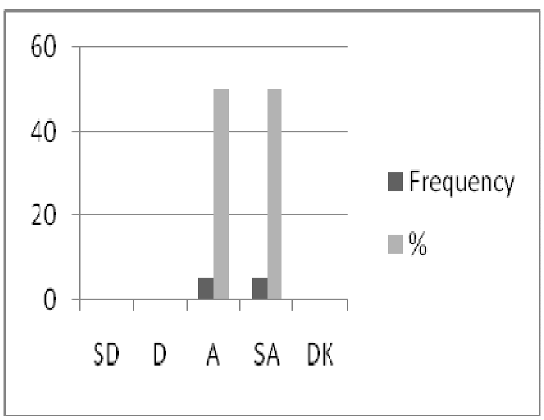


Figure 7-17: CAD allows to model design ideas accurately

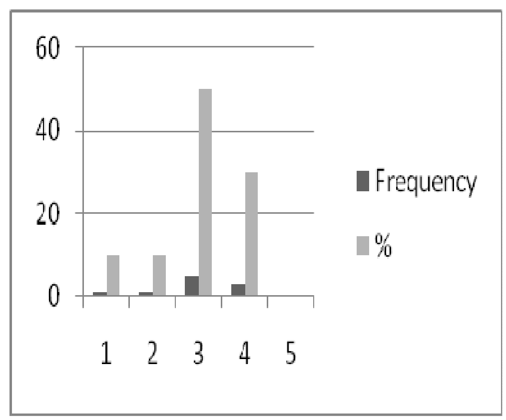


Figure 7-18: CAD allows to visualise what is in mind closer to reality

e) Experienced fluency behaviour whilst using CAD?

2 items were included to explore the emergence of fluency behaviour whilst respondents use CAD and the findings are presented in Figure 7-19 to 7-20. The items were developed based on the description of the fluency of ideas: the ability to generate ideas to fulfil certain requirements in some degree of time.

In Figure 7-19, most of respondents agree that they saved a lot of time developing design concepts through CAD, which means, less time was spent developing design ideas. Similarly, the majority of respondents agree that CAD allowed further development of design concepts in less time and a very small number of respondents disagreed (see Figure 7-20). Overall, both figures indicated that most of respondents had experienced fluency behaviour whilst using CAD.

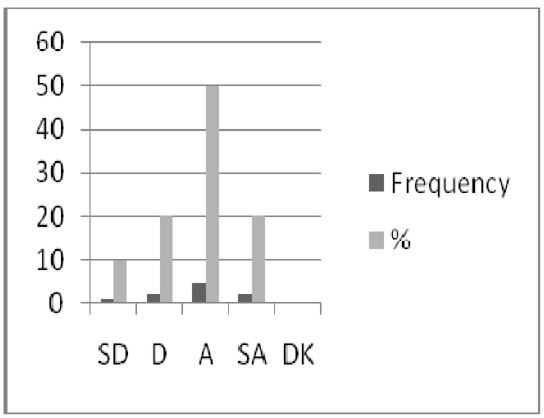


Figure 7-19: Saving a lot of times developing design concepts through CAD

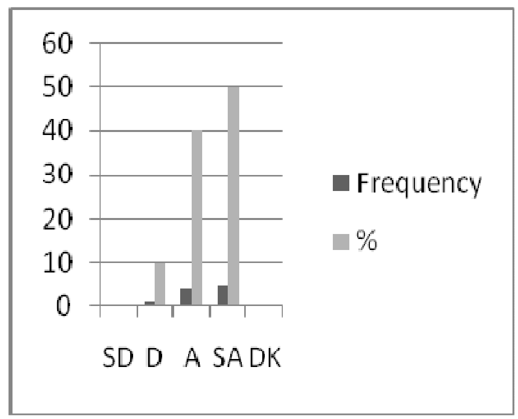


Figure 7-20: Allows further development of design concept in less time

f) Experienced motivation behaviour whilst using CAD?

4 items were included to check whether motivation behaviour emerged when respondents engaged with CAD. Both, Figure 7-21 and 7-22 indicated that all respondents feel enthusiastic to see the resulting outcome of CAD, and excited to see the design outcome when using CAD.

Figure 7-23 and 7-24 were related to the 'risk taking' when suggesting design ideas through CAD by users. 7 respondents agree that CAD encouraged them to go ahead with ideas, 5 Strongly Agree. More significant data is displayed in Figure 7-24 where 9 respondents agree that CAD made them feel confidence to have a go with their design ideas and only one disagreed. Based on the data, it was shown that most respondents had experienced motivation behaviour whilst using CAD, in particular, enthusiastic and risk-taking descriptors.

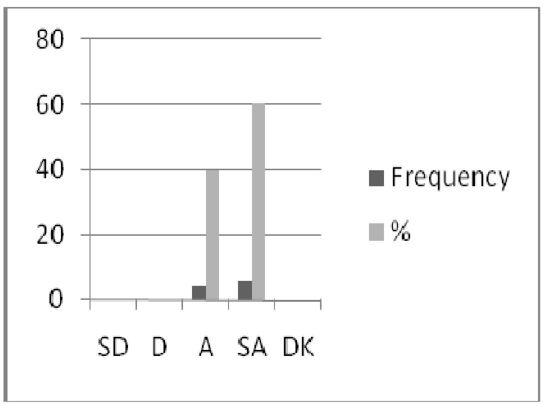


Figure 7-21: Keen to see the resulting outcome of CAD

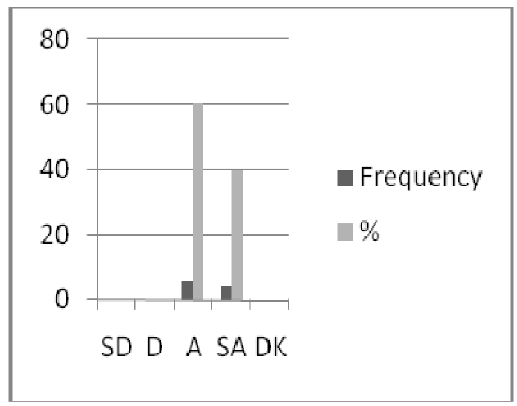


Figure 7-22: Excited to see the design outcome when using CAD

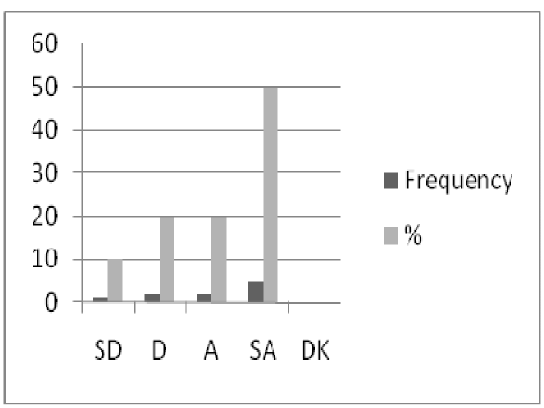


Figure 7-23: CAD encouraged respondent to go ahead with ideas

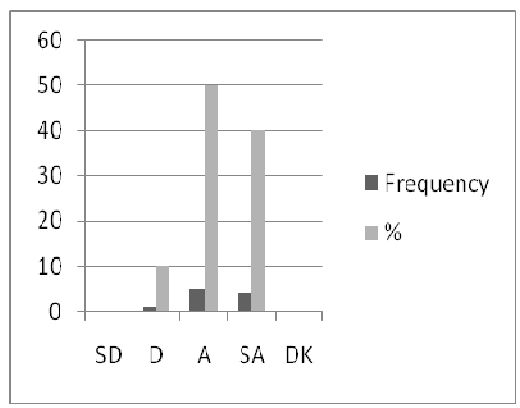


Figure 7-24: Feel confidence to 'have a go' with design ideas

g) Experienced novelty behaviour whilst using CAD?

This sub-section was exploring the novelty behaviour whilst respondents used CAD and 2 items were included. The findings from Figure 7-25 indicated that CAD enabled the generation of surprising ideas by respondents with 7 of them agreeing. Similarly, most respondents agreed that CAD usage could lead to the emergence of a unique design concept (see Figure 7-26). The findings indicated that most of respondents had experienced the emergence of novelty behaviour whilst using CAD.

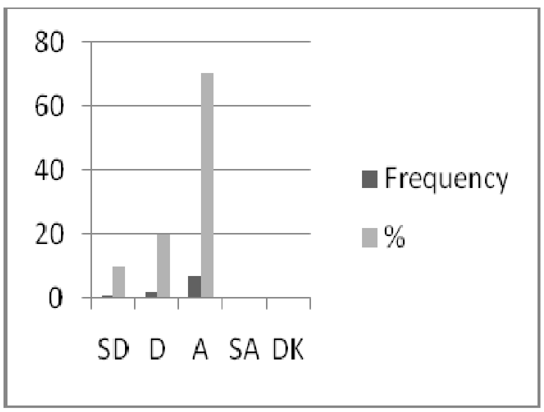


Figure 7-25: CAD enabled the generation of surprising ideas

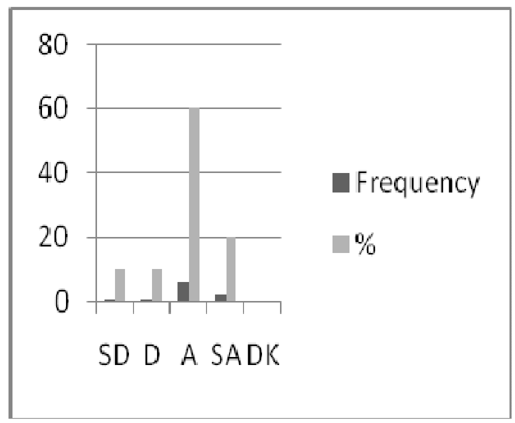


Figure 7-26: CAD usage could lead to the emergence of unique design concept

h) Experienced appropriateness behaviour whilst using CAD?

3 items were included in exploring the appropriateness behaviour whilst using CAD in designing. In Figure 7-27 and 7-28, the majority respondents agreed that CAD helped produce practical design output, and helped to distinguish useful design ideas. All respondents agreed that CAD helped to develop potentially functional design concepts which is also a descriptor of appropriateness (see Figure 7-29). There was a consistent pattern exhibited in

all the figures where most respondents agree that CAD encouraged to the emergence of appropriateness behaviour in designing.

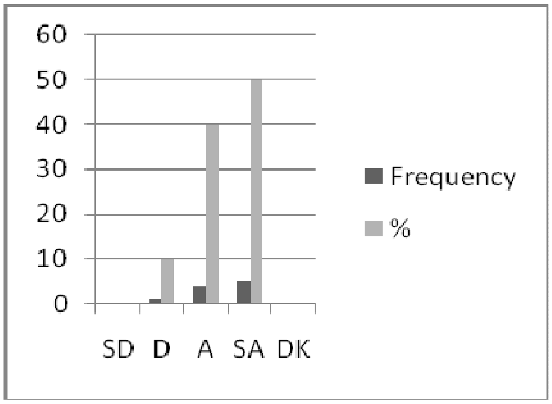


Figure 7-27: CAD help producing practical design output

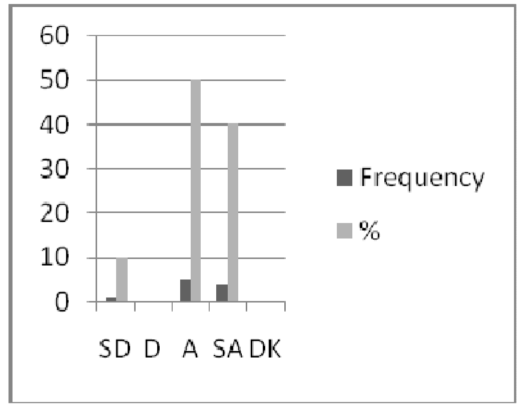


Figure 7-28: CAD help to distinguish useful design ideas

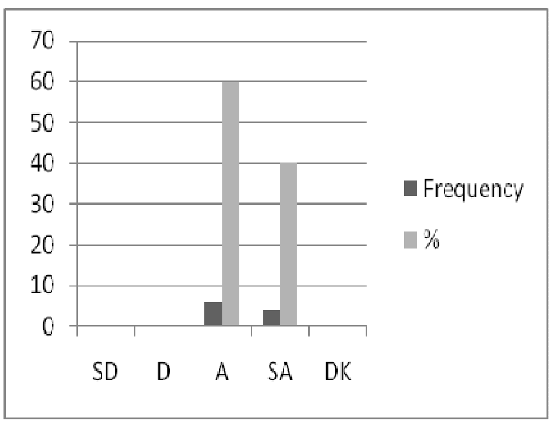


Figure 7-29: CAD help to develop potentially functional design concepts

i) Experienced flexibility behaviour whilst using CAD?

4 items were included to explore the flexibility behaviour whilst using CAD and the findings were presented in Figure 7-30 to 7-33. Most respondents agree that CAD allowed respondents to play around with their ideas and only 2 respondents disagreed (see Figure 7-30). To another item, all respondents agree that CAD allows them to explore the design ideas (see Figure 7-31.

In terms of the ability to continuously assess the design development, 9 respondents agreed that CAD enabled respondents to assess the design development from time to time (see Figure 7-32). This was supported by data in Figure 7-33, where all of the respondents agreed that whilst using CAD they continuously assessed their design concepts. Overall the respondents had experienced flexibility behaviour whilst using CAD.

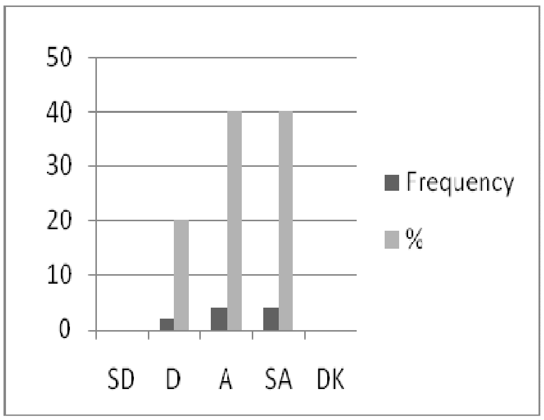


Figure 7-30: CAD allows respondents to play around with ideas

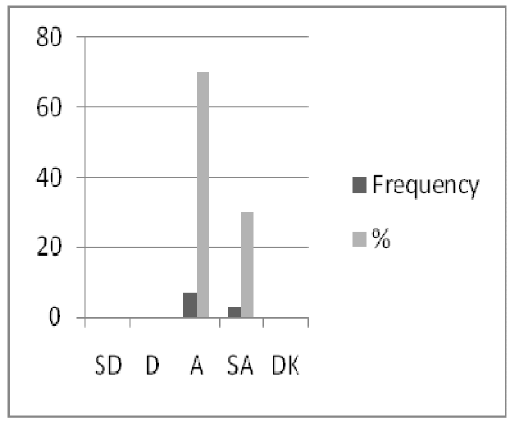


Figure 7-31: CAD allows respondents to explore their ideas

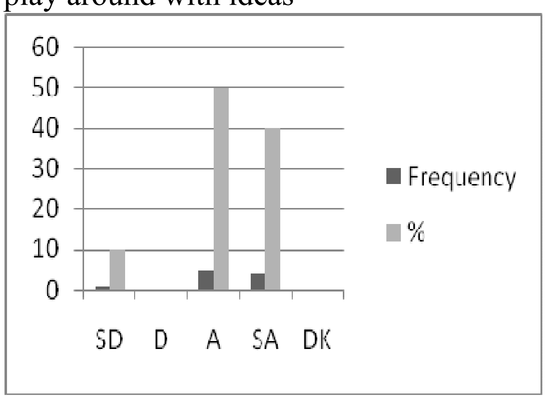


Figure 7-32: CAD features enabled respondents to assess the design development from time to time

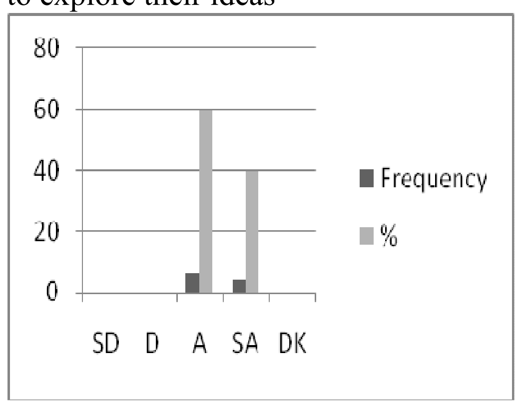


Figure 7-33: Whilst designing in CAD respondents continuously assess their design concept

j) Experienced sensitivity behaviour whilst using CAD?

The sensitivity behaviour was explored through 4 items included in the questionnaire and presented in Figure 7-34 to 7-37. Most of the respondents agreed that CAD encourages them to improve their design ideas when designing and only one respondent disagreed (see Figure 7-34). When the respondents were provided with the description of ‘seek perfection ‘(one of the sensitivity behaviour descriptors in the questionnaire), all of them agreed that they had displayed at least one aspect of this behaviour whilst designing with CAD based on the description given (see Figure 7-35).

As shown in Figure 7-36, 8 respondents agreed that CAD enabled them to see problems which they had not encountered before and all respondents agreed that CAD allowed them to realise problems that may exist in the design concept (see Figure 7-37). Overall, most of respondents had experienced sensitivity behaviour whilst using CAD in designing.

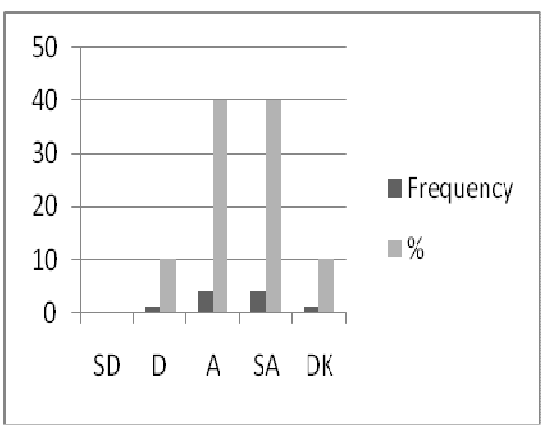


Figure 7-34: CAD encourages respondents to improve their design ideas

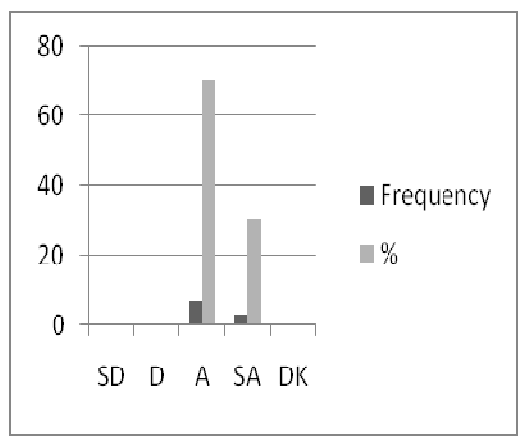


Figure 7-35: Respondents displayed at least one aspects of seek perfection behaviour whilst designing in CAD

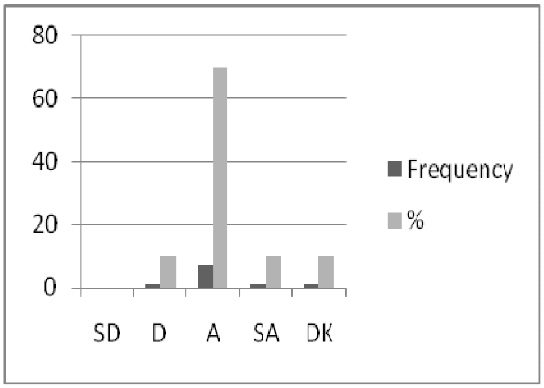


Figure 7-36: CAD enabled respondents to see problems which they had not thought before

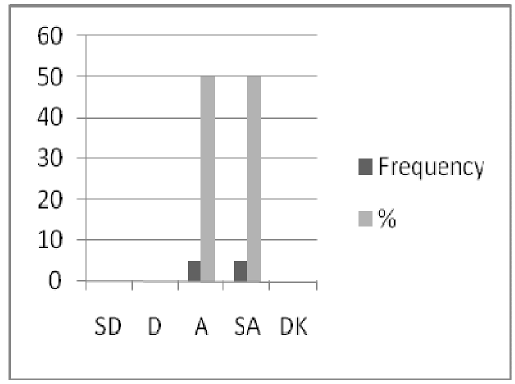


Figure 7-37: CAD allows respondents to realise problems that may exist in the design concept

k) Experienced insightfulness whilst using CAD?

4 items were included to explore the insightfulness behaviour whilst respondents used CAD and findings are presented in Figures 7-38 to 7-41. The findings in Figure 7-38 indicated that CAD had enabled respondents to put together old and new information to produce new design ideas. 9 respondents agreed with 5 of them strongly agreeing (see Figure 7-38).

In terms of the easy storage and accessibility of information within CAD, all respondents agreed with 7 of them strongly agreeing (see Figure 7-39). To the item that CAD sometimes enables users to make certain suggestions without any logical reasoning, most respondents agreed and only a small number of them disagreed (see Figure 7-40). However, Figure 7-41 shows that all respondents felt comfortable making necessary assumptions for design decisions whilst in CAD where the ratio between agree and strongly agree was 1:1. Overall, most of the respondents had experienced insightfulness behaviour whilst using CAD in designing.

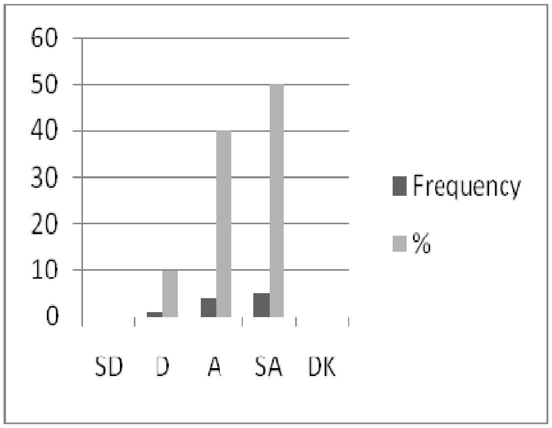


Figure 7-38: CAD enabled respondents to put together old and new information to produce new design ideas.

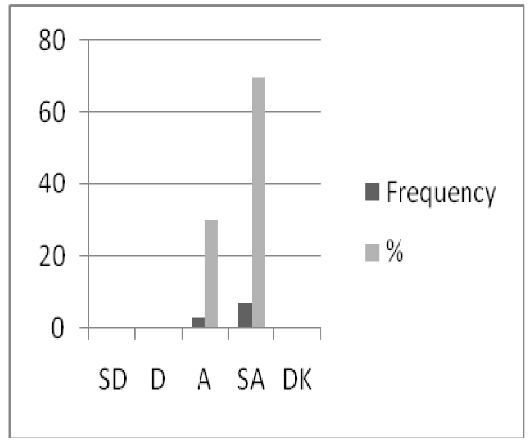


Figure 7-39: It is easy to store and retrieve information within CAD that would help respondents in the process of design development

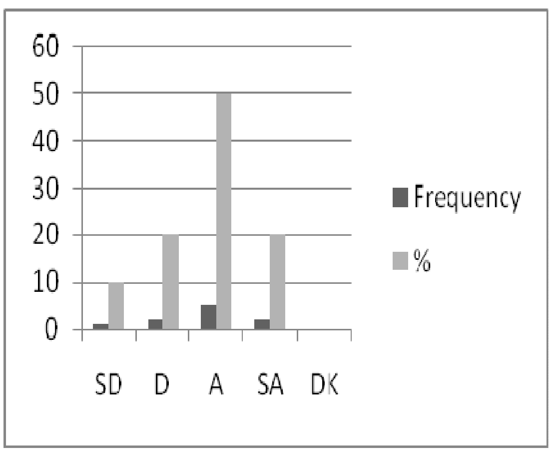


Figure 7-40: CAD sometimes enabled respondents to make certain suggestions without any logical reasoning

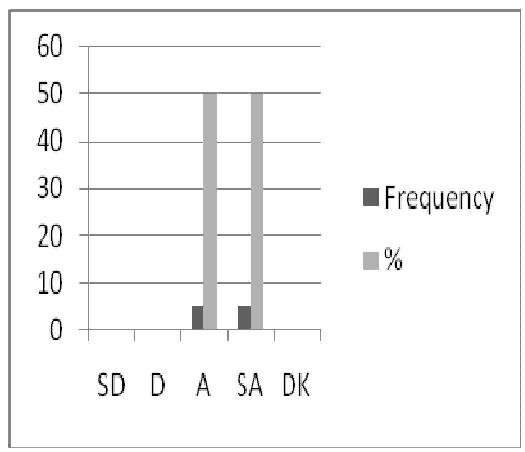


Figure 7-41: Respondents feel comfortable to make necessary assumption for design decisions whilst in CAD

7.3.3 Research Findings Feedback

In section 3, two items were related to the findings of the case study. One of the items seeks to responses whether the respondents were surprised that quite a number of creative behaviours had been displayed by CAD users. 6 respondents were surprised with the results, but 3 other respondents disagree.

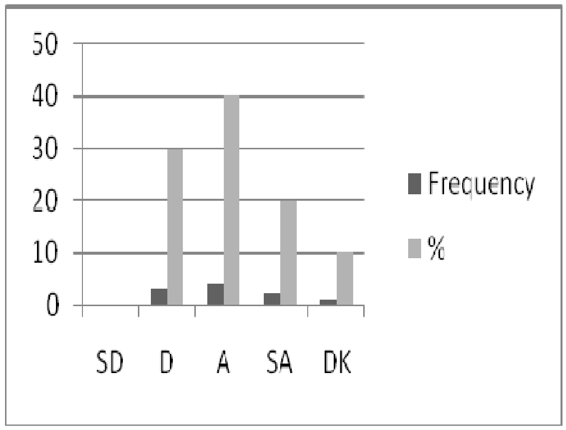


Figure 7-42: Respondents surprised that quite a number of creative behaviours had been displayed by CAD users.

To the item seek responses to whether respondents considered themselves as a CAD recorder or CAD designer, only 5 responded: 2 Strongly Disagree, 1 Disagree, 1 Agree and 1 Strongly Agree (see Figure 7-43)

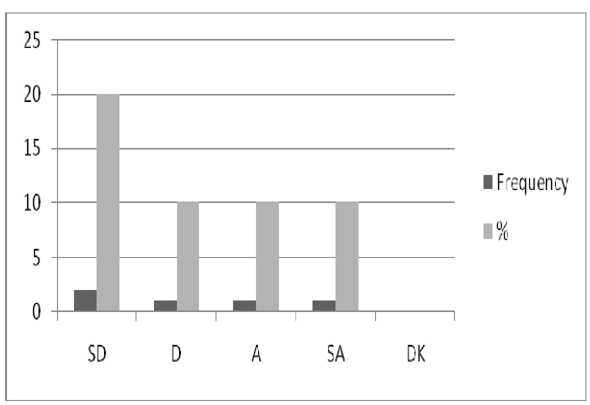


Figure 7-43: Respondents considered themselves as a CAD recorder rather than CAD designer

7.3.4 The Creative Behaviours Framework in Wider Applications

This section was aimed at design educators to provide feedback on how the Creative Behaviours Framework could contribute to current teaching and assessment in the wider education context. There were only 8 respondents who gave feedback to this section. The data shows that the respondents have been involved in the teaching job not more than 20 years and most of the respondents had at least 5 years experience (see Figure 7-44).

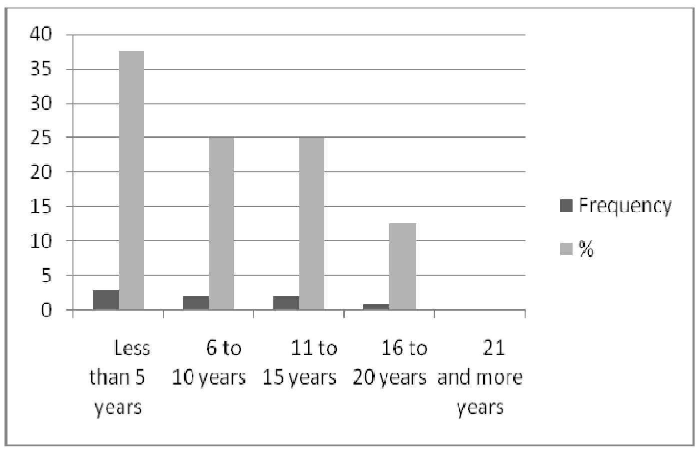


Figure 7-44: Involvement in the teaching job

a) Respondents' current exercises related to creativity assessment

3 items were included to explore respondents' current exercises related to creativity assessment. The data from Figure 7-45 shown that most of the respondents agreed that they included creativity as part of their lesson planning objectives. 4 respondents agreed that they used systematic technique for observing creative behaviours, but 3 others disagreed with 1 Don't Know (see Figure 7-46). In assessing their students' creativity, most respondents

agreed that they were evaluating the students by final product (see Figure 7-47).

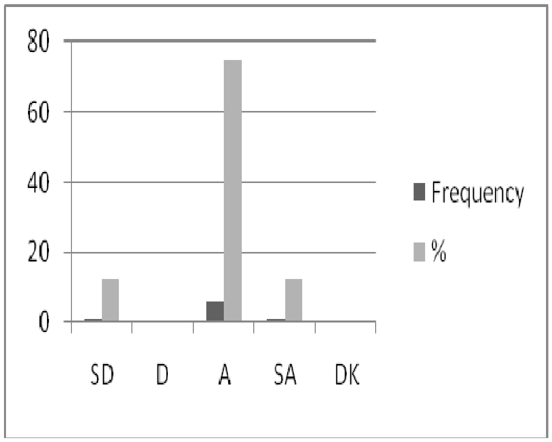


Figure 7-45: Include creativity as part of lesson planning objectives

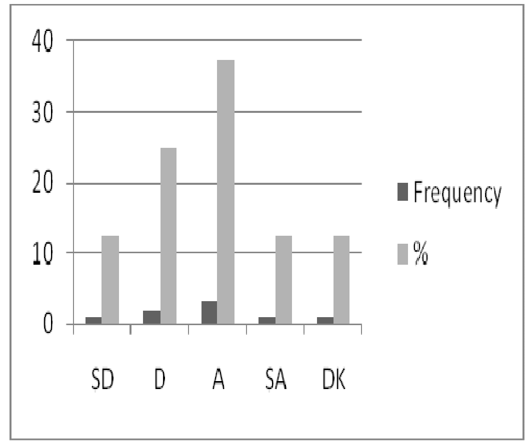


Figure 7-46: Presently using a systematic technique for observing students' creativity

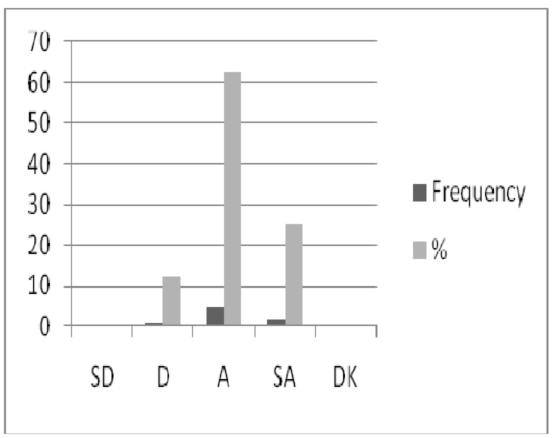


Figure 7-47: Assess students' creativity through the final product

b) Respondents' opinion on potential Creative Behaviours Framework roles

3 items were included to explore respondents' opinion on potential Creative Behaviours Framework roles. Figure 7-48 indicated that most respondents agreed that the Creative Behaviours Framework might be useful in facilitating their lesson outlines. Almost all respondents agreed that the Creative

Behaviours Framework would provide them with a systematic technique for observing creative behaviours, with 1 Don't Know (see Figure 7-49).

To the item seek responses to whether Creative Behaviours Framework would allow respondents to assess students' creativity during the learning activities, all of them agreed (see Figure 7-50). However, there was 1:1 ratio between 'Yes' and 'No' whether this framework would have any impact on the current teaching and assessment approaches (see Figure 7-51).

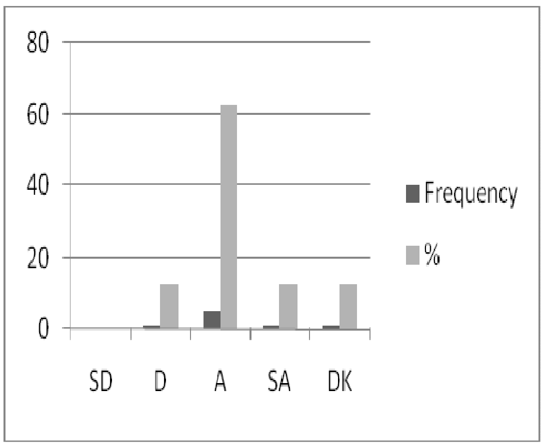


Figure 7-48: Creative Behaviours Framework might be useful in facilitating respondents to prepare lesson outlines

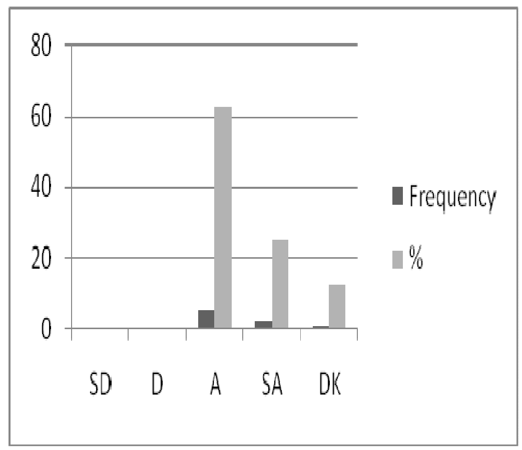


Figure 7-49: Creative Behaviours Framework would provide respondents with a systematic technique for observing creative behaviours

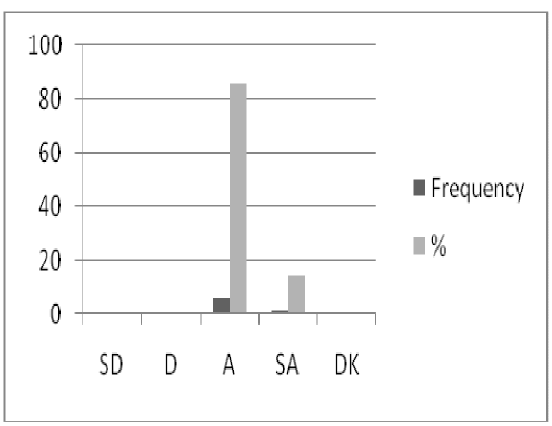


Figure 7-50: Creative Behaviours Framework would allow respondents to assess students' creativity during the learning activities

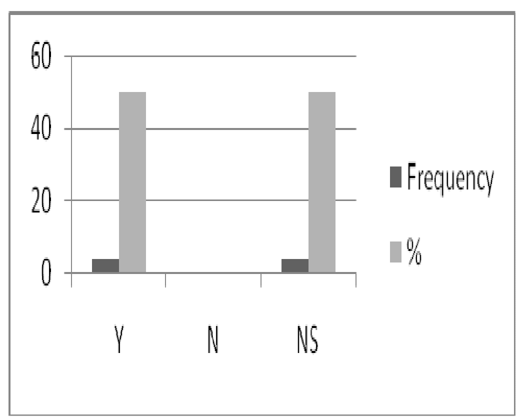


Figure 7-51: Could the Creative Behaviours Framework have any impact on the current teaching and assessment approaches?

7.4 Paper Questionnaire

This questionnaire was intended to provide feedback from the students of the Design and Technology Department, Loughborough University. Initially, the questionnaire was suggested to be the online questionnaire survey as in the prior approach. However, due to some comments from the respondents in Malaysia regarding the online survey, the strategy was substituted for paper-based questionnaire. The respondents had brought out some issues such as:

a) poor image quality such as diagrams, tables, charts not clear,
b) some items overlapped with other items;
c) not all items in the research findings section developed from the results itself.

When remedies had been undertaken, issues (b) and (c) were resolved, however, there was no significant improvement achieved for (a). Due to that, paper-based questionnaire was considered as an appropriate approach to be undertaken.

The students that were invited to participate as respondents were undergraduates (1, 2, and 3), Masters students, and PGCE students. They were approached in four ways:

a) emails were sent to their student email groups providing information about the survey; when, where to reply, why them, etc.,
b) the researcher himself giving a brief about the survey in the beginning of selected class sessions,

c) the lecturers helped to distribute the questionnaires to the students in the lectures.

d) some copies of the questionnaires were also provided in the CAD Lab. where students who were using the facilities for their assignment or attending lectures could also participate if they were interested.

The questionnaires were distributed to the students based on the Table 7-1 shown.

Table 7-1: Questionnaires distribution to target group

Course	Subject	Group	Instructor
UG-year 1	Computing for Designers	Group 1 – C4D BA	Dr. Richard Bibb
		Group 2 – C4D BSc	Sean Kearslake
		Group 3 – C4D BA	Sean Kearslake
		Group 4 – C4D BA	Dr. Ian Campbell
UG-year 2	Design and Manufacturing	Group 2 – DM&T BA and BSc	Kevin Badni
UG-year 3	Final Year Project Lecture	BA and BSc final year	Dr. Richard Bibb
Masters Students	NA	NA	Kevin Badni
PGCE students	NA	NA	Nigel Zanker

In order to allow all the respondents who completed the questionnaires to return it easily, three 'questionnaire return boxes' were provided for them. The boxes were available and located at Computer Labs in the Design and Technology Department foyer. From 100 questionnaires distributed, 41 completed questionnaires were returned; a 41% of return rate. The details about the respondents will be discussed in the next section.

7.4.1 Demographic Information

7 items were included to record information about the respondents. The information requested concerned the respondents' age, role, years of CAD use, skill level, source of CAD knowledge, types of CAD frequently used, and recent use of CAD. The results were shown in Figure 7-52 to 7-58.

All of the respondents aged were between 19 to 39 years old with 97.5% aged below 29 years old (see Figure 7-52). The respondents consisted of undergraduate students (year 1, 2, and 3), Masters' students, lecturers, and designers, where 91.8% were undergraduate students (see Figure 7-53). In terms of number of years in using CAD, 64% of the respondents had between 1 to 4 years experience, and 12.2% had more than 5 years experience (see Figure 7-54). The data in Figure 7-55 shows that all of the respondents fall under three categories: novice (51.2%), intermediate (41.5%) and expert (7.3%). None of the respondents was a non-CAD user.

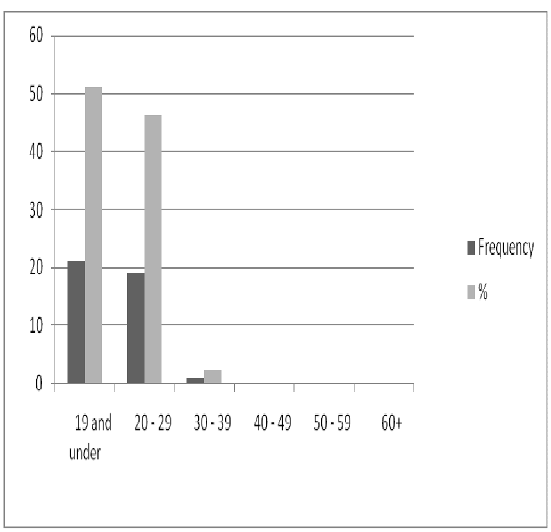


Figure 7-52: Respondents' age

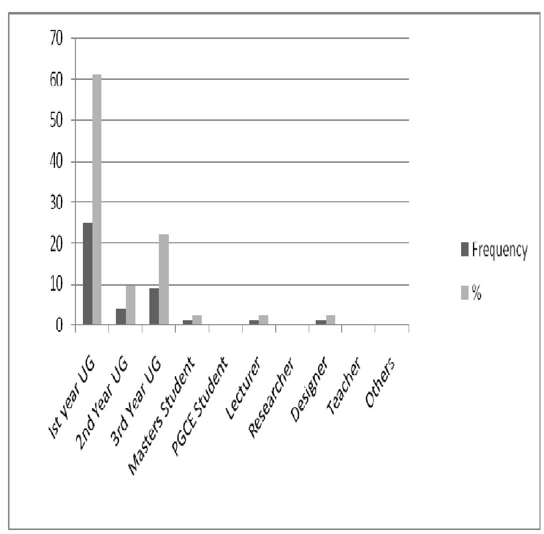


Figure 7-53: Respondents' role

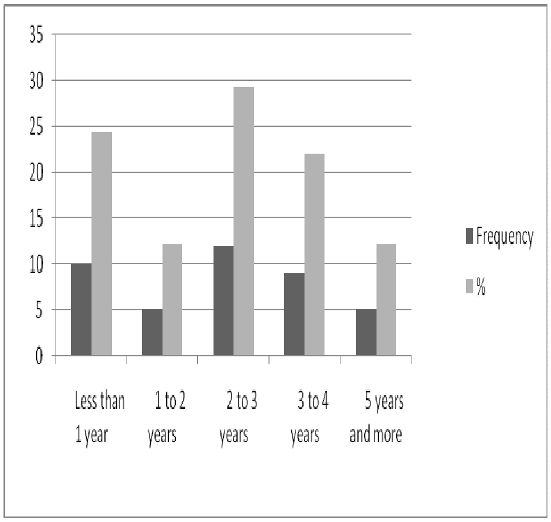


Figure 7-54: Number of years has using CAD

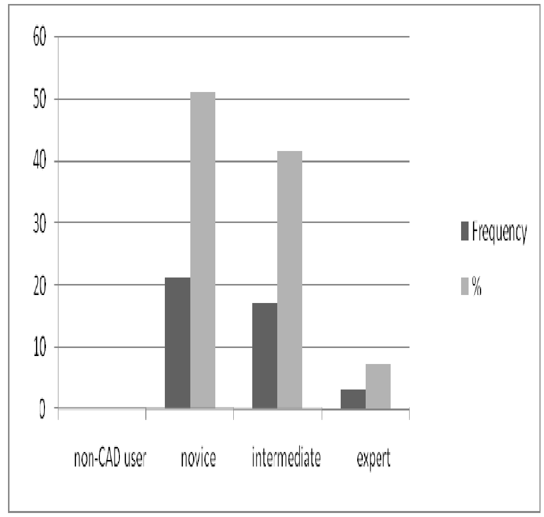


Figure 7-55: CAD user skill level

The responses indicated that CAD knowledge was mostly acquired during undergraduate courses and by self-learning (see Figure 7-56). In terms of type of software frequently used by respondents, 58.2% were using ProEngineer besides other software such as 'Sensable FreeForm', 'ProDeskstop', '3D Studio Max', 'Solid Works', 'Google Sketchup', and 'AutoDesk Inventor' (see Figure 7-57). The data also indicated that 90.2% of respondents had been using CAD for less than one week prior completing the questionnaires (see Figure 7-58). These could be an indication the responses were given from respondents' recent CAD experiences.

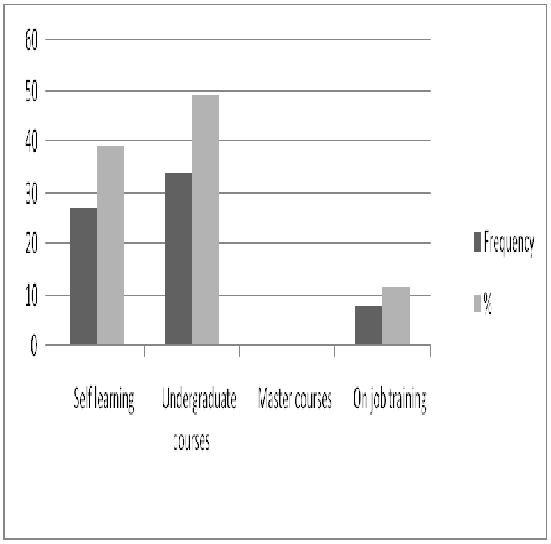


Figure 7-56: Sources of CAD knowledge acquired

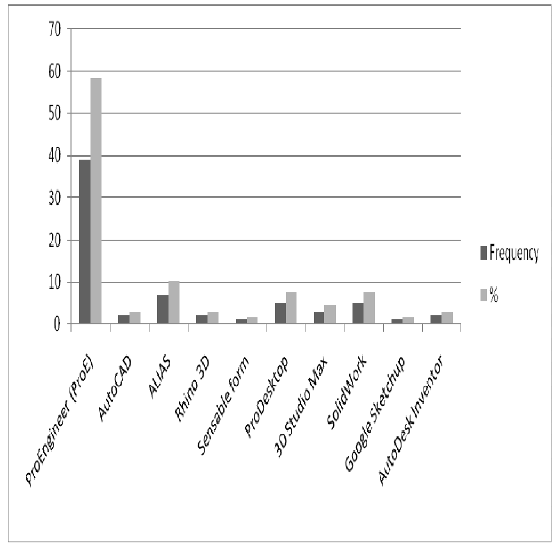


Figure 7-57: Types of CAD software frequently used

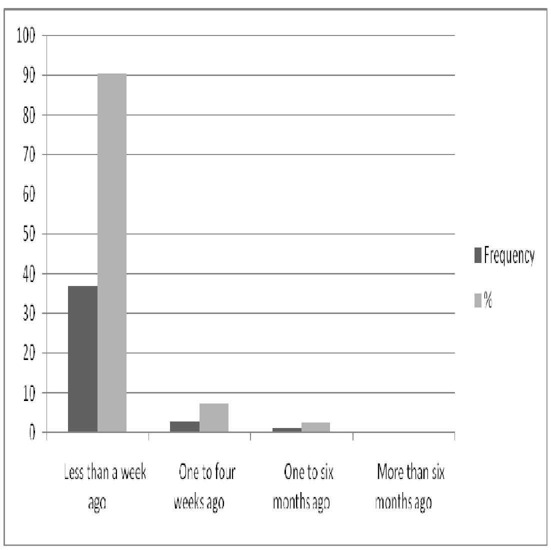


Figure 7-58: Respondents recent use of CAD

7.4.2 CAD Experiences

The respondents' perception and experiences with CAD is reported in this section. A similar procedure as prior section will be implemented in presenting the data.

a) Are they comfortable and keen to use CAD in designing work?

   2 items were included to explore whether respondents feel comfortable when using CAD and keen to use the software in designing work. There are shown in Figure 7-59 and 7-60.

   75.6% of the respondents feel comfortable when using CAD for their design work, and 56.1% agree that they are keen to do designing in CAD. Overall, the findings indicated that the respondents feel comfortable and keen using CAD in their designing work with a minority of respondents, disagreeing.

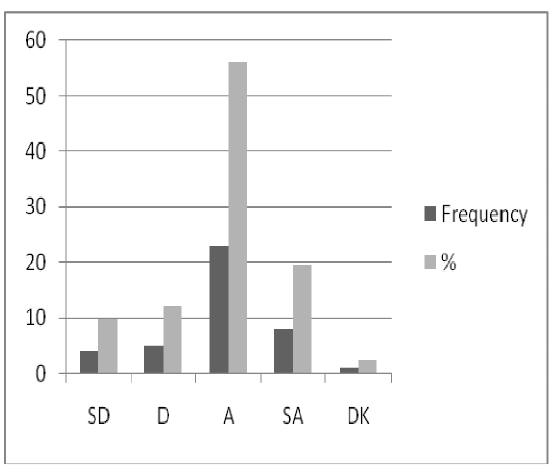


Figure 7-59: Feel comfortable in using CAD

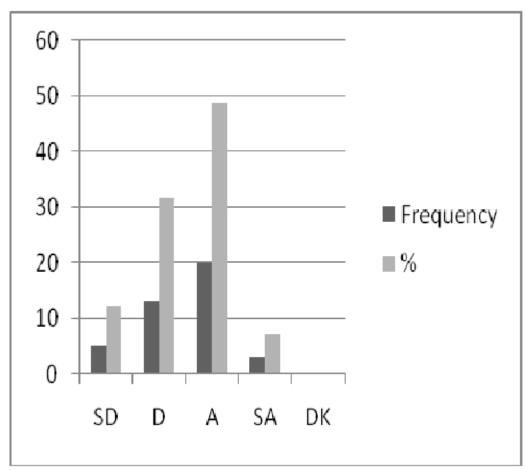


Figure 7-60: Keen to design using CAD

b) Perception of CAD roles in designing.

2 items were included to explore the respondents' perception of CAD roles in designing as shown in Figure 7-61 and 7-62. Most of the respondents considered CAD as a designing tool, and only 7.3% of the respondents disagreed (see Figure 7-61). Figure 7-62 indicated 61% respondents disagreed they only use CAD as a presentational tool and 39.7% agreed. Overall, a majority of respondents considered CAD as a designing tool rather than only as a presentational tool.

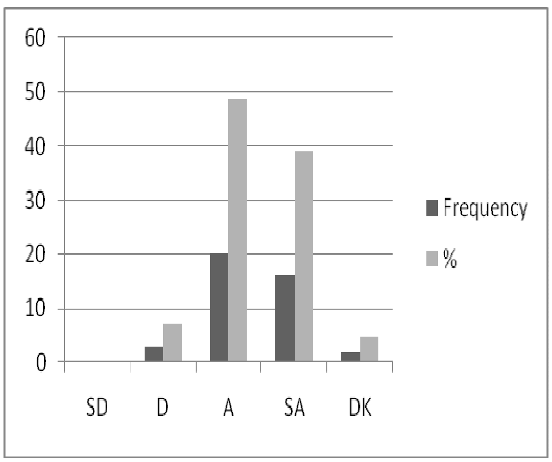


Figure 7-61: Use CAD as a designing tool

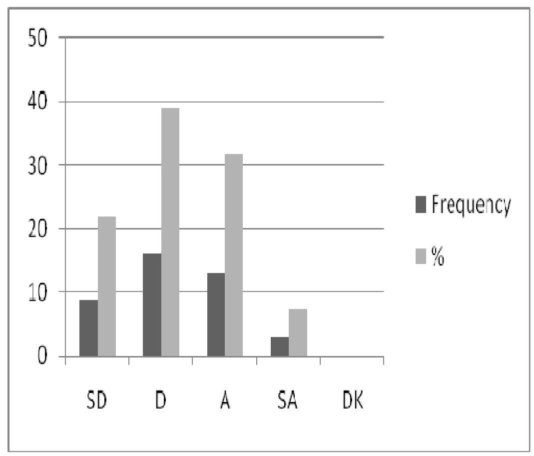


Figure 7-62: Use CAD only as a presentational tool

c) When they are normally using CAD?

3 items were included to explore when the respondents will normally use CAD in designing, and responses are presented in Figure 7-63 to 7-65. 43.9% of respondents disagreed that they use CAD from the initial through to the final phase of their design, 43.9% of respondents disagreed that they use CAD to generate design concepts, and 61% of respondents strongly disagreed that

they used CAD in the concept generation process to seek potential design concepts. The data indicated that most of the respondents were not using CAD in the early stage of the designing which involved concept generation activities.

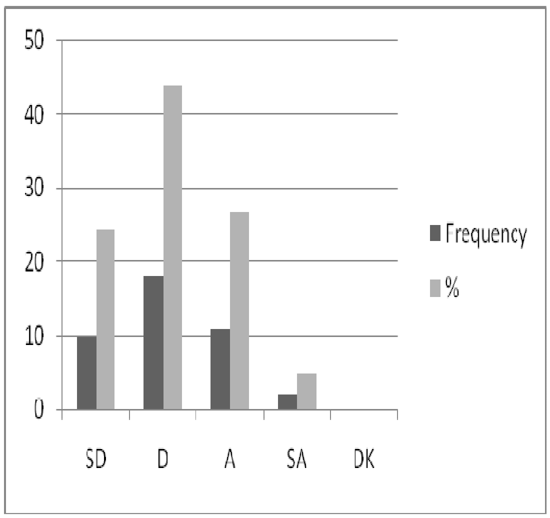


Figure 7-63: Use CAD from initial stage through the final phase of design

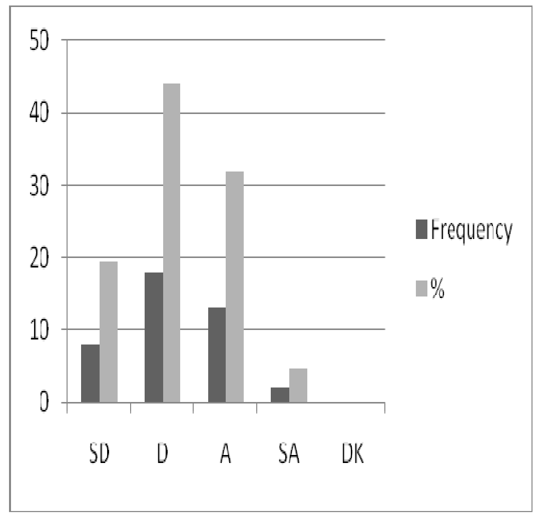


Figure 7-64: Use CAD to generate design concepts

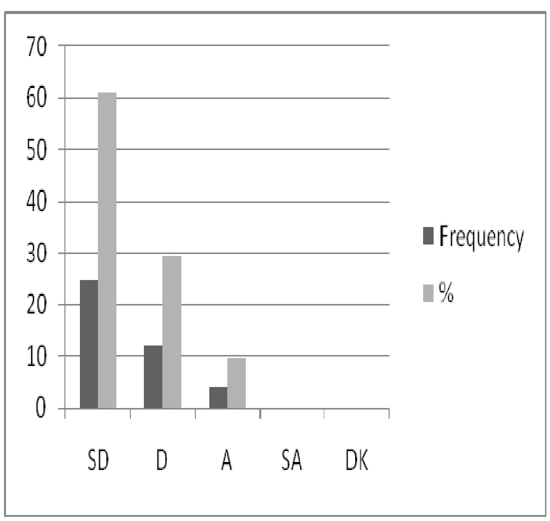


Figure 7-65: Use CAD in the brainstorming process to seek potential design concepts

d) Does CAD facilitate the externalisation of ideas?

2 items were included to explore whether CAD facilitate the externalisation of respondents' ideas. These are shown in Figures 7-66 and 7-67. The findings in Figure 7-66 indicated 51.2% of respondents agreed that CAD allowed them to express their ideas efficiently and 17.1% of the respondents strongly agreed. Similarly, Figure 7-67 shows 63.4% of the respondents agreed that CAD allowed them to externalise their ideas and 4.9% strongly agree. Based on the data, most of the respondents agreed that CAD allows users to express and externalise their ideas efficiently.

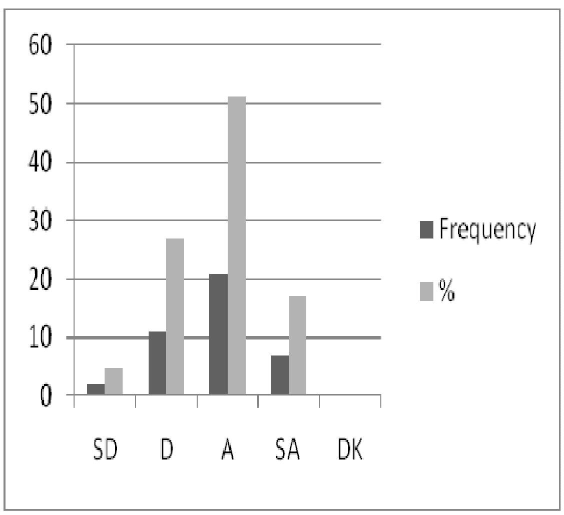


Figure 7-66: CAD allows respondents to express their ideas

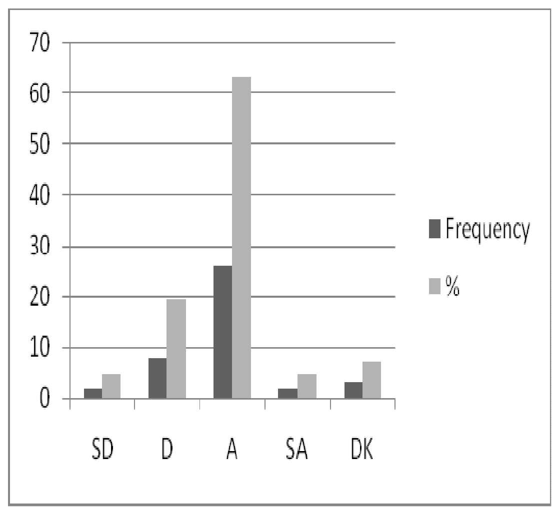


Figure 7-67: CAD allows respondents to externalise their ideas effectively

e) Experienced fluency behaviour whilst using CAD?

2 items were included to explore the fluency behaviour of respondents whilst using CAD. These are shown in Figures 7-68 and 7-69 which related to one of the fluency behaviour descriptors; fluency of ideas. The findings indicated

that most of the respondents disagreed that CAD helped them in saving a lot of time developing design concepts using the software where 31.7% disagreed and 14.6% strongly disagreed. However, 31.7% of the respondents agreed, 9.8% strongly agreed, with 4.9% 'Don't Know'.

A similar pattern is shown in Figure 7-69 where 39% of the respondents disagreed that CAD allows further development of design concept in less time and 14.6% strongly disagreed. Meanwhile, the data also indicated that 34.1% of the respondents agreed, 9.8% strongly agreed with 2.4% 'Don't Know'. Overall, the data indicated that most respondents had not experienced the fluency of behaviour (fluency of ideas) whilst using CAD in designing.

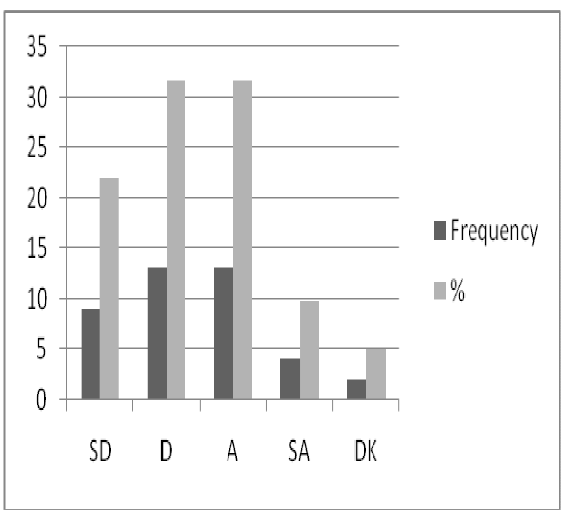


Figure 7-68: Saving a lot of times developing design concepts through CAD

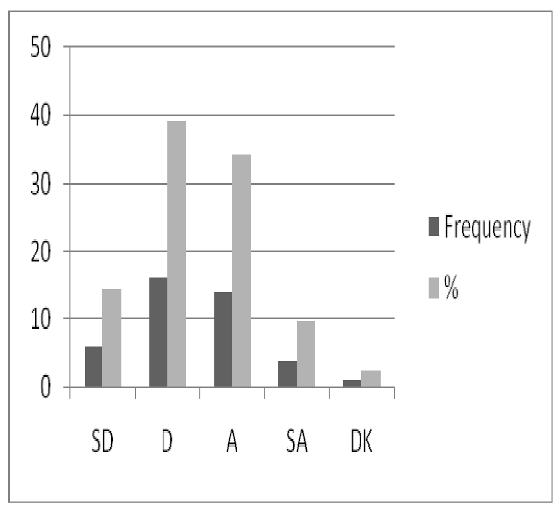


Figure 7-69: Allows further development of design concept in less time

f) Experienced motivation behaviour whilst using CAD?

4 items were included to explore the motivation behaviour of respondents whilst using CAD. These are shown in Figures 7-70 to 7-73. The findings indicated 51.2% of the respondents agreed that they were keen to see the resulting outcome of CAD when using the software in designing, 58.5% respondents agreed that they feel enthusiastic to see the design outcome when involving it in designing, 56.1% of the respondents agreed that CAD use encouraged them to go ahead with the design ideas, and 70.7% of the respondents agreed that 'CAD makes them feel confident to have a go' with their design ideas. Overall, the data indicated that most of the respondents experienced motivation behaviour whilst using CAD in designing and only a minority of them had not experienced it.

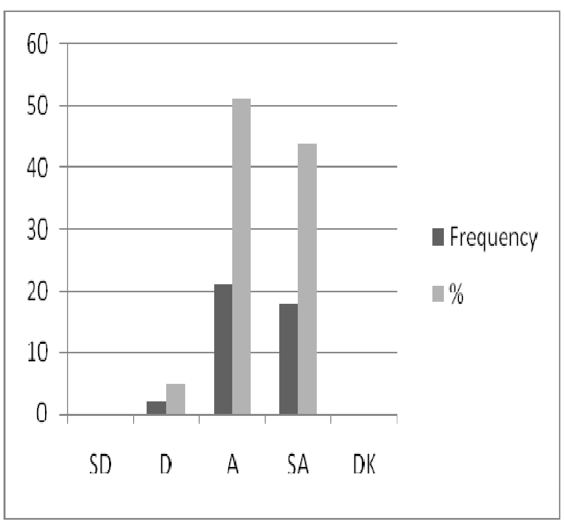


Figure 7-70: Keen to see the resulting outcome of CAD

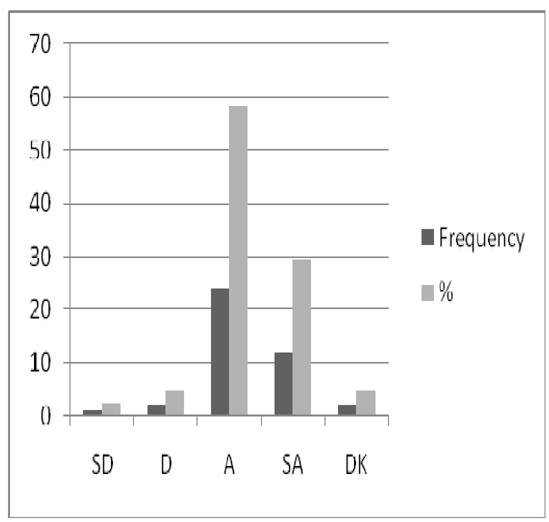


Figure 7-71: Enthusiastic to see the design outcome when using CAD

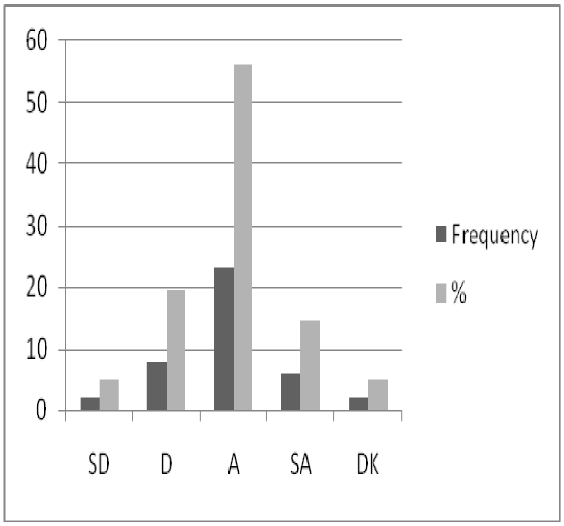


Figure 7-72: CAD encourages respondent to go ahead with ideas

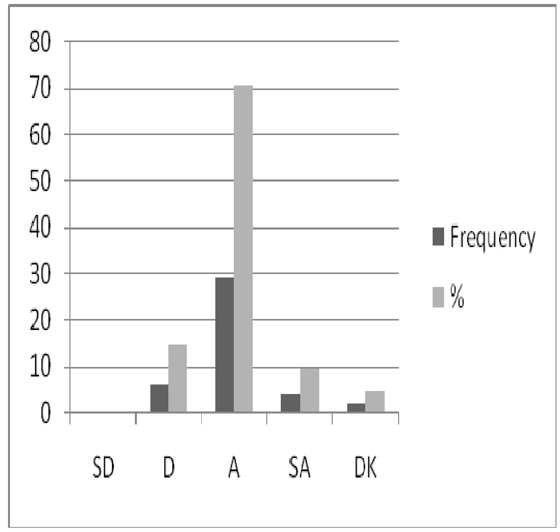


Figure 7-73: Feel confidence to 'have a go' with design ideas

g) Experienced novelty behaviour when using CAD?

This sub-section was exploring the novelty behaviour whilst respondents used CAD and 2 items were included. In Figure 7-74, 39% of the respondents disagreed that CAD enabled the generation of surprising ideas and 19.5% strongly disagreed. Meanwhile, 39% of the respondents agreed with 2.4% 'Don't Know'.

A similar pattern is exhibited in Figure 7-75, where 51.2% of the respondents disagreed that CAD usage could lead to the emergence of unique design concepts and 14.6% strongly disagreed. The data also indicated that only 24.4% agreed with 9.8% 'Don't Know'.

Overall, the data indicated that many of the respondents had not experienced novelty behaviour whilst using CAD especially in relation to the generation of unique and surprising ideas compared to the percentages that experienced them.

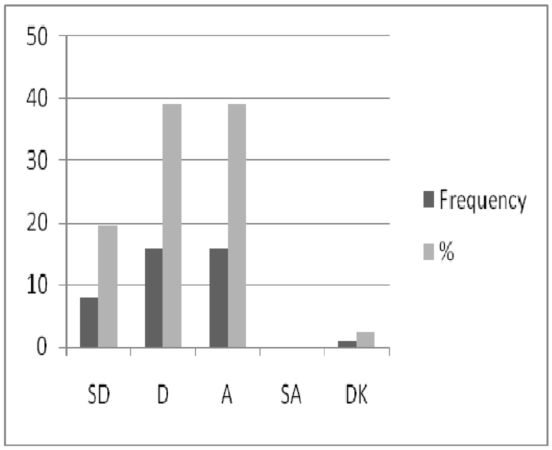


Figure 7-74: CAD enabled the generation of surprising ideas

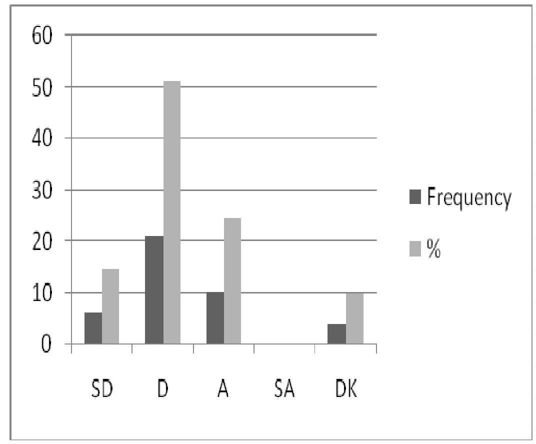


Figure 7-75: CAD usage could lead to the emergence of unique design concept

h) Experienced appropriateness behaviour when using CAD?

3 items were included in exploring the appropriateness behaviour whilst using CAD in designing as shown in Figures 7-76 to 7-78. The findings indicated 63.4% of the respondents agreed that CAD usage has helped them to produce practical design outputs, 68.3% agreed that CAD helped to distinguish useful design ideas, and 58.5% agreed that CAD helped to develop potentially functional design concepts. Overall, most of the respondents had experienced appropriateness behaviour whilst using CAD with only a small percentage of respondents disagreeing that they had ever experienced it especially in Figure 7-78.

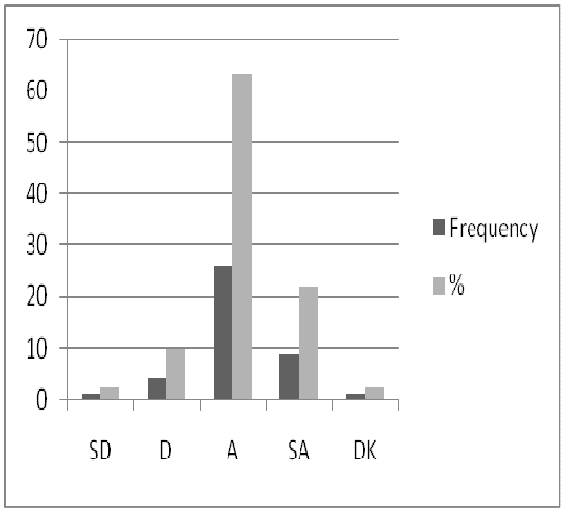


Figure 7-76: CAD help producing practical design output

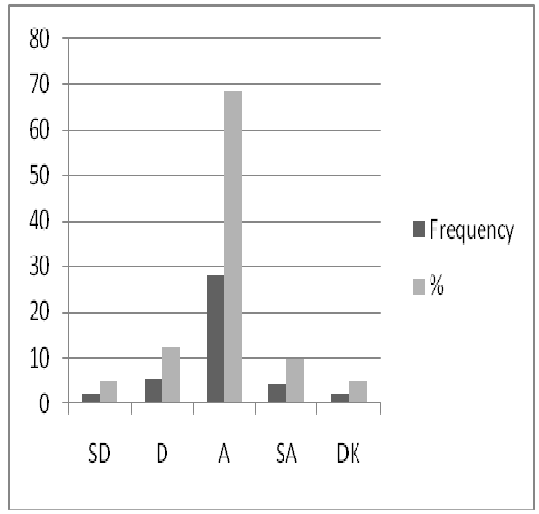


Figure 7-77: CAD help to distinguish useful design ideas

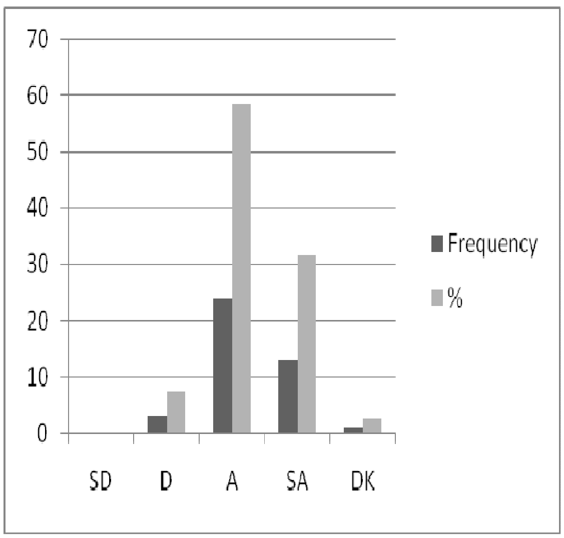


Figure 7-78: CAD help to develop potentially functional design concepts

i) Experienced flexibility behaviour whilst using CAD?

3 items were included to explore the flexibility behaviour whilst using CAD. These are shown in Figure 7-79 to 7-81. 43.9% of the respondents agreed that CAD allowed respondents to play around with their ideas, 73.2% agreed that they have the ability to continuously assess the design development in CAD, and 65.9% agreed that whilst using CAD they continuously assessed their

design concept. Overall, most of the respondents had experienced flexibility behaviour in particular ‘playing with ideas’ and ‘continuous reflection’ – assessing design work continuously.

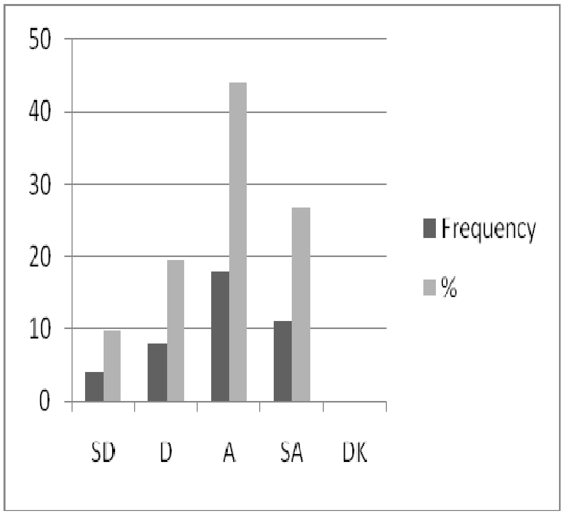


Figure 7-79: CAD allows respondents to play around with ideas

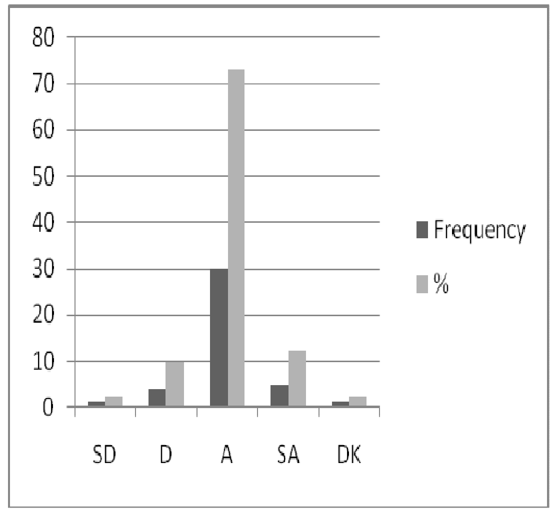


Figure 7-80: CAD features enabled respondents to assess the design development from time to time

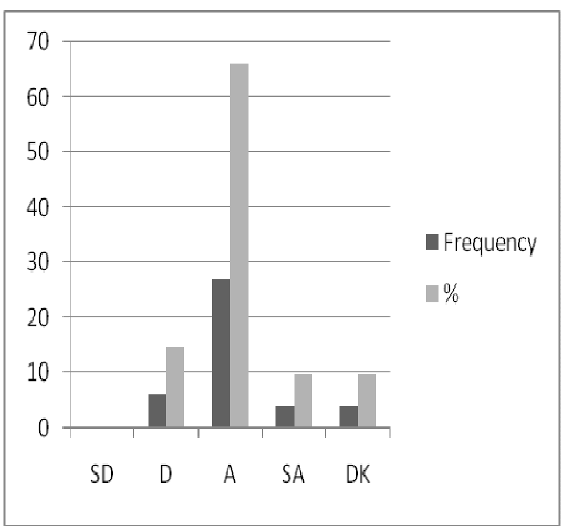


Figure 7-81: Whilst designing in CAD respondents continuously assess their design concept

j) Experienced sensitivity behaviour whilst using CAD?

4 items were included to explore the sensitivity behaviours whilst respondents used CAD. The findings are presented in Figures 7-82 to 7-85. In Figures 7-82 and 7-83, 58.5% of respondents agreed that CAD encouraged respondents to improve their design ideas when designing and 65.9% agreed that they had displayed at least one aspects of 'seek perfection' behaviour whilst designing in CAD.

In Figures 7-84 and 7-85, 61% of respondents agreed that CAD enabled them to see problems which they had not thought of before, and 58.5% agreed that CAD allowed them to realise problems that may exist in the design concept.

Overall data findings indicated that most of the respondents had experienced sensitivity behaviour when using CAD; in particular its usage encouraged users to seek perfection, improvise design ideas, allowed them to realise problems that they had not thought of before, and identify problems that might exist in the design concept.

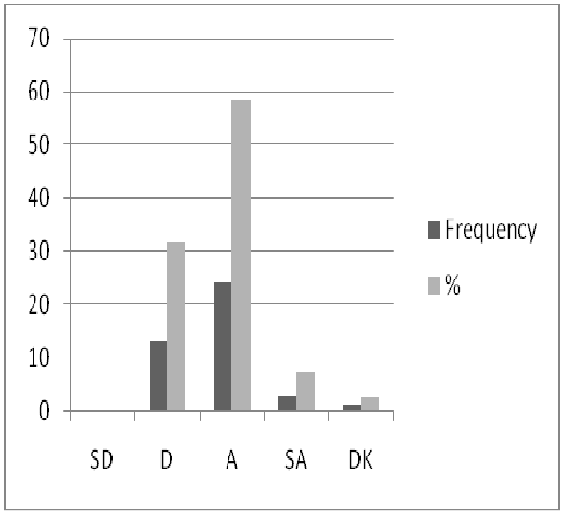


Figure 7-82: CAD encourages respondents to improve their design ideas

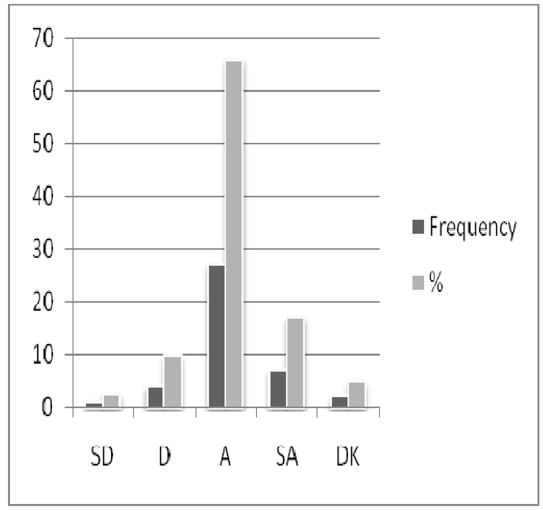


Figure 7-83: Respondents displayed at least one aspects of seek perfection behaviour whilst designing in CAD

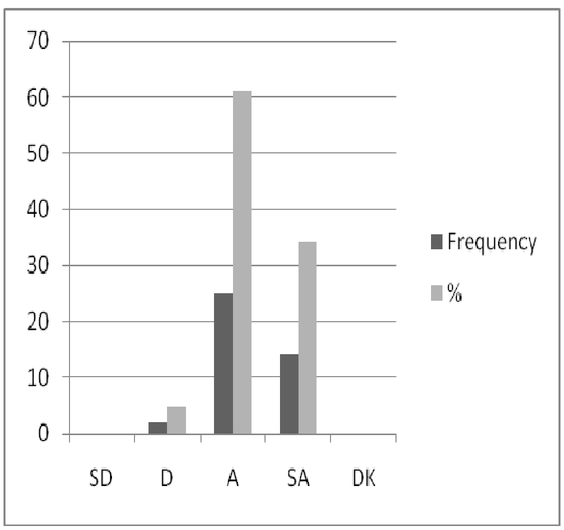


Figure 7-84: Whilst designing in CAD respondents continuously assess their design concept

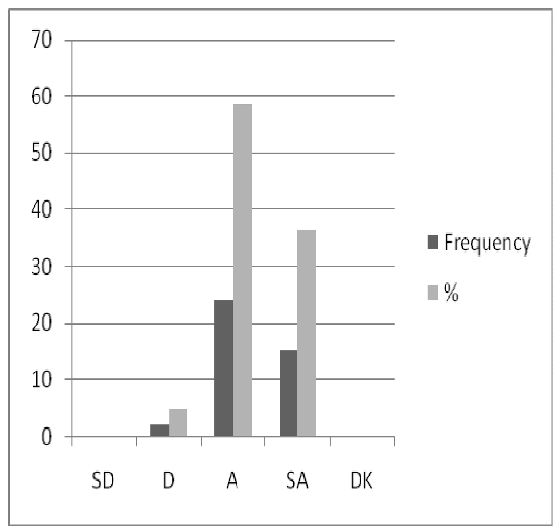


Figure 7-85: CAD allows respondents to realise problems that may exist in the design concept

k) Experienced insightfulness behaviour whilst using CAD?

4 items were included to explore the insightfulness whilst respondents use CAD. The findings are presented in Figures 7-86 to 7-89. 48.8% of respondents agreed that CAD enabled respondents to put together old and new

information to produce new design ideas and 7.3% strongly agreed (see Figure 7-86). Meanwhile, 29.3% of respondents disagreed, 7.3% strongly disagreed with 7.3% ‘Don’t Know’.

In Figure 7-87, 36.6% of respondents agreed that CAD sometimes enabled them to make certain suggestions without any logical reasoning and 2.4% strongly agreed. However, 41.5% of respondents disagreed and 9.8% strongly disagreed. In addition, 9.8% of respondents chose ‘Don’t Know’.

In Figure 7-88, 75.6% of respondents agree that it is easy to store and retrieve information within CAD which would help them in the process of design development and 7.3% strongly agreed. The data also indicated that only 7.3% of respondents disagreed with 9.8% ‘Don’t Know’.

To the item which seeks responses to whether the respondents feel comfortable to make necessary assumptions for design decisions whilst in CAD: 53.7% of them agreed, 7.3% strongly agreed, 26.8% disagreed, 9.8% strongly disagreed with 2.4% ‘Don’t Know’ (see Figure 7-89).

The findings indicated that most respondents agree that CAD enabled them to put together old and new information in producing new ideas, and helps the user to easily store and retrieve information within CAD. However, most respondents had not experienced the ability ‘to make certain suggestions without any logical reasoning’ whilst using CAD in designing. Overall, most of the respondents had experienced insightfulness behaviour whilst using CAD in designing.

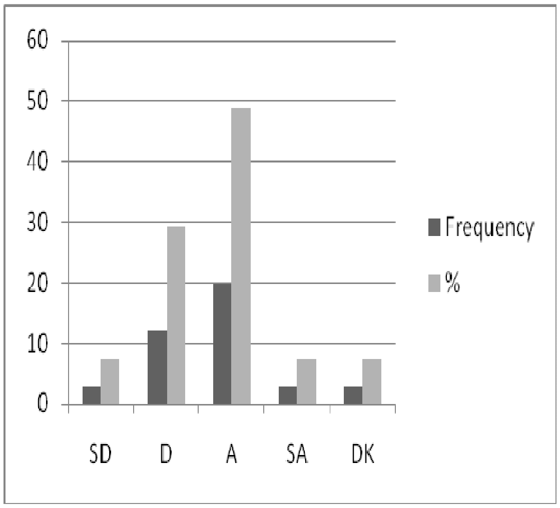


Figure 7-86: CAD enabled respondents to put together old and new information to produce new design ideas

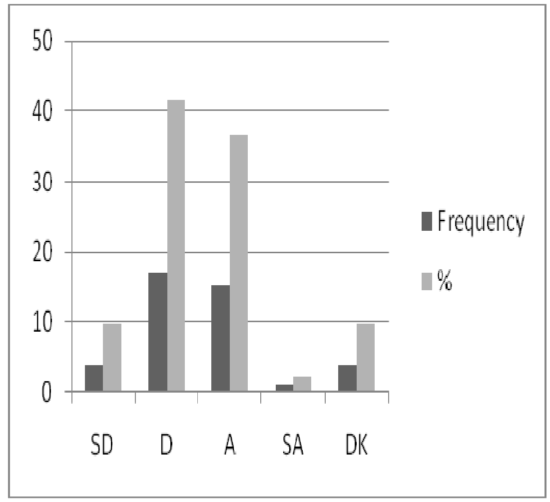


Figure 7-87: CAD sometimes enables respondents to make certain suggestions without any logical reasoning

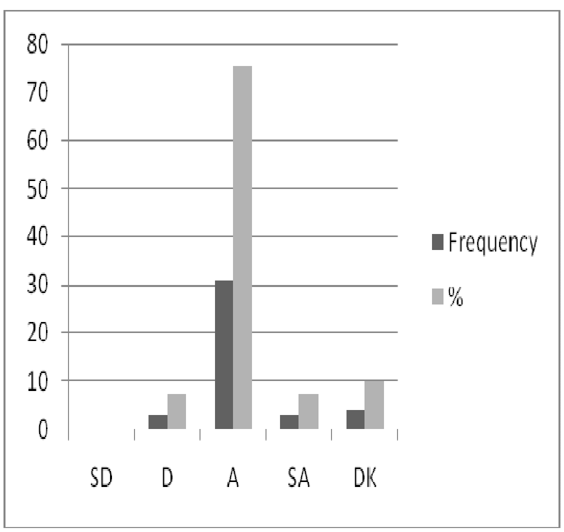


Figure 7-88: It is easy to store and retrieve information within CAD that would help respondents in the process of design development

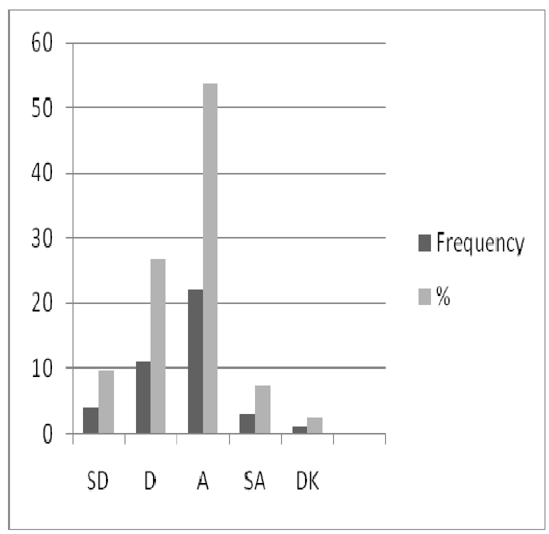


Figure 7-89: Respondents feels comfortable to make necessary assumption for design decisions whilst in CAD

7.4.3 Research Findings Feedback

In section 3 of the paper questionnaire, respondents were presented with the findings from the case study. 58.5% of respondents agreed that they feel surprised that quite a number of Creative Behaviours had been displayed by CAD users and 29.3% strongly agreed. However, only 4.9% disagreed, 2.4% strongly disagreed with 4.9% 'Don't Know' (see Figure 7-90).

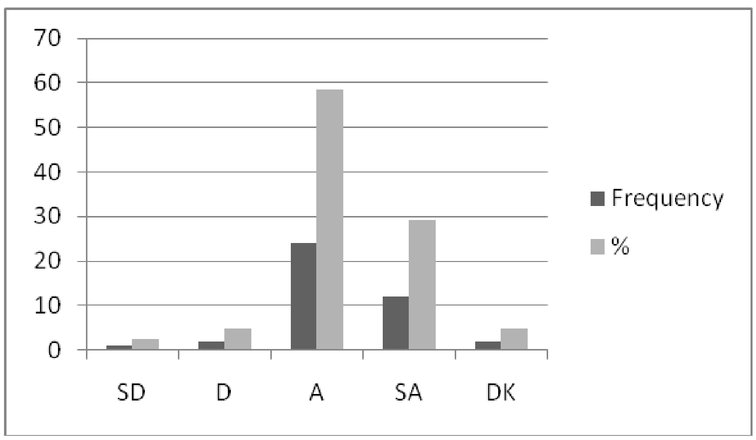


Figure 7-90: Respondents surprised that quite a number of Creative Behaviours had been displayed by CAD users.

In Figure 7-91, 29.3% of respondents agreed that they considered themselves as a CAD recorder rather than a CAD designer and 12.3% strongly agreed. However, 31.7% disagreed, 17.1% strongly disagreed with 9.8% 'Don't Know' (see Figure 7-92).

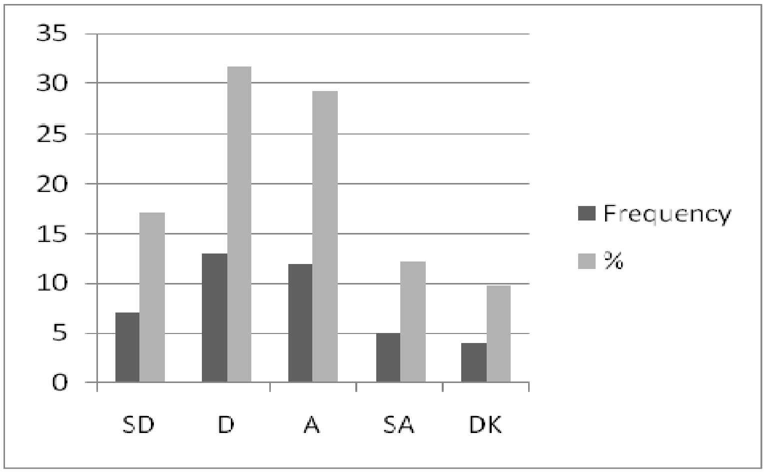


Figure 7-91: Respondents considered themselves as a CAD recorder rather than CAD designer

7.5 The Creative Behaviours Framework in Wider Applications

The findings for the items under this heading was not analysed as there was only one response to the related items.

7.6 Chapter Summary

This section presents the summary of the key findings from the online based and paper based questionnaires. The responses were clustered into ‘Agree’ and ‘Disagree’. ‘Don’t Know’ was excluded as the study was interested to know whether respondents ‘Agreed’ or ‘Disagreed’ with aspects that were discussed. The key findings from the Malaysian CAD users and the UK CAD users are present in Tables 7-2 and 7-3. The table consists of aspects which discussed, related item(s), the frequency of agree or disagree responses, and the overall responses.

Table 7-2: Key summary findings from the online questionnaire (Malaysia)

No	Aspect	Item	Agree (f)	Disagree (f)	Overall
1	Comfortable and keen to use CAD in Designing	8	10	-	Agree
		18	10	-	
2	Perception of CAD roles in designing				
	• CAD as a designing tool	9	10		Agree
	• CAD only as a presentational tool	11	3	7	Disagree
3	When normally using CAD?				
	• From initial stage through the final phase of design	10	8	2	Agree
	• To generate design concepts	16	6	4	
	• Brainstorming	17	4	6	
4	Does CAD facilitate the externalization of ideas?				
	• Express idea efficiently	24	5	5	Agree
	• Externalise idea effectively	31	6	3	
5	Experience fluency behaviour whilst using CAD?				
	• Save a lot of time developing design concept	14	7	3	Agree
	• Allow to further develop the design concept in less time	47	9	1	
6	Experience motivation behaviour whilst using CAD?				
	• Always keen to see the resulting outcome	15	10		Agree
	• Encouraged to go ahead with ideas	23	7	3	
	• Excited to see the design outcome	42	10		
	• Confident to 'have a go' with design ideas	38	9	1	
7	Experience novelty behaviour whilst using CAD?				
	• Enable to generate surprising ideas	19	7	3	Agree
	• Led to the emergence of unique design concepts	20	8	2	
8	Experience appropriateness behaviour whilst using CAD?				
	• Helped to produce practical design output	21	9	1	Agree
	• Helped to distinguish useful design ideas	22	9	1	
	• Helped to develop potentially functional design concepts	45	10	-	
9	Experience flexibility whilst using CAD?				
	• Allows to play around with ideas	25	8	2	Agree
	• Enable to assess the design development from time to time	26	9	1	
	• Continuously assess design concept	37	10		
	• Allows to explore ideas	40	10		
10	Experience sensitivity behaviour whilst using CAD?				
	• Encourages to improve design ideas	27	8	1	Agree
	• Enables to see problems which had not thought	28	8	1	

	of before				
	• Have displayed at least one aspect of seek perfection	36	10		
	• Allows to realise problems that may exist in the design concept	44	10		
11	Experience insightfulness whilst using CAD?				
	• Enables to put together old and new information to produce new design ideas	29	9	1	Agree
	• Enables to make certain suggestions without any logical reasoning	30	7	3	
	• Easy to store and retrieve information within CAD that would help in the process of design development	43	10		
	• Comfortable to make necessary assumptions for design decisions whilst in CAD	46	10		
12	Research findings feedbacks:				
	• Does respondent surprise with the research findings?	35	6	3	Agree
	• CAD recorder rather than CAD designer	48	2	3	Disagree
13	Respondents' current exercise related to creativity assessment				
	• include creativity as part of lesson planning objectives	50	7	1	Agree
	• presently using a systematic technique for observing students' creativity	51	4	3	Agree
	• assess students' creativity through the final product produced by them	52	7	1	Agree
14	Respondents' opinion to potential Creative Behaviours Framework roles				
	• useful in helping to prepare lesson outlines	53	6	1	Agree
	• provide a systematic technique for observing creative behaviours	54	7	0	Agree
	• allow to assess students' creativity during the learning activities	55	7	0	Agree

Table 7-3: Key summary findings from the paper questionnaire (Loughborough University, UK)

No	Aspect	Item	Agree (f)	Disagree (f)	Overall
1	Comfortable and keen to use CAD in Designing	8	31	9	Agree
		18	23	19	
2	Perception of CAD roles in designing				
	• CAD as a designing tool	9	36	3	Agree
	• CAD only as a presentational tool	11	16	25	Disagree
3	When normally using CAD?				

	• From initial stage through the final phase of design	16	13	28	Disagree
	• To generate design concepts	10	15	26	
	• Brainstorming	17	4	37	
4	Does CAD facilitate the externalization of ideas?				
	• Express idea efficiently	24	28	13	Agree
	• Externalise idea effectively	31	28	10	
5	Experience fluency behaviour whilst using CAD?				
	• Save a lot of time developing design concept	14	17	22	Disagree
	• Allow to further develop the design concept in less time	36	18	22	
6	Experience motivation behaviour whilst using CAD?				
	• Always keen to see the resulting outcome	15	39	2	Agree
	• Encouraged to go ahead with ideas	23	29	10	
	• Confident to 'have a go' with design ideas	40	33	6	
	• Feel enthusiastic to see the design outcome when using it in designing	41	36	3	
7	Experience novelty behaviour whilst using CAD?				
	• Enable to generate surprising ideas	19	16	24	Disagree
	• Led to the emergence of unique design concepts	20	10	27	
8	Experience appropriateness behaviour whilst using CAD?				
	• Helped to produce practical design output	21	35	5	Agree
	• Helped to distinguish useful design ideas	22	32	7	
	• Helped to develop potentially functional design concepts	34	37	3	
9	Experience flexibility whilst using CAD?				
	• Allows to play around with ideas	25	29	12	Agree
	• Enable to assess the design development from time to time	26	35	5	
	• Continuously assess design concept	40	33	6	
10	Experience sensitivity behaviour whilst using CAD?				
	• Encourages to improve design ideas	27	27	13	Agree
	• Enables to see problems which had not thought of before	28	39	2	
	• Have displayed at least one aspect of seek perfection	38	34	5	
	• Allows to realise problems that may exist in the design concept	33	39	2	
11	Experience insightfulness whilst using CAD?				
	• Enables to put together old and new information to produce new design ideas	29	23	15	Agree
	• Enables to make certain suggestions without any logical reasoning	30	16	21	
	• Comfortable to make necessary assumptions for	35	25	15	

	design decisions				
	• Easy to store and retrieve information within CAD that would help in the process of design development	42	34	3	
12	Research findings feedbacks:				
	• Does respondent surprise with the research findings?	37	25	15	Agree
	• CAD recorder rather than CAD designer	44	17	20	Disagree

The key findings from the Malaysian and UK respondents were presented in Table 7-4. The overall findings for each aspect were concluded as 'Agree' or 'Disagree' phrases.

Table 7-4: Key summary findings from the online and the paper questionnaire

No	**Aspect**	**Malaysia (n=10)**	**UK (n=41)**
1	Comfortable and keen to use CAD in Designing	Agree	Agree
2	Perception of CAD roles in designing		
	• CAD as a designing tool	Agree	Agree
	• CAD only as a presentational tool	Disagree	Disagree
3	When normally using CAD?		
	• From initial stage through the final phase of design	Agree	Disagree
	• To generate design concepts		
	• Brainstorming		
4	Does CAD facilitate the externalization of ideas?	Agree	Agree
5	Experience fluency behaviour whilst using CAD?	Agree	Disagree
6	Experience motivation behaviour whilst using CAD?	Agree	Disagree
7	Experience novelty behaviour whilst using CAD?	Agree	Disagree
8	Experience appropriateness behaviour whilst using CAD?	Agree	Agree
9	Experience flexibility whilst using CAD?	Agree	Agree
10	Experience sensitivity behaviour whilst using CAD?	Agree	Agree
11	Experience insightfulness whilst using CAD?	Agree	Agree
12	Research findings feedbacks:		
	• Does respondent surprise with the research findings?	Agree	Agree
	• CAD recorder rather than CAD designer	Disagree	Disagree

8 Chapter Eight: Discussion of the Results

8.1 Chapter Overview

This chapter presents a summary of key findings from the three case studies, data triangulation between the case studies, and a discussion of the data validity. The key findings highlighted the important outcomes from the three case studies. The data triangulation allowed comparison to be made in terms of the similarities and dissimilarities of findings between the case studies. The similarities demonstrate that the resulting data in the research were reliable and the methods used were valid to be used as a tool for the detection and observation of creativity behaviours in designing.

8.2 Case Studies Key Findings

As stated in Chapter One, the purpose of this study is to explore the relationship between CAD and creativity in designing which was explored through observing creative behaviours. A framework has been established, namely the Creative Behaviours Framework, to facilitate the observation and identification of the associated behaviours (refer to section 2.11). A case studies approach has been undertaken to generate data and then analysed to provide evidence of the links between CAD and creativity or at least of the creative behaviours. Three case studies were carried out with different level of design students including undergraduates, postgraduates and the researcher himself (refer to section 3.9).

In each case study, multiple methods have been executed including interviews, observations, protocol analysis, and design diaries (refer to Chapter Three - Research Methodology). In the initial study (Case study 1) which can be referred in Chapter Four, all those methods were undertaken. These methods were explored in the initial case study in order to seek plausible method(s) that were capable of capturing useful data for the research intent. However, only some of them were considered in the remaining case studies that will be discussed in this chapter including interviews (pre and post), protocol analysis and design diaries as shown in Table 8-1.

Table 8-1: Proposed methods for case studies

Method	**Pre Interv.**	**(CAD design activity)**					**Post Interv.**
Case Study		**Observations**		**Protocol Analysis**		**Design Diaries**	
		Direct	**Video**	**Video**	**On Screen**		
One	*	*	*	*		*	
Two	*				*	*	
Three	*			*	*	*	*

Summaries of all key findings from the case studies are presented in the following sections.

8.2.1 Summary of Findings for Pre-Interviews

The pre-interviews were analysed based on eight themes which were initially identified in Case study 1 with additional two themes emerged in Case study 3. The findings were already presented in Chapter Four, Five and Six. These key findings will be discussed under the headings below.

8.2.1.1 Participants' perception of the role of CAD in designing

Findings from the pre-interviews indicated that participants had different perceptions when it comes to the role of CAD in the designing work. In presenting this topic, thematic codes of 'Design strategy anticipated (DST)', and 'Where CAD fits? (CFT)' are discussed. Results showed that participants who perceived CAD as a presentational tool, tend to use the software at the final stage of the designing phase. They generated and developed the ideas through conventional design tools (e.g. 2D sketching, 3D sketch modelling) before modelling the ideas for visualization in CAD. For example, this is supported by these quotations:

'*I'm going to…try to finish as much as I can by sketching, and when I feel that I have the idea clear, I will...make a CAD model of all of it. Perhaps, may be the finalised…the final details, like the placement of the button things like that, I will probably be doing using CAD, which rather quickly l can just change some positions…and see how it looks…*' (P01-case study 1)

'…until I have the final design [concept] *then, I'll go to 3D* [CAD] *drawing'* (P02-case study 1)

Then, when the participants were asked at what stage they will probably use CAD more intensively, they clearly emphasised that CAD will be used when the design concept was nearly fully established as stated:

'*Well. Almost the design finished...When I have the idea and...really know what to do. Then, I'll start* [using] *CAD.*'(P01-case study 1)

The results below also showed that CAD was not involved in the early stages of the designing, where in these stages the activity mostly related to ideas or concept generation

'*No, not during the conceptual stages*' (P01-case study1)

'but I mostly use CAD for just to get renders…just to get photo realistic images…. the main purpose' (P01-case study 1)

'...if I have good design to explore to do the experiment [design concept assessment]*, like one or two good design then I will use the software* [CAD]…' (P02-case study 1)

In some cases, CAD was used as part of the idea or design concept development corresponding to 2D sketching and/or 3D sketch modelling.

'*…at first I will do some sketches but just for me to have a general idea what I want to do. And then. I'm using Rhino, for draft the modelling. It's like a … I don't care about size ….I don't care about if the surface is perfect. I just want to get the general shape, and then if I decide to use the shape, I'll model it again and to make it really good* [presentation].*'* (P03-case study 1)

'*….the beginning of the design process which is when I don't have any structured ideas …what is the form?…the shape?...what is the type of product I'm going to design? So, maybe I'll start a little bit using sketching but when I see…I could visualize the form even if it is semi structured, so I'll try to use CAD for the evaluation. And maybe, I'll keep going back and forth between sketching and CAD.*' (PS01-case study 2)

However, those who perceived CAD as a designing tool were using the software from the early stages of designing. This showed that for these cases, as well as using conventional design tools (e.g. 2D sketching, 3D sketch modelling), CAD was involved throughout.

'*Basically, I'm using CAD from the start to finish*' (P04-case study 1)
'*I think I will introduce computer even like in the beginning of my designing…*' (P03-case study 1)

From one of the discussions between the researcher and his supervisors (Eddie Norman and Tony Hodgson), it was acknowledged that the types of CAD user are in a spectrum between using CAD only as a presentation tool and using CAD as a designing tool. However, in general these users can be divided into two groups that can be named as:

- CAD recorder **-** a CAD user who uses the software for presenting the final design ideas without actively involving it during the development of design ideas.
- CAD designer - a CAD user who actively involves the software during designing and also in presenting the final ideas or design intent.

Hence, the participants in the case studies can be categorised into two types of CAD user based on the pre-interviews as shown in Table 8-2.

Table 8-2: Types of CAD user from pre-interviews

Case study	Participant	Types of CAD user
1	P01	CAD recorder
	P02	CAD recorder
	P03	CAD designer
	P04	CAD designer
2	P201	CAD designer
3	MP01	CAD designer
	MP03	CAD recorder

8.2.1.2 Reasons to use CAD in design work.

From the pre-interviews, a number of reasons were sought why the participants use CAD as part of their design activities. The thematic codes of 'Reason to use CAD (RUC) and 'CAD experience (CAE)' are discussed. Based on the analysis the reasons can be listed as follows:

a) for conceptual visualisation

It is important for designers to be able to bring out their ideas from imaginary form to reality that can be viewed and understood by others. The idea which is hidden in the designer's mind can then be conceived by others, even before the physical form exists.

'*In terms of like visualization, it allows me to give the people … looking at the project and understanding what's going to look like when it's finish …*' (P04-case study1)

'*Basically, I hope that by using the software I could easily or could visualize much easier the part of the design that I'm trying to establish and which is sometimes quite difficult to visualize when you do it in 2D form.*' (PS01-case study 2)

'...model of the image...of the idea and so as to use that in the context of presenting the idea to other people...so they understand what it is I'm doing and they've got some idea how...it will look and ... and then...[what I'm] *thinking...*'(MP03-case study 3)

'...but I mostly use CAD for just to get renders… just to get photo realistic images… the main purpose.' (P01-case study 1)

For those designers who lack the ability to sketch very well, CAD would allow them to provide good quality images for visualisation.

'...for the first stage it will easier for visualize and showing it to other people to get feedback, to get a more accurate visualization of it because I can't sketch that good...' (P01-case study 1)

'*I think is easier [*to draw in CAD] *because I'm not so good in sketching*' (P03-case study 1)

'...well you see it useful to me that in ProEngineer I can make a model which first and foremost lets me...visualize my idea...my concept in 3D...you know which is lot easier than sketching and a lot more versatile' (MP03-case study 3)

b) design assessment

Most of CAD software has features which allows designers to undertake computer design analysis (e.g. Finite Element Analysis (FEA), Computational Fluid Dynamics) to design concepts before making any decision to produce them. The analysis would provide indications to the extent that the design concepts established were fulfilling the design aims and reliable for production.

'...for manufacturing process it will allow me to see will this really worked in the real life. I will be able to analyze it.' (P01-case study 1)

'*...very easy to make 3D* [CAD] *and we have software like ProE to analyze it*.' (P02-case study 1)

'*I just can see how it puts together and what space the constraints are. So to make sure everything is fit. And it's about being firm about the initial idea… the initial designing of the product*.' (P04-case study 1)

'...I hope I could establish the 3D graphical model which is I hope is as realistic as I can because it is very important in terms of...whether it is reliable or not for production later on.' (PS01-case study 2)

'I need the CAD to really see if it's work. And fit it together and see where the problems occur.' (MP01-case study 3)

'...to actually test it [mechanisms] *I need CAD. And I need to see the forces to push down* [that to arm]*......to actually...do the mechanism and making it works inside the foam it's not possible...it's not strong enough'* (MP01-case study 3)

c) ideas generation

Some of the participants were comfortable to use CAD for ideas generation in the early design phase.

'*Because I kind like to use a computer to generate some more rough ideas. I'm ought using Rhino to do that because quick and spare me a lot*' (P03-case study 1)

'......for develop the initial ideas more way to the final system...' (P04-case study 1)

d) having prior CAD background

Most of the participants chose to use CAD as they had prior knowledge and experience with the software. This possibly provided a tendency towards using CAD in their designing.

'*I have been taught how to use that* [CAD]' (MP01-case study 3)

'*ProEngineer* [CAD software] *as it is what I have been taught to use'* (MP03-case study 3)

'*I've been trained to use the software* [CAD] *before'* (P01-case study 1)

'*All those software...Photoshop Ilustrator...ProEngineer.. ALIAS...we all have been given in the support on over the years'* (MP03-case study 3)

Once exposed and taught to use a type of CAD software, the participants had more confidence to learn and use other CAD software themselves.

'*Once you learn one CAD package, they're quite similar. The only different is how easy is to use… in comparison. And this software package I taught myself…completely from scratch*' (P04-case study 1)

'*I think I learn all those software* [CAD] *by my own'* (P03-case study 1)

'...for ProE I don't have any formal training. But previously I've used AutoCAD and basically…the nature of the software is the same. But, although, in term of the features is quite different, but I think I can manage in using ProE' (PS01-case study 2)

e) difficult to produce physical model

Another reason for designers to use CAD was the difficulty to produce a physical model because of the size (e.g. too small, too big), the complications (e.g. having a lot of mechanisms), and the limitation of 3D sketch modelling material characteristics to form the design shape (e.g. fragile)

'*It's very crude model. Because...I'm using syringes...syringe are such a small scale that it is very hard to make it from foam without it breaking. So I can't test if I've got levers or anything on my...anything in button...and I need a spring, but I can't make all of these little components to model with...*' (MP01-case study 3)

8.2.1.3 CAD complementing other design tools

The findings from the pre-interviews indicated that all the participants had also used other design tools, even, those who had been categorised as CAD designers. CAD and other design tools (e.g. 2D sketching, 3D sketch modelling) had been used in parallel with each other. The ‘Other design tools use (ODT)’, and ‘Reason to use other tools (RUO)’ are discussed.

‘*I might be doing some quick prototype… like basic prototype… some blue foam’* (P01-case study 1)

‘*Umm …the rapid prototyping is one of it …and the blue foam.’*
‘maybe, I just have something like paper simple like that’ (P03-case study 1)

‘*I’m going to make a number of different prototypes. The first prototype will be very simple and it literally made by wood*.’ (P04-case study 1)

‘*I've start doing sketches of mechanisms for my ideas’*
‘... I've done a few mock up too like foam.’(MP01-case study 3)

The reasons for the participants to use other design tools beside CAD have also been established from the pre-interviews. The reasons were:

a) to assess design ergonomics and practicality,

‘*Just to evaluate the ergonomics. So, you just you can feel and evaluate the idea…and get understand the form*’ (P01-case study 1)

‘*Because I need to check it’s actually going to work in term of the fact when something is pictured out it feels about right. I mean…I made it in CAD and I don’t know if it’s going to work…and making the prototype to check*.’(P04-case study 1)

b) to get the sense of touch,

‘*…so making the physical model. It’s give you some ideas. It’s not just looking at 3 dimension is not enough you just need to touch it*’ (P04-case study 1)

c) to generate ideas

‘*if you get stuck… then, you need to do the mock-up. Can be made by paper or whatever we can touch we can feel the 3D* [sketch modelling]’ (P03-case study 1)

‘...just quick...re-rough sketching...just to work out what I'm trying to do.’ (MP01-case study 3)

‘...CAD won't let me explore all the things I need to explore. And I don't feel that CAD would let me generate ideas as easily as sketching will. Coz it’s not quick like I said and frustrating to use...’ (MP03-case study 3)

8.2.1.4 Criteria for CAD software use

The findings also indicated that participants tend to use certain CAD software based on criteria suiting it to particular design activities. The thematic codes of ‘Types of CAD proposed to be used (TOC)’, and ‘CAD feature expectation (CFE)’ are presented to highlight this heading. The criteria governing CAD software choice for particular designing tasks were as follows:

a) less complicated to operate

‘*I’m going to use Rhino…which is a surface modeller because it’s not…you do not have many constraint, so I can just change and do things more quickly and more fluently*’ (P01-case study 1)

b) having user friendly features

‘The software is user-friendly itself’ (P02-case study 1)

c) parametric or non-parametric based software

‘*And at that moment that I’m also using things like 3DStudiomax, Rhino and other stuff. But I’m not using that very often because they are not parametric*.’ (P04-case study 1)

d) design analysis feature

‘... it's not [involved] *surfacing in my project, this is more solid geometry and the testing hopefully I can use it to test that the mechanism works...the simulation or something’* (MP01-case study 3)

The participants also seem to use certain CAD software for certain tasks as shown in Table 8-3. CAD software which was mentioned, but for which the appropriate design tasks were not described were not included in the table.

Table 8-3: Types of CAD software for design tasks

.

CAD types	Design Task
ProE	*‘...perhaps for the manufacturing, maybe using Pro-Engineer…’ (P01-case study 1)* *‘I will definitely use ProE as my err..tool for designing*’ (P02-case study 1) ‘*Basically in this stage I’m going to use ProE but for example during the process of designing if I find out that I need other type of software so I might consider to use them. But, in this stage I’m going to use err … predominantly err … ProE*’ (PS01-case study 2) ‘*I mean ProEngineer mainly for modelling…*’ (MP03-case study 3)
Photoshop	*‘…Photoshop for presentation and rendering as well’* (P02-case study 1) *‘…in Photoshop as well [*rendering*] which is then make it easier’* (MP03-case study 3)
Rhino	‘*but for…err visualization, for rendering, I’m going to use Rhino…*’ (P01-case study 1)
Alias	*‘…may be I’m using the Alias for rendering…*’ (P01-case study 1) ‘*…may be some ALIAS for rendering*’ (MP03-case study 3)

Nonetheless, one participant has highlighted the shortcoming of CAD where the resulting outcome may not be what was expected. This was referring to software one of the participant had experienced using.

'*Hard to get one it to look right...it can compromise the design...so the product doesn't look like you imagine... you look at the first place'* (MP01-case study 3).

When asked whether this was the consequence of the software limitations or the lack of the participant's skill in using it, the participant responded as follow:

'*A bit of both...I think* [lack of skill and software limitation]'

'*And also that possibly my skill from not knowing how to create it from the first place.*' (MP01-case study 1).

8.2.2 Summary of Findings for Protocol Analysis

The protocol analysis involved observing and identifying the creative behaviours during the CAD designing activity. Data obtained from the protocol analysis of CAD activities in the case studies are tabulated in Table 8-4. As presented in the table, the data were reported based on the creative behaviours categories and the descriptors. The emergence of the creative behaviours was based on the identification of any of the descriptors. The detection of a descriptor was considered as an emergence of the corresponding creative behaviour. The numbers of descriptors that emerged in the case studies were reported in columns 3 to 5 and the total of them was then reported in the last column of the table.

Table 8-4: Data findings of protocol analysis from the case studies

Creative Behaviours	Creative Behaviours descriptor	Case study 1 (n=3)	Case study 2 (n=1)	Case study 3 (n=2)		Total
		CAdvid	CADvid	CAD vid	CAD Cam	
Novelty	uncommon	0	0	0	0	0
	unexpected	0	0	0	0	
	original	0	0	0	0	
Appropriateness	useful	0	0	2	0	32
	sensible	23	2	1	2	
	functional	1	0	1	0	
Motivation	enthusiastic	1	0	0	1	50
	determined	3	3	5	2	
	risk-taking	15	4	10	6	
Fluency	spontaneity	0	3	1	3	22
	open to new ideas	2	0	5	2	
	fluency of ideas	5	0	0	1	
Flexibility	exploring possibilities	14	4	9	6	91
	continuous reflection	23	7	18	9	
	associate remote ideas	0	0	0	1	
Sensitivity	understand problem	3	0	1	0	49
	display curiosity	4	0	1	0	
	seek perfection	18	4	9	9	
Insightfulness	organizing information	10	0	2	0	17
	intuitive decision	0	1	3	0	
	influence by inspiration	0	1	0	0	
	Total	122	29	68	42	261

(Notes: CADvid – referring to CAD activity video recorded by the researcher, and CADcam – referring to CAD activity video recorded by on-screen videoing using CAMTASIA software by participants)

The findings indicated that the novelty behaviour could not be detected in any of the case studies. None of the three descriptors that were assigned to this behaviour were observed and identified. This shows the difficulty in identifying the novelty behaviour during the process of designing, in particular whilst participants were operating CAD software. The attempt to interpret participants' behaviour whilst using CAD to the novelty behaviour's descriptors proved not to be a straightforward task. The participants' verbalisations were also essential to provide wider insight for the analysis by the researcher. They were key to identifying creative behaviours in six of seven categories. This was supported from the findings shown in Table 8-5 where the data obtained from the CADvid method seems to identify more creative behaviours occurrences compare to those from CADcam. During the CADvid data capturing sessions, the researcher had the opportunity to encourage the participants to verbalise their CAD activity and allowed more information to be acquired. However, in the CADcam, no verbalisation had been carried out and the analysis was based on retrospective video transcripts (P201), post guided explanation (MP01), and retrospective verbalisation (MP03).

Table 8-5: Number of creative behaviours occurrences by each participant in protocol analysis

Case study	Participant	Types of CAD user	Creative behaviours occurrences (protocol analysis)	
			CADvid	CADcam
1	P02	CAD recorder	44	-
	P03	CAD designer	43	-
	P04	CAD designer	35	-
2	P201	CAD designer	-	29
3	MP01	CAD designer	33	27
	MP03	CAD recorder	35	15

The aspect that could also have influenced the number of outcomes identified was the different types of design projects undertaken by the participants. Different design projects would need different strategies in seeking the design solutions.

Designing is described as an ill-defined problem with no particular rules for obtaining the possible design solutions (Archer and Roberts, 1992; Ahmed et al, 2002). The participants could undertake different approaches in seeking the appropriate proposal to solve the design problems. However, there was no evidence provided from the case studies as this is just a snapshot of the designing undertaken by the participants.

It would seem from the findings that six creative behaviours were consistently observed through the emergence of their descriptors during the CAD activities engaged in by the participants. The flexibility behaviour was the most frequent category that emerged with 60 occurrences, followed by motivation (33), sensitivity (33), appropriateness (28), fluency (15), and insightfulness (44). This indicates the reliability of the protocol analysis approach to identifying creative behaviours in CAD activities using the Creative Behaviours Framework. The data were acquired from six different design projects and post interviews were undertaken with the participants to validate the findings.

8.2.3 Summary of Findings for Design Diaries

The data obtained from the design diaries is tabulated in Table 8-5. A similar format to Table 8-6 was employed in presenting the design diary data findings from the case studies.

Table 8-6: Data findings of design diaries from the case studies

Creative Behaviour	Creative Behaviour descriptor	Case study 1 (n=1)	Case study 2 (n=1)	Case study 3 (n=2)	Total
Novelty	Uncommon	0	0	1	13
	Unexpected	0	2	4	
	Original	0	0	6	
Appropriateness	Useful	4	1	11	50
	Sensible	0	1	14	
	Functional	7	0	12	
Motivation	Enthusiastic	3	4	6	58
	Determined	6	8	22	
	Risk-taking	2	7	0	
Fluency	Spontaneity	0	3	4	33
	Open to new ideas	2	5	12	
	Fluency of ideas	3	0	4	
Flexibility	Exploring possibilities	1	8	18	38
	Continuous reflection	0	4	6	
	Associate remote ideas	1	0	0	
Sensitivity	Understand problem	3	0	7	39
	Display curiosity	3	0	3	
	Seek perfection	5	1	17	
Insightfulness	Organising information	2	0	12	31
	Intuitive decision	0	2	9	
	Influence by inspiration	4	0	2	
	Total	46	46	170	262

Interestingly, the findings from the design diaries reported occurrences of novelty creative behaviour in Case study 2 and 3 which could not be identified by other methods. All the three descriptors under this category were identified by the participants in Case study 3 and a descriptor, uncommon has been detected in case study 2. The researcher and the participants with their understanding of the novelty behaviour descriptors' definitions had been able to interpret, identify and report the occurrences. Although this was considered a small number of occurrences compared to the other creative behaviours categories, these provided useful findings for the research. These findings implied that the creative behaviours, in particular novelty behaviour had better potential for being identified by the participants themselves through their own design reflection. This was supported by a larger number of creative behaviours occurrences identified by the design diaries approach compared to the protocol analysis method.

It would seem from the findings that all of the seven creative behaviours categories were consistently observed through the descriptors during the CAD activities engaged in by the participants. In total, 262 creative behaviours occurrences were recorded by the participants. The motivation behaviour was the most frequently reported with 58 occurrences, followed by appropriateness (50), sensitivity (39), flexibility (38), fluency (33), insightfulness (31), and novelty (13). This indicates the reliability of the design diary approach to identify the creative behaviours in CAD activities using the Creative Behaviours Framework. To validate the findings, post-interviews were undertaken except for participant P03 in Case study 1 (see Section 4.4.6).

8.3 Chapter Summary

This chapter discussed the findings from the pre-interviews undertaken from the case studies. The discussion has highlighted four aspects including participants' perception of CAD's role in designing, reasons to use CAD, how CAD complemented other design tools and criteria for CAD software selection by the participants.

Triangulation had been undertaken by using different approaches of data collection and gathering data from different case studies. This chapter has brought together the findings of the protocol analysis and the design diaries from the three case studies. The findings indicated that these two approaches had been able to identify the creative behaviours in the case studies, except the novelty behaviour by the protocol analysis. This is discussed and the likely reason for this was because of the difficulty for participants to reflect on novelty whilst using CAD. The findings suggested that these two approaches were reliable and the data acquired were valid.

9 Chapter Nine: Discussion

9.1 Chapter Overview

This chapter provides a discussion of the results that have been presented in this thesis, drawing on data from the literature review, case studies and questionnaires and referring to each of the research questions (RQs). This is followed by a discussion of the wider implications of these findings.

9.2 Discussion Relating Directly to the Research Questions (RQs)

In this section, the discussion of the findings from the literature review, case studies and the questionnaires is addressed in relation to each of the RQs..

9.2.1 RQ1: Can a theoretical framework be developed to support empirical investigations of creativity during the use of CAD in designing?

The literature review in Chapter 2 had attempted to seek understanding about creativity and highlighted the intricacy in researching creativity. For this study a framework, named as the Creative Behaviours Framework, was developed (see Section 3.2) to facilitate the observation and identification of creative behaviours during CAD use in designing. This framework was established from creativity literature mostly published by cognitive psychologists (see Section 2.11) and used in this research as a strategy to establish links between CAD and creativity (see Section 2.10). The framework has facilitated the researcher and the participants in distinguishing the creative behaviours occurrences by categorising the significant events recognised with the corresponding descriptors' (see Figure 3-2 and Table 3-1). The Creative Behaviours Framework has therefore supported empirical investigations of creativity during the use of CAD in designing, albeit indirectly and by 'standing on the shoulders' of research by cognitive psychologists.

9.2.2 RQ 2: Can methods be developed for creativity to be observed, identified and described during the use of CAD in designing?

Case studies have been undertaken to facilitate the development of the framework (see Chapter Four), to gather data and establish the analysis methods (see Chapter Four, Five and Six). From a number of data gathering methods explored in Case study 1, it was decided to use three methods comprising interviews (pre-interview and post-interview), protocol analysis and design diaries in the later case studies. The interviews were mainly undertaken to provide data 'prior to' and 'after' the completion of the design projects. The pre-interview has facilitated the pre-arrangement of the data collection processes by providing information about the participants' perception on CAD and how they anticipated using it in their design projects (see Section 4.4.1 and 5.4.1). The post-interviews were carried out to clarify the findings gathered; in particular from the design diaries of Case study 3 (see Section 3.5.2). This allowed the confirmation of the data obtained and validation of the findings to take place.

The protocol analyses were carried out to facilitate the observation and identification of creative behaviours occurrences whilst CAD was being used in designing. This method has consistently identified creative behaviours in the case studies with the exception of the novelty behaviour category (see Section 8.2.2). Protocol analysis allowed the researcher to identify the creative behaviours by interpreting the significant events based on the framework and the participants' verbalisations where they were available to support the analysis (see Section 4.4.5, 5.5.1 and 6.7). The verbalisations allow the elucidating of participants' design thinking that provides context to the activities that had been demonstrated (e.g. Hayes, 1986; Young, 2005; Shahriman, 2008; Ke, 2008).

The findings indicated that design diaries had efficiently identified creative behaviours when CAD was used in the case studies including the novelty behaviour category which could not be captured by other methods (see Section 8.2.3). The number of novelty creative behaviour occurrences that were distinguished was relatively small compared to other categories; however, the findings have provided indications of the capability of data gathering through the use of design diaries to record such occurrences. The participants were encouraged to reflect on their use of CAD when designing and report their findings based on the format of the design diary at the end of each CAD activity (see Section 3.8). These allowed the participants to report the significant events while the experiences were still fresh in their minds.

The rich data collected during the case studies suggested that the Creative Behaviours Framework and data gathering methods used enabled creative behaviours to be captured during the use of CAD in designing. Whilst again acknowledging that these creative behaviours are linked to creativity through the Creative Behaviours Framework, the observation of such behaviours was always likely to be the most effective strategy given the difficulties of directly identifying creativity during the processes of designing.

9.2.3 RQ 3: Are there any significant links between creativity and the use of CAD in designing?

The empirical evidence from the case studies suggested that there were significant links between creative behaviours and the use of CAD in designing such. The findings indicated that the seven Creative Behaviours were observed and captured when designers engaged in CAD during designing activities.

This was supported by the questionnaire results from Malaysian respondents. However, there were mixed responses from UK respondents (see Table 7-4) where the majority disagreed that novelty, motivation and fluency were encouraged by CAD. The different level of CAD skill between these two groups possibly explains why they had different perceptions on these aspects. The Malaysian respondents were all experienced CAD users and educators whereas the UK respondents were essentially undergraduate design students. This would parallel Bhavnani *et al* (1993) findings, who suggested that users' proficiency in using CAD influenced the way they used the software and consequently affected the quality of the outcomes produced.

To seek the possible links between CAD and creativity, it was important to understand whether the creative behaviours observed when using CAD had any connection with the emergence of creative aspects in the product outcomes. Thus, the creative characteristics which were highlighted by stakeholders (e.g. the designers, clients and lecturers) were tracked back to the CAD activities observed (see Section 5.6 and 6.7). The findings suggested links between the creative behaviours and products' creative characteristics; however, this was established from a small evidence base. Hence, the evidence for links between the use of CAD and creative outcomes, although found, was inconclusive.

9.2.4 RQ 4: Does the theoretical framework developed apply to modelling activities widely recognised as being creative?

The Creative Behaviours Framework has been used to analyse participants' behaviour whilst engaged in modelling activities (e.g. 2D sketching, 3D sketch modelling) in order to assess its capability in recognising creative behaviours within these design tools. These were supported by findings in Case study 2 and 3 (see Sections 5.4.2, 5.4.3, 6.4.2 and 6.4.3). The analysis showed that creative behaviours could also be observed and distinguished when using these design tools. This suggests that the Creative Behaviours Model provides a potentially useful framework for the observation of creative behaviours within at least three modelling media, including CAD modelling, 2D sketching, and 3D sketch modelling.

As 2D sketching and 3D sketch modelling are conventionally regarded as creative activities, the findings that the Creative Behaviours Framework can be successfully applied to them is further evidence for its validity. It also suggests the potential for further research related to other design modelling methods.

9.2.5 RQ 5: Does the theoretical framework have potential application beyond the analysis of creativity and CAD use?

The possibility for the Creative Behaviours Framework to be applied beyond the analysis of the relationship of creativity and CAD use is something that would be interesting to explore further. In this study, this aspect had been investigated through a questionnaire survey. The findings implied that the framework has potential in wider applications including facilitating lesson planning, providing a systematic technique for observing creative behaviours and allowing the assessment of students' creativity during learning activities (see Chapter 7). However, since these findings came from a small number of respondents the findings must be considered useful, but inconclusive. This suggests that these possibilities would need further research and some potential directions are discussed in the next section.

9.3 Discussion of the Wider Applications of the Research

The limitations of the data obtained from this case study research in order to reach general conclusions are evident. However, it is also clear that there are a number of areas in which the research could find wider application. These are discussed in this section before making suggestions for future work.

9.3.1 Researching Design Modelling

This study has provided evidence of the efficiency of the Creative Behaviours Framework in capturing creative behaviours in a number of design modelling activities including CAD, 2D sketching, and 3D sketch modelling. The potential of this framework in facilitating research in various aspects of interest in these areas is discussed.

9.3.1.1 CAD

The Creative Behaviours Framework was established with the aim of identifying aspects of creativity, and in particular creative behaviours when CAD is used in design activities, because CAD had previously not been consistently recognised as a creative tool. Findings from the study have established significant evidence of the links between CAD and creative behaviours in designing. The creative behaviours have been associated with creative outcomes through the published research of cognitive psychologists and this provides great potential for research concerning the relationship between creativity and the use of CAD. Some evidence linking creative behaviours to creative characteristics of product outcomes was found (e.g. Case study 2 and Case study 3) and there is significant potential to develop this avenue of research.

The findings from the study also provide hints of the potential for researching other areas, such as the ranges and types of CAD software used. It was found that a number of CAD software packages had been used in the participants' design projects based on certain features which, according to them, could effectively support their designing tasks. These findings have been presented in Chapter 8 (see Section 8.2.1.4). Further research should be undertaken in order to explore possible aspects which influence the selection of particular software by designers in their design activities, and whether these different software packages have any influence on the number of creative behaviours occurrences that emerge.

Data from the case studies has also indicated that CAD was used to support designing tasks which it would have been difficult to undertake through other modelling methods because of sizes (e.g. too big, too small), material characteristics (e.g. fragile), design complexity (e.g. too many parts), etc. Some examples have been presented and discussed in Chapter 8 (see Section 8.2.1.2). There is the possibility of investigating whether the use of CAD in such circumstances results in greater number of creative behaviours being observed when compared with conventional modelling strategies.

9.3.1.2 2D Sketching and 3D Sketch Modelling

Generally, many people consider 2D sketching and 3D sketch modelling to be creative design tools. However, there is little or no evidence provided to support this claim beyond the evident reality that they are used for designing, which is a creative activity. Interestingly, this research has provided some evidence of this kind whilst attempting to validate the findings from CAD observations through conducting similar observations whilst designers were engaged in 2D sketching and 3D sketch modelling. Although these observations were undertaken with a small number of designers, they did, provide evidence that these were appropriate research instruments to capture and analyse the data in identifying creative behaviours in these conventional designing tools. Such data could help to articulate those particular aspects of 2D sketching and 3D sketch modelling that support the occurrence of creative behaviours, and hence their further development as designing tools.

9.3.2 Design Education

The establishment of the Creative Behaviours Framework has provided potential for the development of creativity assessment tools for classroom teaching and learning activities. It is current practice for many design educators to rely on finished products (e.g. visual images, 3D physical models) in facilitating creativity assessment of their students' design outcomes. However, based on the Creative Behaviours Framework, an assessment tool could possibly be developed to facilitate the observation and identification of creative behaviours during a class session i.e. whilst the designing is in progress. The tool could provide information on whether certain aspects of creativity have been achieved by the students before the class sessions' end. This would support existing skills which have already been acquired by experienced teachers and allow the observations to be reported systematically. The Creative Behaviours Framework could also provide a training tool for new teachers to develop their skill in observing the creative behaviours of their students whilst conducting class sessions. Feedback following a conference paper addressing these issues has shown some interest among the audience in such a proposal which suggests there is potential value in the development of such a tool for training purposes (Design and Technology Association Education and International Research Conference 2009). An exemplar set of creative behaviours together with detailed descriptions of the behaviours being demonstrated could be useful in facilitating the educators to observe and record such behaviours of their students.

9.3.3 Software Development

Findings from the study have provided new perspectives on the potential of CAD in promoting the emergence of creative behaviours when designers are engaged in CAD. These findings could provide useful information to software developers in enhancing particular aspects which potentially encourage designers' creativity in designing. The discussion of the research data in Section 8.2.1.4 implied that CAD software was used by designers to facilitate their design tasks based on its advantages, for example features such as user friendliness, ease of operation, and support for design analysis. The methods used and data obtained from the case studies could potentially provide a platform for software developers to verify whether the software has achieved its development objectives. For example, methods based on the Creative Behaviours Framework could possibly be used to investigate whether CAD software that aims to facilitate ideation based on non-parametric image visualisation (e.g. Rhino, 3D Max Studio) could effectively support this activity. Such analysis would also provide suggestions on any aspects of CAD software features which need to be improved in supporting designing activities and enhancing designers' potential (e.g. creative behaviours, creative ideas, useful design)

9.3.4 Professional Practice

This study has mainly involving a number of industrial design students (e.g. undergraduates, postgraduates) at Loughborough University in the data gathering activities. A small number of CAD users among design educators within Malaysian Higher Education Institutions also participated as respondents in the online questionnaire. This has provided an initial platform for a comparison of findings to be undertaken between the CAD users in the UK and Malaysia who have differences in terms of geographical location, culture, educational background, age, level of skill, roles, etc. The data from the questionnaires approach has indicated a few differences in terms of their experiences in observing the emergence of creative behaviours when using CAD. The data showed that these behaviours: novelty; motivation; fluency (see Table 7.4) were not linked to CAD by respondents from the UK which was contradicted with the responses from Malaysian respondents who suggested that there were links between these behaviours and the CAD used. These differences were interesting and could be further explored.

Hence, the similarities and the differences between the findings between different groups of CAD users (e.g. between amateur and professional, between novice and expert users) has indicated the importance of this research in promoting further study to investigate the influences of these aspects of the CAD users' behaviour and creativity. Another aspect which is important to be highlighted is that the participants of the case studies were industrial designers who were engaged in product design activities. The findings have provided substantial evidence of the emergence of creative behaviours when such designers were engaged in CAD. This could spark interest in future explorations of whether CAD would encourage similar occurrences in other design areas, such as in architecture, engineering design, fashion design etc.

9.3.5 Potential Raw Data Mining for Other Research Interests

A number of data collection approaches such as interviews, protocol analysis, observations and design diaries were involved throughout this research study. These have provided significant data resources in the form of texts, audio, video, and diaries which could prove useful for further analysis, not only to this research but also to other research areas that are related to student design activities e.g. student design project management, criteria in design tool selection, and design strategies. For example, the data from the interviews which consists of preliminary and post-interviews could provide a rich source for those who are interested in researching on how designers, particularly student designers, planned and then how they actually undertook their design projects.

Further, the video data which recorded the participants' modelling activities could be useful in providing raw data for studying design behaviours when designers are engaged with certain design tools in particular CAD, 2D sketching, and 3D sketch modelling. The design diaries which were completed by the participants to record their CAD activities could also provide information for further analysis on other aspects such as problem solving skills, design decision-making, design motivation, level of stress etc.

9.4 Chapter Summary

This research has successfully addressed the research questions that were established in Chapter One. The Findings also indicate the potential to undertake further research subsequent to this study. These have been addressed in five main headings including 'researching design modelling', 'design education', 'software development', professional practice', and 'potential raw data mining for other research interets'.

10 Conclusions, Contributions to Knowledge and Suggestions for Future Work

10.1 Chapter Overview

This chapter completes the thesis by providing conclusions, a summary of the contributions to knowledge and suggestions for future work.

10.2 Conclusions

The conclusions of this thesis are as follows:

a) It was possible to establish a framework for researching the links between CAD and creativity by focusing on behavioural aspects.

b) A Creative Behaviours Framework founded on published research from the area of cognitive psychology was developed to link CAD and its use in designing.

c) From a range of initial research methods, three were found to be most appropriate for this research; interviews; protocol analysis; and design diaries.

d) Six of the seven categories (excluding novelty) were consistently observed in all the case studies through protocol analysis and the post-interviews.

e) Novelty was only observed in Case studies 2 and 3 through records from design diaries.

f) Some categories of creative behaviour were also observed in 2D sketching and 3D sketch modelling, supporting the validity of the Creative Behaviours

Framework suggesting wider potential application for this framework in analysing design modelling.

g) The observation of creative behaviours in all the case studies and in all three modelling methods (CAD, 2D sketching, and 3D sketch modelling) confirms the validity and reliability of the research methodology.

h) The literature review, case study and questionnaire outcomes were in agreement, except for the responses from Loughborough which disagreed that novelty, motivation and fluency were facilitated by CAD modelling.

i) The Malaysian questionnaire responses confirmed the outcomes of the case studies in linking the 7 categories of creative behaviours to the use of CAD.

j) The potential for using the Creative Behaviours Framework in wider applications was suggested from the Malaysian questionnaire responses. The framework could find application in developing professional design and classroom practice, and software development.

k) The potential to undertake further research using the Creative Behaviours Framework in other research modelling activities such as 2D sketching and 3D sketch modelling in observing and capturing creative behaviours of designers when using these design tools has been identified.

l) The potential to develop creativity assessment tools to facilitate design educators in observing and capturing creative behaviours of their students during design lessons has been noted.

m) The potential to provide information for software developers on the effectiveness of their software in supporting design activities and suggestions of aspects which could be further improved has been identified.

n) This study has encouraged future research to be undertaken in exploring the relationship between CAD and the creative behaviours of various groups of users (e.g. different geographical locations, levels of skill, design areas etc).

10.3 Research Contributions

The objectives of this research hasve been realised through the following contributions.

a) *To explore, understand, and develop a framework for gathering empirical evidence to support the analysis of links between CAD and creativity.*

- A Creative Behaviours Framework has been established to link CAD and designing, based essentially on literature from the area of cognitive psychology.
- The Creative Behaviours Framework had seven categories which could facilitate the observation of creative behaviours in design modelling activities.

The establishment of the Creative Behaviours Framework is the most significant outcome of this study. This framework provides a more structured approach to observe and identify creative behaviours based on the categories suggested. This is particularly valuable in facilitating design education and design practice researchers in providing a tool to observe and identify creative behaviours whilst student and professional designers are engaged in designing activities.

b) *To analyse, and develop methods of analysis for creativity occurrences to be identified during the use of CAD in designing*

- Appropriate methods for observing creative behaviours have been identified namely; interviews; protocol analysis; design diaries.
- These methods have demonstrated the recordings of creative behaviours occurrences in six case studies.

The significance of this is the successful recognition of a number of research tools which efficiently facilitate the data gathering process, and supported the subsequent analysis methods for identifying creative behaviours. This is particularly valuable in providing reliable data gathering and analysis tools for capturing creative behaviours.

c) *To analyse, and determine whether the use of CAD in designing has significant links with creativity*.

- Some links between creative characteristics of product outcomes with CAD were established through data from design diaries.

The significance of this is the establishment of evidence that linked the creative characteristics of product outcomes with CAD from design diaries data. This is particularly valuable in providing substantial grounds for future research to further explore other possible links between CAD and creativity in designing eg in different design areas.

d) *To evaluate the framework developed with modelling activities which are recognised as creative approaches to designing such as 2D sketching and 3D sketch modelling.*

- The Creative Behaviours Framework was shown to be applicable to 2D sketching and 3D sketch modelling, as well as CAD.
- The analysis with the Creative Behaviours Framework supported previous research concerning the analysis of 2D sketching and 3D sketch modelling.

The significance of this is the evidence of wider application of the Creative Behaviours Framework to other design modelling approaches such as 2D sketching, and 3D sketch modelling. This is particularly valuable in supporting prior suggestions which associate these design modelling tools with creativity through empirical findings, and the potential to gather further evidence.

e) To explore the potential of the framework for use in wider contexts, such as teaching and learning.

- The potential for wider application of the Creative Behaviours Framework beyond the analysis of CAD use was established e.g. in teaching and learning.

The significance of this is the potential of this framework in facilitating the observation of creative behaviours both in design activities related to teaching and learning and in non-designing activities. This could be particularly valuable in supporting other research areas such as general education, psychology, management, engineering etc.

10.4 Suggestions for Future Work

The present study has indicated several areas where further work would be useful. These areas are outlined below.

a) Improving the Creative Behaviours Framework.

- The Creative Behaviours Framework established for this research consisted of seven categories including novelty, appropriateness, motivation, fluency, flexibility, sensitivity, and insightfulness. Feedback at a conference attended suggested that the framework should include another category which could be known as elaboration. Due to the limited time to complete the research, the suggestion could not be considered in this study. It would be interesting if this category or other relevant categories could be included and further investigated in future research work.
- The creative behaviours have been assigned with three descriptors to provide context when observing CAD activities. Hence, the analysis will be focused on identifying events which fit to the description of the descriptors given. If more descriptors are added in the framework for each category of behaviours, there is possibility that more occurrences of creative behaviours could be distinguished.

b) Wider studies.

- The observations in this study were made in relation to designing being undertaken by a small sample of students of the Design and Technology Department, Loughborough University, but other students and/or professional designers might be expected to exhibit similar patterns of behaviour. Since only a very small number of responses had been received from Malaysia through the online questionnaire, the comparisons that have been made were useful, but inconclusive. Thus, further study to seeking feedback from a larger number of respondents from Malaysia or other countries could provide more accurate perspectives in terms of the similarities and differences between CAD users, with different experiences and from different culture.
- Exploring 2D sketching and 3D sketch modelling and other design activities to establish more general principles relating behavioural characteristics to creativity. The Creative Behaviours Framework developed has established some, but further research might reveal more.

c) Wider applications.

- Creativity needs to be a key aspect of designing in general education and the Creative Behaviours Framework could support this goal by facilitating the structured observation of creative behaviours during designing. Hence, creativity assessment could be an aspect of systematic formative assessment carried out as designing takes place. It is likely that experienced teachers are already pursuing similar strategies, but their articulation is a key aspect of supporting those less experienced in developing effective classroom and studio practice in support of creative behaviours exhibited by their students.

- CAD has increasingly been playing important roles in facilitating and supporting design activities especially in the stage of design development. This study has provided useful findings on how CAD supports designers in dealing with the complexity of the design process including size matters (e.g. too small, too large), material characteristics limitation (e.g. fragile, hard), and complicated design (e.g. multiple parts, complex shapes). However, there is still only a small amount of evidence concerning the potential CAD could provide to designers. Further research is vital to help software developers in identifying critical aspects which need to be looked into and improved.

11 References

Aguilar-Alonso, A. (1996). ‘Personality and Creativity’. *Person Individual Differences* 21(6), 959-969.

Allison, B. O’Sullivan, T. Rice, A. Rothwell, A. and Saunders, C. (1996). *Research Skills for Students*. London: Kogan Page.

Altier, W. J. (1988). ‘From experience: A perspective on creativity’. *Product Innovation Management*, 5, 154-161.

Amabile, T. M. (1983). *The Social Psychology of Creativity.* New York: Springer-Verlag.

Amabile, T. M. (1996). *Creativity in Context*. Boulder, Colorado: Westview Press.

Amabile, T. M. and Conti, R. (1999). Motivation/Drive. In M.A Runco and Pritzker, S.R (Eds.). *Encyclopedia of Creativity*, *Volume 2*. San Diego: Academic Press, 251-259.

Angrosino, M. (2007). *Doing Ethnographic and Observation Research*. London, California, New Delhi, Singapore: SAGE Publication Ltd.

Archer, B. (1992). ‘As Complex as ABC’. In Roberts P, Archer B and Baynes K (Eds.). Modelling: Language of Designing. *Occasional Paper No* 1. Loughborough, UK: Loughborough University of Technology. 7-11.

Archer, B. and Roberts, P. (1992). ‘Design and Technological Awareness in Education. Modelling: The Language of Designing’. In Roberts, P *et al* (Eds.). Modelling: Language of Designing. Occasional Paper No. 1. Loughborough, United Kingdom, UK: Loughborough University of Technology. 3-4.

Arieti, S. (1976). *Creativity: The Magic Synthesis*. New York: Basic Books Inc.

Asperl, A. (2005). ‘How to Teach CAD’. *Computer-Aided Design Applications*, 2(1-4), 459-468.

Bairstow, J. *et al* (1999). *Design Modelling: Visualising Ideas in 2D and 3D*. London: Hodder & Stoughton.

Balchin, T. (2005). 'A Creativity Feedback Package for Teachers and Students of Design and Technology (in the UK)'. *Design and Technology Education: An International Journal,* 10(2), 31-43.

Barlex, D. (2002). *Creativity in Crisis*. Design and Technology at KS3 and KS4, The Design and Technology Association.

Barlex, D. and Miles-Pearson, S. (2008). 'Introducing CAD/CAM into Primary Schools Part 1 of a Case Study-Developing the Curriculum'. In Norman, E.W and Spendlove, D (Eds.) *Proceedings of the Education & International Research Conference 2008*, 2 - 4 July 2008, Loughborough University, UK: The Design and Technology Association.

Barron, F. (1969). *Creative Person and Creative Process*. New York, London: Holt, Rinehart & Winston.

Barron, F. and Harrington, D. M. (1981). 'Creativity, Intelligence, and Personality'. *Annual Reviews*, 32, 439-476.

Baskinger, M. (2008). 'Pencil Before Pixels: A Primer in Hand Generated Sketching'. *Interactions,* March/April 2008, Volume XV (2), From http://interactions.acm.org/content/?p=1081. Accessed: 23 January 2009.

Berg, B. L. (1989). *Qualitative Research Methods For The Social Sciences*. Boston, London; Toronto, Sydney, Tokyo, Singapore: Allyn & Bacon.

Bhavnani, S.K. *et al* (1993). Leading Indicators of CAD Experience. *Proceedings of the Fifth International Conference on Computer Aided Architectural Design Future '93*. Pittsburgh, Penssylvania, US: Elsevier Science Publisher BV.

Blatter, J (2008). 'Case Study'. In Given, L.M (Ed.). The SAGE Encyclopedia of Qualitative Research Methods. Thousand Oaks, London, New Delhi, Singapore: SAGE Publications.

Bostrom, R. P. and Nagasundram, M. (1998). Research in Creativity and GSS. *Proceedings of the Thirty-First Hawaii International Conference on System Sciences 1998*, Volume 6, 6-9 January. Hawaii, US: IEEE.

Bowers, K.S. *et al* (1995). Intuitive Antecedents of Insights.

Brinkmann. S. (2008). 'Interviewing'. In Given, L.M (Ed.). The SAGE Encyclopedia of Qualitative Research Methods. Thousand Oaks, London, New Delhi, Singapore: SAGE Publications.

Brown, R. T. (1987). 'Creativity: What Are We to Measure?'. In Glover, J. A *et al* (Eds.). *Handbook of Creativity*. New York, London: Plenum Press. 3-32.

Bull, K.S. and Davis, G.A. (1982). 'Inventory for Appraising Adults Creativity'. *Contemporary Educational Psychology,* 7, 1–8.

Candy, L .and Edmond, E. (1999). 'Introduction Creativity to Cognition'. *Proceedings of the Third Conference on Creativity & Cogniton 1999,* 11–13 October. Loughborough, UK.

Cao, Q. and Protzen, J. (1999). 'Managing Design Information'. *Design Studies*, 20(24), 343–362.

Charlesworth, C. (2007). 'Student Use of Virual Physical Modeling in Design Development-An Experiment in 3D Design Education'. *The Design Journal,* 10(1), 35-45.

Chester, I. (2007). '3D-CAD: Modern Technology-Outdated Pedagogy?'. *Design and Technology Education: An International Journal*, 12(1), 7-9.

Conti, R. and Amabile, T.M. (1999). 'Motivation/Drive'. In Runco, M.A and Pritzker, S.R (Eds.). *Encyclopedia of Creativity*, Volume 2. San Diego: Academic Press. 251-59.

Cooley, M. J. (1977). 'Impact of CAD on the Designer and the Design function.' *Computer-Aided design*, 9(4), 238-242.

Corti, L. (1993). 'Using Diaries in Social Research'. *Social Research Update*, 9(4), 238-242.

Cropley, A. J. (2001). *Creativity in Education and Learning*. London: Kogan Page.

Cropley, A.J. (1967). *Creativity.* London: Longmans, Green & Co. Ltd.

Crosbie, T. (2006). 'Using Activity Diaries: Some Methodological Lessons'. *Research Practise,* 2, 1-13.

Cross, N. (1999). 'Natural Intelligence in Design'. *Design Studies*, 20(1), 25-39.

Cross, N. *et al* (1996). 'Introduction; The Delft Protocols Workshop in Analysing Design Activity'. In Cross, N. Christiaans, H. and Dorst, K. (Eds.). *Analysing Design Activity*. Chichester. New York, Brisbane, Toronto, Singapore: John Wiley and Sons.

Crutchfield, R. S. (1973). 'The Creative Process'. In Bloomberg, N. *Creativity: Theory and Research.* New Haven, Connecticut: College and University Press.

Dacey, J.S. and Lennon, K.H. (1998). *Understanding Creativity: The Interplay of Biological, Psychological and Social Factors*. San Francisco, California: Jossey Bass.

Dakers, J. (2004). 'Exploring Creativity as a Component of the Manufacturing or Making Process: Implications for Assessment'. *Creativity and Innovation: Design and Technology Association Annual International Research Conference 2004.* Wellesbourne: The Design and Technology Association.

Davies , D. *et al* (2002). 'Creativity, Culture and Citizenship in Primary Design and Technology'. *Journal of Design and Technology Education*, 7 (1). From https:// *ojs.lboro.ac.uk/ojs/index.php/JDTE/article/view/446/423.* Accessed: 15 September 2009.

Davies, S. P. (1999). 'Effects of Concurrent Verbalization on Design Problem Solving'. *Design Studies*, 16, 102-116.

Davis, G. A. (1999). 'Barriers to Creativity and Creative Attitudes'. In Runco, M.A and Pritzker, S.R. *Encyclopedia of Creativity, Volume 1.* San Diego: Academic Press.

De Bono, E. (1994). *Parallel Thinking*. London: Penguin Group.
Demirkan, H. and D. Hasirci (2009). 'Hidden Dimensions of Creativity Elements in Design Process'. *Creativity Research Journal*, 21(2), 294- 301.

Dewulf, S. and Bailie, C (1999). *How To Foster Creativity*. United Kingdom: Department for Education and Employment.

Dorst, K. (1995). ‘Analysing Design Activity: New Directions in Protocol Analysis’. *Design Studies*, 16(2), 139-142.

Dorst, K. and Cross, N. (2001) ‘Creativity in the Design Process: Co-evolution of Problem-Solution’. *Design Studies,* 22, 425-437.

Dorst, K. and Dijkhuis, J. (1995). ‘Comparing Paradigms for Describing Design Activity’. *Design Studies,* 16, 261–274.

Doyle, M. (2004). ‘The Evolution of Technicity: Whence Creativity and Innovation’. *The Design and Technology Association: Education and International Research Conference 2004*. https://dspace.lboro.ac.uk/dspace-jspui/handle/2134/2868. Accessed: 12 December 2009.

El-Murad, J. and West, D.C. (2004). ‘The definition and Measurement of Creativity: What Do We Know?’. *Journal of Advertising Research*, 44(22), 188-201.

Epstein, R. (1999). ‘Generativity Theory’. In Runco, M.A and Pritzker, S. R. (Eds.). *Encyclopedia of Creativity, Volume 1*. San Diego, London, Boston, New York, Sydney, Tokyo, Toronto: Academic press. 759-766.

Finke, R.A. *et al* (1992). *Creativive Cognition: Theory, Research, and Applications*. Cambridge, Massachusetts, London , England: MIT Press.

Flyvbvjerg, B. (2006). ‘Five Misunderstandings about Case-Study Research’. *Qualitative Inquiry*, 12(2), 219-245.

Fraser, A. and Hodgson, A.R. (2006). ‘The Application of Computer Aided Design and Manufacture in School-Based Design’. In Norman, E.W *et al* (Eds.). *The Design and Technology Association: Education and International Research Conference 2005.* Wellesbourne: The Design and Technology Association.

Fraser, A. and Hodgson, A.R. (2007). ‘Computer Aided Design: Implications for Pupil Attainment and Assessment’. In Norman, E.W and Spendlove, D (eds.). *The Design and Technology Association: Education and International Research*

Conference 2007, Telford, 4-6 July 2007. Wellesbourne: The Design and Technology Association.

Gardner, H.C. (1989). *To Open Minds*. New York: Basic.

Garner, S. (1989). 'Drawing and Designing: Exploration and Manipulation on Through Two-Dimensional Modelling'. *DATER Conference 1989*. Loughborough: Loughborough University. From https://dspace.lboro.ac.uk/dspace-jspui/handle/2134/1116. Accessed: 18 October 2009.

Gero, J.S. and McNeil, T. (1998). 'An Approach to the analysis of design protocols'. *Design Studies*, 19(1), 21-61.

Gero, J.S. and Kannengiesser, U. (2007). 'Locating Creativity in a Framework of Designing for Innovation. In Leon-Rovira, N (ed.). *Trends in Computer Aided Innovation*. Boston: Springer Boston.

Gilchrist, M. (1972). *The Psychology of Creativity*. Hong Kong: Melbourne Press.

Goel, V. (2000). 'Dissociation of Design Knowledge'. In Eastman, C and Newstetter, W.C . Knowing and Learning to Design: Cognitive Perspectives in Design Education. http://www.yorku.ca/vgoel/reprints/Goel_design.pdf. Accessed: 5 August 2009.

Goel, V. and Pirolli, P (1992). 'The Structure of Design Spaces'. *Cognitive Sciences.* 16(3), 395-429.

Goldschmidt, G. (1999). 'Design'. In Runco, M.A and Pritzker, S.R (eds.). *Encyclopedia of Creativity*. San Diego, London: Academic Press. 525-552.

Goldschmidt, G. and Tatsa, D. (2005). 'How Good Are Good Ideas? Correlates of Design Creativity'. *Design Studies,* 26(6), 593-611.

Guilford, J. P. (1973). 'Traits of Creativity'. In Vernon, P.E . *Creativity*. 167-18 Great Britain: Penguin Education. 167-188

Hanna, R. and Barber, T. (2001). 'An Inquiry into Computers in Design: Attitudes Before-Attitudes After'. *Design Studies*, 22, 255-281.

Hanna, S. (2005). 'Where Creativity Comes From'. *Proceedings of Human Interaction 2005*, Computational and Cognitive Models of Creative Design, University of Sydney, 45-70.

Hayes, S. C. (1986). 'The Case of the Silent Dog-Verbal Reports and the Analysis of Rules: A review of Ericsson and Simon's Protocol Analysis: Verbal Reports as Data'. *Journal of the Experimental Analysis of Behaviour*, 45(3), 351-363.

Hicks, G. *et al* (1982). *Understanding Design and Technology*. Assessment of Performance Unit.

Hocevar, D. and P. Bachelor (1987). 'A Taxonomy and Critique of Measurements Used in the study of Creativity'. *Handbook of Creativity*. In Glover, J.A (eds.). New York, London: Plenum Press. 53-75.

Hodgson, A.R. (2006). Digital Design-the potential of Computer Aided Designing in design learning environments. Design and Technology Education: An International Journal, 11(1), 10-16.

Hodgson, A.R. and Allsop, C. (2003). 'Beyond Pro DESKTOP Computer Aided Design (CAD): The Transfer of CAD-based Design Modelling Skills From Schools to Higher Education'. *The Design and Technology Association: International Research Conference 2003*. The Design & Technology Association. 45-49.

Hodgson, T. and A. Fraser (2005). The Impact Of Computer Aided Design and Manufacture (CAD/CAM) on School-Based Design work. In Norman, E.W *et al* (Eds.). *The Design and Technology Association International Research Conference 2005.* The Design and Technology Association.

Hornby, A. S. (2000). *Oxford Fajar: Advanced Learner's English – Malay Dictionary*. Shah Alam: Oxford University Press and Penerbit fajar Bakti.

Jackson, P. W. and Messick, S. (1965). 'The Person the Product, and the Response: Conceptual Problems in the Assessment of Creativity'. *Journal of Personality,* 33(3), 309-329.

Kavakli, M. and Gero, J.S. (2002). 'The Structure of Concurrent Cognitive Actions: A Case Study on Novice and Expert Designers'. *Design Studies*, 23(1), 25-40.

Kavakli, M. *et al*. (1998). Structure in Idea Sketching Behaviour'. *Design Studies*, 19(4), 485-517.

Kawulich, B. (2005). Participant Observation as a Data Collection Method. *Forum: Qualitative Social Research*, 6(2). http://www.qualitative-research.net/index.php/fqs/article/view/466. Accessed: 9 May 2007.

Ke, F. (2008). 'A Case Study of Computer Gaming for Math: Engage Learning from Gameplay?'. *Journal of Computer & Education,* 51, 1609-1620.

Kimbell, R. *et al* (2002). 'Pro/DESKTOP in SchoolsL A Pilot Research Study'. *Journal of Design & Technology Education*, 7(1). 29-36.

Krosnick, J. A. (1999). 'Survey Research'. *Annual Review of Psychology,* 50, 537-567.

Lawson, B. (1999). 'Fake' and 'Real' Creativity Using Computer Aided Design: Some Lesons from Herman Hertzberger. Proceedings of the 3rd conference on Creativity & Cognition, Loughborough, 174-179.

Lee, H.L. and Fulton, D.W. (2003*). Computer Aided Design with UniGraphics*. Dubuque, Iowa: Kendall/Hunt Publishing Company.

Lee, K.H. (2005). 'The Relationship Between Creative Thinking Ability and Creative Personality of Preschoolers'. *International Education Journal***,** 6(2), 194-199.

Lubart, T. (1999). 'How Can Computers be Partners in the Creative Process: Classification and Commentary on the Special Issue'. *International Journal of Human-Computer Studies*, 63(4-5), 365-269.

Mack, N. *et al* (2009*).Qualitative Research Methods: A Data Collector's Field Guide*. *Family Health International Website*. http://search.fhi.org/cgi-bin/MsmGo.exe?grab_id=102665800&extra_arg=&page_id=286&host_id=1&query=Qualitative+research+methods&hiword=QUALITATIVE+RESEARCH+METHODS+RESEARCHERS+METHOD+RESEARCHER+RESEARCHED+

METHODES+METHODE+RESEARCHBASED+RESEARCHS+RESEARCHING+QUALITATIVELY+QUALITATIVA+QUALITATIVO+METHODIST+RESEARCHES. Accessed: 10 October 2009.

Macedo, L. and Cardoso, L. (2001). 'Creativity and Surprise'. *Symposium on Creativity in Art and Science (AISB) 2001*, York, UK. 84-92.

MacCrimmon, K.R. and Wagner, C. (1994). 'Stimulating Ideas Through Creativity Software'. Management Science, 40(11). 1514-1525.

Malterud, K. (2001). 'Qualitative Research: Standards, Challenges, and Guidelines'. The LANCET, 358. 483-488.

Mandler, G. (1995). 'Origins and Consequences of Novelty'. In Smith, S.M *et al* (eds.). *The Creative Cognition Approach*. Massachussetts: Massachussets Institute of Technology.

Martindale, C. (1995). Creativity and Connectionism. In Smith, S.M *et al* (eds.). *The Creative Cognition Approach.* Massachussett: Massachussetts Institute of Technology.

Mc Kernan, J. (1996). *Curriculum Action Research: A Handbook of Methods and Resources for the Reflective Practitioner*. London: Kogan Page Ltd.

McCartney,J. *et al* (2000). 'Dedicated 3D CAD for Garment Modelling. *Journal of Material Processing Technology,* 107(1-3), 31-36.

McGown. A. *et al* (1998). 'Visible Ideas: Information Patterns of Conceptual Sketch Activity'. *Design Studies*, 19(4), 431-453.

McKechnie, L. (2008). 'Observational Research'. In Given, L.M (Ed.). The SAGE Encyclopedia of Qualitative Research Methods. Thousand Oaks, London, New Delhi, Singapore: SAGE Publications.

McNamara, C. (2008). 'Interview'. In Given, L.M (Ed.). The SAGE Encyclopedia of Qualitative Research Methods. Thousand Oaks, London, New Delhi, Singapore: SAGE Publications.

McQueen, R. and Knussen, C. (2002). *Research Methods for Social Science: An Introduction*. Harlow, Essex: Pearson Education.

Molteni, M. T. (1989). *The Clay Modelling Handbook: Learning from the Masters.* London: Aurum Press.

Morgan, D. (2008). 'Sample'. In Given, L.M (Ed.). The SAGE Encyclopedia of Qualitative Research Methods. Thousand Oaks, London, New Delhi, Singapore: SAGE Publications.

Morgan, D. and Guevara, H. (2008). Interview Guide. In Given, L.M. *The SAGE Encyclopedia of Qualitative Research Methods*. Thousands Oak, London, New Delhi, Singapore: SAGE Publications.

Mouly, G. J. (1978*). Educational Research: The Art and Science of Investigation.* Boston, London, Sydney, Toronto: Allyn and Bacon Inc.
NACCCE (1999). All our Futures: Creativity, Culture & Education. United Kingdom, Department for Education and Employment.

Miller, P. (2008). 'Reliability'. In Given, L.M (Ed.). *The SAGE Encyclopedia of Qualitative Research Methods*. Thousands Oak, London, New Delhi, Singapore: SAGE Publications.

Nagai, Y. and Taura, T. (2006). Role of Action Concepts in Creative Design Process*. 2006 International Design Research Symposium.* www.jaist.ac.jp/ks/labs/t-taura/img/taura_pub/58.pdf. Accessed: 22 October 2008.

Nakakoji, K. and Y. Yamamoto (2003). Towards a Taxonomy of Interaction Design Techniqus for Externalizing in Creative work. *10th International Conference on Human-Computer Interaction (HCII2003).* Crete, Greece. http://www.kid.rcast.u-tokyo.ac.jp/~kumiyo/mypapers/HCII03.pdf. Accessed: 22 October 2008.

National Science Foundation, 5 December 2008. *Overview of Qualitative Methods and Analytic Technique.* From http://www.nsf.gov/publications/. Accessed: 15 October 2009.

Nicholl, B. and R. McLellan (2007). 'Oh Yeah, Yeah...You Get a Lot of Love Hearts. The Year 9s are Notorious for Love Hearts. Everything is Love Hearts. ' Fixation in Pupils ' Design and Technology Work (11-16 years)'. *Design and Technology Education: An International Journal***,** 12(1), 34-44.

Norman, E. W. (2006). 'The Cox Report and the Key Stage 3 Review: Creativity, Design, And Innovation in the UK'. *Design and Technology Education: An International Journal***,** 11(1), 3-6.

Norman, E. W. and Pedgley, O. (2005). Technicity as the Conceptual Basis for Explaning Innovation in Design and Technology. In Norman, E.W *et al* (Eds.). *The Design and Technology Association: International Research Conference 2005*, Wellesbourne, UK: Design and Technology Association.

Palys, T. (2008). 'Purposive Sampling'. In Given, L.M. *The SAGE Encyclopedia of Qualitative Approaches*. Thousands Oak, London, New Delhi, Singapore: The SAGE Publications.

Paterson, B.L. *et al* (2003). 'Blending Observational Methods: Possibilities, Strategies, and Challenges'. *International Journal of Qualitative Methods*, 2(1). From http://www.ualberta.ca/iiqm/backissues/2_1/html/patersonetal.html. Accessed: 5 May 2007.

Patton, M.Q. (2002). *Qualitative Research and Evaluation Methods*. Thousand Oaks, London, New Delhi: SAGE Publications Inc.

Pedgley, O. (1999). Industrial Designers' Attention to Materials and Manufacturing Processes: Analyses at Macroscopic and Microscopic Levels. Ph.D. Loughborough University.

Pedgley, O. (2007). Industrial Designers' Attention to Materials and Manufacturing Processes: Analyses at Macroscopic and Microscopic Levels. Ph.D. Loughborough University.

Pedgley, O. (2009). 'Cool Acoustics: Innovation in Guitar Design'. *Quick on the Draw Exhibitions 2009*, Design and Technology Department, Loughborough University.

Policastro, E. (1999). 'Intuition'. In Runco, M.A and Pritzker, S.R (eds). *Encyclopedia of Creativity.* Volume 2. San Diego: Academic Press. 89-94.

Prats, M. and Earl, C.F. (2006). 'Exploration Through Drawings in the Conceptual Stage of Product Design'. *Design Computing and Cognition*, 9, 83-102.

Rawson, P. (1971). *Ceramics.* London: Oxford University Press.

Richards , P. (1999). 'Four Ps of Creativity'. In Runco, M.A and Pritzker, S.R (Eds.) *Encyclopedia of Creativity.* Volume 1. San Diego: Academic Press. 33-42.

Riley, J. (1990). *Getting the Most from Your Data: A Handbook of Practical Ideas on How to Analyse Qualitative Data.*_ Bristol: Technical and Education Services Ltd.

Ripple, E. (1989). 'Ordinary Creativity'. *Contemporary Educational Psychology*, 14, 189-202.

Roberts, P. (1992). Models, Modelling, and Design: An Applied Philosophical Enquiry in Modelling. In Roberts P, Archer B and Baynes K (Eds.). Modelling: Language of Designing. *Occasional Paper No* 1. Loughborough, UK: Loughborough University of Technology, Loughborough University.: 33-43.

Robertson, B. F. and Radcliffe, D.F. (2008). 'Impact of CAD tools on Creative Problem Solving in Engineering Design'. *Computer-Aided Design* In press, Corrected Proof.

Robertson, B.F. *et al* (2007). 'Creativity and the Use of CAD Tools: Lessons for Engineering Design Education from Industry'. *Journal of Mechanical Design***,** 129, 753-759.

Robertson, D. and Allen, T. J. (1993). 'CAD System Use and Engineering Performance'. *Transaction on Engineering Management***,** 40(3), 274-282. http://ieeexplore.ieee.org/iel1/17/6027/00233189.pdf. Accessed: 8 April 2007.

Robertson, D. and Allen, T.J. (1991). CAD System Use and Engineering Performance in Mechanical Design. Working Paper 3251-91, Sloan School Management, Massachussetts Institute of Technology. http://hdl.handle.net/1721.1/2338. Accessed: 3 March 2007.

Rodgers, P.A. *et al* (2000). 'Using Concept Sketches to Track Design Progress'. *Design Studies*, 21(5), 451-464.

Rogers, C. R. (1970). Towards a Theory of Creativity. In Vernon, P.E. *Creativity*. Harmondsworth, Baltimore, Ringwood: Penguin Education.

Rothbauer, P. (2008). 'Triangulation'. In Given, L.M. *The SAGE Encyclopedia of Qualitative Approaches*. Thousands Oak, London, New Delhi, Singapore: The SAGE Publications.

Rowan, M. and Huston, P. (1997). 'Qualitative Research Articles: Informations for Authors and Peer Reviewers'. *Canadian Medical Association Journal*, 157(10). 1442-1446.

Runco, M.A. and Sakamoto, S.O. (1990).Experimental Research on Creativity. In Sternberg, R.S (ed.). Handbook of Creativity. New York: Cambridge University Press. 62-92.

Schenk, P. (1991). 'The Role of Drawing in the Graphic Design Process'. *Design Studies*, 12(3), 168-181.

Schneiderman, B. (1999). User Interfaces fo Creativity Support Tools. In Edmonds, E and Candy, L. *Proceedings of the 3rd Conference on Creativity & Cognition 1999*, Lougborough: ACM SIGCHI.

Sedivy, J. Johnson, H (1999). Supporting creative work tasks: Potential of multimodal tools to support sketching. . In Edmonds, E and Candy, L. *Proceedings of the 3rd Conference on Creativity & Cognition 1999*, Lougborough: ACM SIGCHI. *citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.93.3793&rep*. Accessed: 23 March 2009.

Shahriman, Z.A. et al (2008). 'The Embodied Mind in Relation to Thinking about Form Development. Proceedings of the NordDesign 2008, Tallinn, Estonia, 21-23 August.

Shalley, C. E. *et al* (2004). 'The Effects of Personal and Contextual Characteristics on Cretivity: Where Should We Go from Here?' *Journal of Management*, 30(6), 933-958.

Sharif, A.M. and Sa,n, K.M. (2001). The Invention Curriculum: A Malaysian Experience. INNO Data Monographs 11. International Bureau of Education, UNESCO. http://www.ibe.unesco.org/publications/innodata/inno11.pdf. Accessed: 2 January 2007.

Silverman, D. (2001). *Interpreting Qualitative Data: Method for Analysing Talk, Text and Interaction.* London, Thousand Oaks, New Delhi: SAGE Publications.

Sinnott, E.W. (1970). 'The Creativeness of life'. In Vernon, P.E. *Creativity*. Harmondsorth, Baltimore, Ringwood: Penguin Education.

Smith, J. S. *et al* (2001). 'The Current and Future Role of Modelling in Design and Technology'. *The Journal of Design and Technology Education,* 6(1): 5-15.
Smith. T.W. and Strahan, D. (2004). 'Toward a Prototype of Expertose in Teaching: A Descriptive Case Study'. *Journal of Teacher Education*, 55, 357-371.

Smith-Sullivan, K. (2008). 'Diaries and Journals'. In Given, L.M. *The SAGE Encyclopedia of Qualitative Approaches.* Thousands Oak, London, New delhi, Singapore: The SAGE Publications.

Stables, K. (2008). Designing Matters; Designing Minds: The Importance of Nurturing the Designerly in Young People. *Design and Technology Education; an International Journal*, 13(3), 8-18.

Sosa, R. and Gero, J.S. (2005). 'A Computational Study of Creativity in Design: The role of Society. *AIEDAM: Artifical Intelligence for Engineering Design, Analysis, and Manufacturing*, 19(4), 229-244.

Southee, D. (2009). 'Anonymous Marking in Design – How Does that Work?'. *International Conference on Engineering and Product Design Education 2009.* 10-11 September. Brighton, United Kingdom: The Design Society.

Speight, C. F. (1983). *Hands in clay: An introduction to ceramics.* Sherman Oaks, California: Alfred Publishing Co. Inc.

Spendlove, D. (2005). 'Creativity in Education: A Review'. *Design and Technology Education: An International Journal*, 10(2), 9-18.

Spendlove, D. and Hopper, M. (2004). Creativity and Technology and ICT: Imagining Possibilities in a Digital Age. *The Design and Technology*

Association International Education and Research Conference 2004. The Design & Technology Association: 6.

Stappers, P.J. and Hennessy, J.M. (1999). 'Computer-Supported Tools for the Conceptualization Phase'. *Proceedings of the 4th International Design Thinking Research Symposium on Design Representation*, Boston, USA.

Sternberg, R.J. and Davidson, J.(1999). 'Insight'. In Runco, M.A and Pritzker, S.R (Eds.). *Encyclopedia of Creativity*, Volume 1. San Diego, London: Aacademic Press. 57-70.

Sternberg, R.J. and Lubart, T.I (1999). The Concept of Creativity: Prospects and Paradigms. In Sternberg, R.J. Handbooks of Creativity. Cambridge: Cambridge University Press: 3-15.

Sternberg, R.J. and O'Hara, L.A. (1999). Creativity and Intelligence. In Sternberg, R.J (Ed.). Handbook of Creativity. Cambridge: Cambridge University Press. 251-272.

Stokes, P. D. (1999). 'Novelty'. In Runco, M.A and Pritzker, S.R. *Encyclopedia of Creativity*, Volume 2. San Diego, London: Aacademic Press. 297-304.

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

Suwa. M. *et al* (1998). 'Macroscopic Analysis of Design Process Based on a Scheme for Coding Designers' Cognitive Action'. Design Studies, 19(4), 455-483.

Tano, S. *et al* (2003). 'Godzilla: Seamless 2D and 3D Sketch Environment for Reflective and Creative'. Human-Computer Interaction, INTERACT '03. http://www.idemployee.id.tue.nl/g.w.m.rauterberg/conferences/INTERACT2003/INTERACT 2003-p311.pdf. Accessed: 23 March 2007.

Taylor, I.A. (1975). 'A Retrospective View of Creativity Investigation'. In Taylor, I.A and Getzels, J.W (eds.). *Perspectives in Creativity*. Chicago: Aldine Publishing Company. 1-36.

The Division of Instructional Innovation and Assessment, University of Texas (Last updated: 19 December 2007). *Instructional Assessment Resources*

Website. Analysing Focus Group Data. From http://www.utexas.edu/academic/diia/assessment/iar/research/report/focus-analyze.php. Accessed: 26 June 2007.

Thistlewood, D. (1990). The essential Disciplines of design Education. In Thistlewood, D. New York, London: Longman. 14-29.

Thompson, G. and Lordan, M. (1999). 'A Review of Creativity Principles Applied to Engineering Design'. *Proceeding of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering,* 213(1), 17-31.

Thurston, B.J. and Runco, M.A. (1999). 'Flexibility'. In Runco, M.A and Pritzker, S.R (eds). *Encyclopedia of Creativity, Volume 1.* San Diego, London: Academic Press. 729-731.

Tovey, M. (1989). Drawing and CAD in Industrial Design'. *Design Studies,* 10(1), 24-39.

Trimingham, R.L. (2007). An Exploration of the Roles Values Play in Design Decision Making. Ph.D. Loughborough University.

Tseng, W. *et al* (2002). 'The Impact of Functional Knowledge on Sketching'. *Creativity and Cognition 2002*, Loughborough: ACM.

Turner, B.T. and Dunn, S.C. (1970). 'The Range of Procedures and Strategies: Part 2'. In Gregory, S.A (ed.). Creativity and Innovation in Engineering Conference Birmingham 1972.

Van der Lugt, R. (2005). 'How Sketching Can Affect the Idea Generation Process in Design Group Meetings. *Design Studies*, 26(2), 101-122.

Verstijnen, I. *et al* (1998a). 'Sketching and Creative Discovery'. *Design Studies,* 19(4), 519-546.

Verstijnen, I. *et al* (1998b). 'Creative Discovery in Imagery and Perception: Combining is Relatively Easy, Restructuring Takes a Sketch'. *Acta Psychologica.* 99(2), 177-200.

Ward, T.B. *et al* (1995). *Creativity and the Mind: Discovering the Genius Within*. New York, London: Plenum Press.

Warr, A. and O'Neill, E (2005). 'Understanding Design as a Social Creative Process'. *5th Conference on Creativity & Cognition*. London: ACM.
Weisberg, R. W. (1993). *Creativity Beyond The Myth of Genius.* New York: W H Freeman Company.

Weisberg, W. (1993). *Creativity Beyond the Myth of Genius.* New York: W H Freeman Company.

Welch, M. and Lim, H.S. (2000). 'The Strategic thinking of Novice Designers: Discontinuity Between Theory and Practice'. *The Journal of Technology Studies*, XXVI(2).

Wiseman, V. et al (2005). 'Using diaries to Collect Data In resource-Poor Setting: Questions on Design and implementation'. *Oxford Journals: Health Policy Planning*, Nov 2005, 20(6), 394-404.

Wright, K.B. (2005). 'Researching Internet-Based Populations: Advantages and Disadvantages of Online Survey Research, Online Questionnaire Authoring Software Packages, and Web Survey Services'. *Journal of Computer-Mediated Communication*, 10(3). http:/*/jcmc.indiana.edu/vol10/issue3/wright.html* . Accessed: 3 January 2010.

www.askoxford.com. From http://www.askoxford.com/concise_oed/behaviour?view=uk. Accessed: 3 July 2007.

Yang, M.C. and Cham, J.G. (2009). An Analysis of Sketching Skill and Its Role in Early Stage Engineering Design. *Journal of Mechanical Design*, 5(7), 476-482.

Young, K. A. (2005). 'Direct from the Source: The Value of'Think-Aloud' Data in Understanding Learning'. *Journal of Eucational Inquiry,* 6(1), 19-33.

Zeid, I (2005), *Mastering CAD/CAM*, Boston: McGraw Hill

12 Appendices

Appendix 1 – Participant Consent form

Appendix 2 – Example of a respondent's feedback of creative characteristics of product outcome in Case Study 2

Appendix 3 – Online Questionnaire (Malaysia)

Appendix 4 – Paper Questionnaire (Loughborough)

13 Annexes

Annex 1- Example of a full transcription of a participant's pre-interview

Annex 2- Example of a thematic table from a participant's pre-interview analysis.

Annex 3 - An example of full version of video observation data analysis.

Annex 4 – An example of full version protocol analysis.

Annex 5 - An example of a PowerPoint to present the protocol analysis findings.

Annex 6 - An example of full design diaries data analysis.

Annex 7 – An example of a pre-interview transcription the transcription using Transana software

Appendix 1
Participant consent form

Participant Consent Form

Department of Design and Technology
Loughborough University

Loughborough University

I...(print name) consent to taking part in this CAD/CAM research.

[Email address : ______________________________ Mobile : ______________________]

An explanation of the nature and purpose of the study has been given to me by the researcher. I understand that I may withdraw from the study at any time, and that I am under no obligation to give reasons for my withdrawal.

I understand that any photographs and video images taken and any information given about myself will be treated as strictly confidential by the researcher and not use in any publication without specific permission.

I agree to being photographed, and/or audio and video recorded and that what I say and do may be used anonymously for research purposes e.g seminar/conference presentations, journal papers, reports, publications, thesis.

Signed .... Date: .../......./2008

Participant Code [ ]

For Researcher use:	
Researcher name:	Signature: ....

Appendix 2
Example of a respondent feedback to creative characteristics of product outcome.

Feedback form

It would be most appreciated if you could give some feedback about this product conceptual design:

1) Are any aspects of the design innovative in your view?

Yes.

2) If so which aspect(s)?

First of all, the concept itself, i.e. creating a handheld device as a music therapy is quite innovative (assuming that creating music at any time is indeed providing therapeutic effect). Looking at more details on the device feature, in my opinion, the sounding pad is an innovative, i.e. combining touch/pressure technology, which is commonly used to interact with electronic devices, to create sound. The next one is the chord, although it is a bit strange that only four chord is available (I assume that the chord is the key chord for the music).

The left and right handed button is also innovative. However, I don't really see its relevance here as the buttons are already simple and easy to use interchangeably between left/right handed person.

Thank you for your response, comments, and suggestions.

Best regards,

Aede H Musta'amal
Research Student
Design & Technology Department
Loughborough University
cdahm@lboro.ac.uk

Appendix 3
Online Questionnaire

Appendix 4
Paper Questionnaire