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for Industrial Designers & Engineering Designers.....

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FACULTY OF SOCIAL SCIENCES AND HUMANITIES  
DEPARTMENT OF DESIGN AND TECHNOLOGY

**Building a Common Language of  
Design Representations for  
Industrial Designers & Engineering Designers**

BY

**EUJIN PEI**, BA (Hons.), MSc

A Doctoral Thesis  
Submitted in partial fulfilment of the requirements  
for the award of

Doctor of Philosophy  
of Loughborough University

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## **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.

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28 October 2009

## **Abstract**

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To achieve success in today's competitive environment, companies are realising the importance of design collaboration during new product development. The aim of this research was to develop a collaborative design tool for use by industrial designers and engineering designers. To achieve this, a literature review was undertaken to understand the working relationship among the two disciplines during new product development. Following this, empirical research through interviews and observations outlined three problem areas: conflicts in values and principles; differences in education; and differences in representational tools and methods. The latter was chosen because the problem area of design representations was found to be highly significant.

In looking at bridging differences in design representations, a taxonomy comprising 35 forms of sketches, drawings, models and prototypes was generated. A second stage of empirical research was conducted to establish the popularity of each representation and the type of design / technical information that industrial designers and engineering designers communicated with. The information was indexed into 'CoLab' cards that would enable the two disciplines to gain joint understanding and create shared knowledge when using visual design representations.

Following a pilot evaluation and minor modifications, student and practitioner interviews with a case study were employed to assess the significance of CoLab. The findings revealed that 82% of the interviewees felt CoLab to have built a common ground through the use of visual design representations. 75% gave a positive rating when asked if the system would enhance collaboration and 91% gave the physical cards a positive response as it provided instant access to information and allowed easy sharing. This thesis is a step towards a greater understanding of collaboration between industrial designers and engineering designers. The use of the CoLab system provides the prospect of achieving a common ground between the two disciplines.

## **Keywords**

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industrial design, engineering design, collaboration, co-design, visual design representation, new product development.

## **External Examiner**

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The External Examiner for the PhD was Professor Robert A. Young.

## About the Author

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Eujin Pei obtained his Postgraduate degree in Industrial Design from Loughborough University and holds a Bachelors degree in Product Design from Central Saint Martins, University of the Arts London in 2004. He is a member of the British Chartered Society of Designers.

During his industrial design education, his undergraduate studies centred on the aesthetical aspects, while his postgraduate studies focused on engineering based knowledge.

With one foot in the aesthetic aspect of industrial design and the other in the engineering field, Eujin returned to Loughborough University to conduct the research work on industrial design and engineering design collaboration that is described in this thesis.

## **Acknowledgements**

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This research was conducted In the Department of Design & Technology at Loughborough University. The dissertation presents the background, theory and development of the CoLab design tool.

In all, this research has been very rewarding. I would like to thank my supervisors, Dr Ian Campbell and Dr Mark Evans who have guided and shaped this research.

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Special thanks to my fellow research colleagues for their moral support, and for providing the office a sociable working environment.

My deepest gratitude goes to my family, especially to my parents and my grandmother, for their encouragement and who have always been there for me.

I would like to thank Loughborough University for archiving my thesis and making it available in full colour online through the institutional repository.

*This thesis is dedicated  
to my parents and my grandmother*

## **Used Acronyms / Abbreviations**

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2D	- Two-dimensional
3D	- Three-dimensional
CAD	- Computer-aided design
CE	- Concurrent engineering
CSCW	- Computer Supported Cooperative Work
ED	- Engineering Design / Engineering Designer
ID	- Industrial Design / Industrial Designer
IDSA	- Industrial Designers Association of America
NPD	- New product development
QFD	- Quality function deployment
RP	- Rapid prototyping
VR	- Virtual reality



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# 1 INTRODUCTION

---

## **1.1 Overview**

The role of this chapter is to provide the reader with an understanding of the background. It provides an overview of the methodology for the research, justifying the empirical study and discussing the strategy, reliability and data collection methods used during interviews and observations. The research aims and objectives are defined, followed by a review of the strategy for how the data was to be effectively collected. Finally, the overall thesis structure is presented to guide the reader through this work.

## **1.2 Research Background**

Today's highly competitive global markets have emphasised the growing importance of value-added products. Organisations are also under constant pressure to operate at optimum efficiency. For products to stand out from each other, innovative features and aesthetic appeal are paramount for market success and to enable a company to outperform its competitors (Kimura 1997; 2007). Alasdair Barnett of DesignEdge (Barnett 2006) was quoted as saying that 'If two products are the same in every way, nine out of ten buyers would choose the most aesthetically pleasing product'. Barnett goes on to say that products must balance the aesthetical and technical elements, requiring both industrial design and engineering design to work in tandem within an integrated environment.

In this thesis, industrial design refers to creating a product appearance encompassing aesthetics, semantics, ergonomics and usability with consideration to user needs and manufacturing (IDSA 2006). Engineering design is referred to as using science-based problem solving methods for the specification and development of technical systems, including functional, technical, structural and material properties and design for manufacture (Persson 2005b). While design and engineering should cooperate and

complement each other, they are often in conflict. Industrial designers have been identified as focusing on aesthetics and product usability; while engineering designers focus on cost and manufacture (Heskett 1980). Workspace barriers such as physical distance, contrasting responsibilities, dissimilar 'thought-worlds', and using a different language are other problems that create issues between them (Griffin and Hauser 1996a).

Most products are determined by requirements from several stakeholders and require intense cooperation in their development (Jonas 1993; Fiell and Fiell 2003b). Members must work together at different stages, but as they have distinct communicative codes, the design intent may not be uniformly interpreted. In addition, when the design representations used do not have a defined meaning, they are subjected to personal interpretation that can result in misunderstandings that negatively impact on the design process and group cohesion (Stacey and Eckert 2003; Giannini *et al.* 2006).

Although research has been undertaken in the area of multi-disciplinary collaboration, they have focused towards interfaces between engineering design and manufacturing engineering (Beskow 1997; Ulrich and Eppinger 2003); engineering and marketing (Griffin and Hauser 1996a); and architecture with engineering (Lawson 1997).

Holland *et al.* (2000) commented that there has been very little guidance for practitioners to achieve effective multi-disciplinary collaboration. More importantly, very little empirical research has been conducted on the nature of multi-disciplinary collaboration between industrial designers and engineers in new product development (Persson 2005b; Kleinsmann 2006; Kim and Kang 2008).

The following sections outline the scope, research audience, research aims and objectives, data collection methods and the thesis structure.

### **1.3 Scope of Research**

This research is concerned with understanding how the use of a common ground in visual design representations could support a collaborative environment between industrial designers and engineering designers. The research covers aspects related to design, industrial design, engineering design, collaboration and visual design representations as shown in Figure 1.

<b>1. Design</b> Mental processes, Design Methods, New Product Development	<b>2. Industrial Design</b> Background, Working Practices, Methods and Tools	<b>3. Engineering Design</b> Background Working Practices, Methods and Tools
<b>4. Collaboration</b> Design teams, Communication, Interaction, Coordination, Cooperation, Integration, Collaboration	<b>5. Design Representations</b> Sketches, Drawings, Models, Prototypes	

Figure 1: Scope of research

### **1.4 Research Audience**

This thesis is intended to be relevant to three groups of people (Figure 2). Firstly, to various practitioners involved in new product development including industrial designers and engineering designers. It should allow them to be aware of the different viewpoints on visual design representations, thus enabling effective management of multi-disciplinary collaboration.

Secondly, to design managers, team leaders, business developers and marketing consultants, etc. who are involved in new product development, allowing them to understand issues surrounding multi-disciplinary



collaboration, and to use this thesis as a learning tool for future collaborative design projects.

Thirdly, to academic researchers with the same area of interest allowing them to build subsequently on the knowledge generated. The research also provides researchers with a literature review on the main aspects of collaborative design.

<b>Research Audience</b>	Industrial Design and Engineering Design Practitioners	New Product Development Stakeholders, Managers, Leaders, etc	Academic Researchers
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Figure 2: Research audience

### **1.5 Research Aim & Objectives**

This work argues that current integrative tools are not sufficient for successful collaboration between industrial designers and engineering designers. The research highlights that visual design representations are subject to personal interpretation, leading to distorted views. The aim of the research is to build a common ground in visual design representations that will support collaboration between industrial designers and engineering designers. The research aim and objectives are listed in the following pages. The initial research objectives were to be achieved by conducting the literature view, while answering the research questions would be achieved through empirical studies. The overall research plan is illustrated in Figure 3.

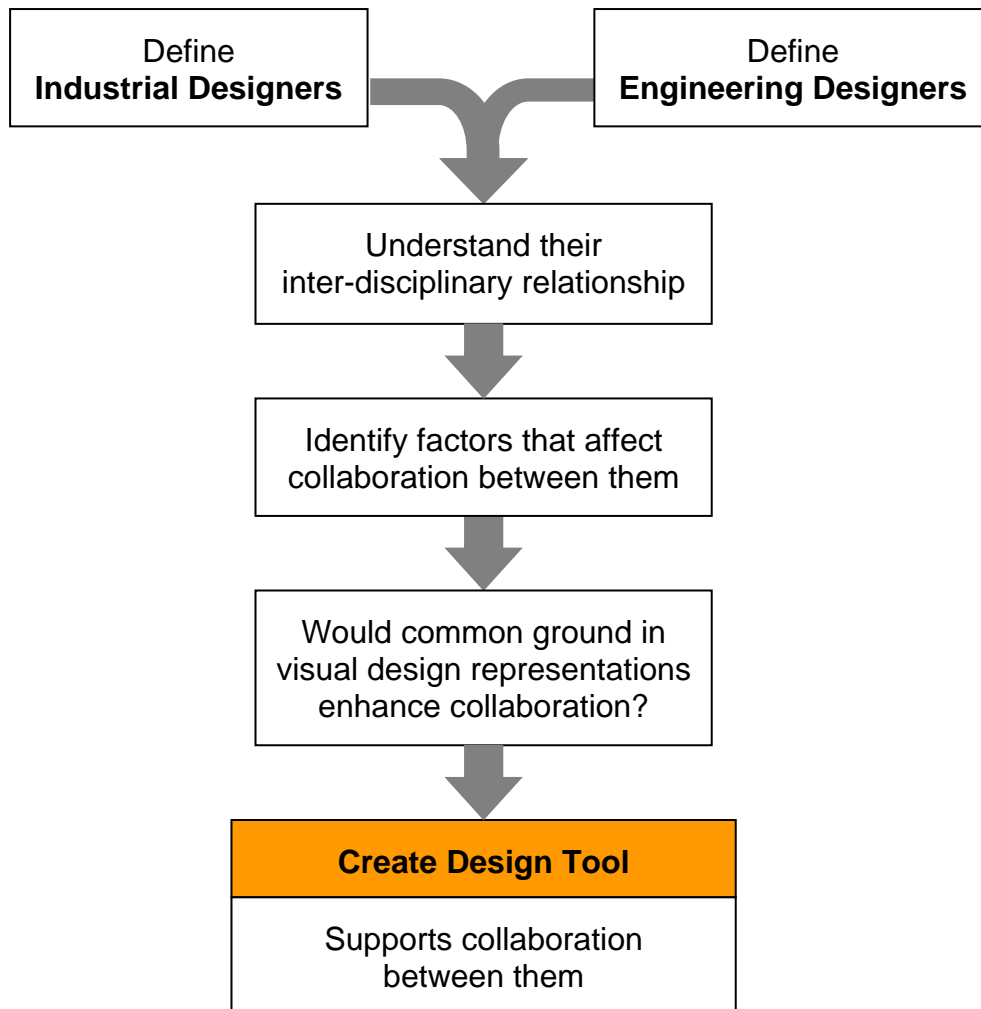


Figure 3: The research plan

### **Aim of research**

1. To develop a design tool that supports collaboration between industrial designers and engineering designers during new product development.

### **Initial Objectives for Literature Review**

The initial objectives of this research were to critically review the literature relating to:

1. Defining the terms industrial design and engineering design.

2. Understanding collaboration within the context of new product development.
3. Investigating issues and identifying factors affecting collaboration between the two disciplines in new product development.
4. Determining whether a common ground in visual design representations will support collaboration between the two disciplines.

### **Research Questions for Empirical Studies**

Following the literature review, Objective 4 resulted in the most substantial part of the research. These specific research questions emerged which were to be undertaken by empirical studies.

1. To ascertain what factors most greatly affect collaboration between industrial designers and engineering designers during new product development.
2. To determine what visual design representations are used by both disciplines in the design process.
3. To investigate if a common ground in visual design representations would support collaboration between industrial designers and engineering designers.

### **1.6 Data Collection with Literature Review**

Developing an appropriate research strategy was one of the challenges faced in this research. To begin, Phase 1 comprised of clarifying the research direction by formulating the aim, objectives and research questions.

Phase 2 comprised literature reviews on multi-disciplinary product development so as to provide a better understanding of the background and to identify gaps in prior knowledge. In addition, undertaking the literature review would avoid carrying out research that had already been conducted, so that the work would be original and make a contribution to new knowledge.

A list of associated keywords and synonyms (Table 1) facilitated the literature search from relevant books, journals, conference papers and periodicals. The use of a web-based search using MetaLib, Loughborough University's Online Public Access Catalogue (OPAC) and Google Scholar enabled up-to-date information to be obtained. Zetoc Alert was also used to automatically receive notification of the latest research papers, new publications and conference proceedings.

Major Keywords	
Industrial design Engineering design Collaboration	Co-design Visual design representation New product development
Additional Keywords	
Alignment Barriers Co-design Collaboration Common Understanding Communication Concurrent Engineering Conflict Contradict Cooperation Cooperative Co-ordination Co-participation Cross-disciplinary Cross-functional Design Engineering Design Engineering Designer Group Industrial Design Industrial Designer	Information Exchange Integrated Interaction Inter-disciplinary Interface Inter-relationship Intra-disciplinary Language Management Modelling Multi-disciplinary Mutual Understanding New Product Development Organisation Relationship Representation Shared Understanding Strategy Team Understanding Visualisation

Table 1: List of keywords used as part of the literature review

To catalogue the substantial amount of information, three databases were developed and tested. Refworks (Figure 4) was initially used for bibliographical database management, but the required internet access proved to be difficult while working on the move. A second system using Microsoft Access (Figure 5) was created. It allowed customisable searching and sorting of information relevant to the research. However, the drawback was that it could not automatically extract bibliographical references. A stand-alone package, Thomson ResearchSoft EndNote 7 (Build 98) was finally chosen as it was relatively easy to use and allowed references to be inserted automatically into Microsoft Word (Figure 6).

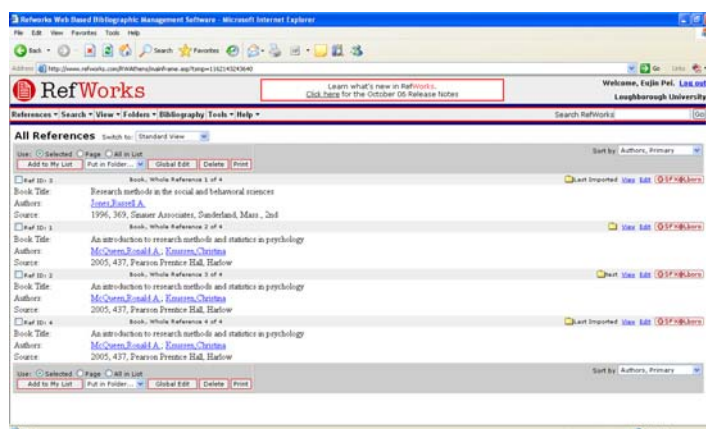


Figure 4: Screen shot of Refworks

The screenshot shows the Microsoft Access interface with the 'Article Review Form' open. The form is divided into several sections for data entry:

- Header Section:** Contains 'Review no' (2) and 'Rating' (a dropdown menu).
- Metadata Section:** Includes fields for 'Title' (A Short Course in Industrial Design), 'Author' (Eckst Jahn), 'Publisher' (Butterworth & Co. (Publishers) Ltd), 'Place of Publication' (London), 'Type of publication' (Book), 'Year of Publication' (1975), 'Volume' (empty), and 'Issue' (empty).
- Identification Section:** Includes 'Date Reviewed' (24/02/2006), 'Source' (empty), 'Category' (empty), 'Sub Category' (empty), 'Library Code' (620.0042 TJA), 'ISBN/ISSN' (empty), and 'Misc' (empty).
- Summary Section:** A table with two columns: 'Page No.' and 'Keyword'. It contains three rows of data:
  - Page 1: Creation of a product
  - Page 2: The iterative design process in creating a product
  - Page 3: In the initial analysis stage, the problem is examined from all sides. This results on a concrete description of a desired function and a list of properties that constitute the criteria

The status bar at the bottom indicates the record number: 'Record 1 of 1'.

Figure 5: Screen-shot of a database created in Microsoft Access

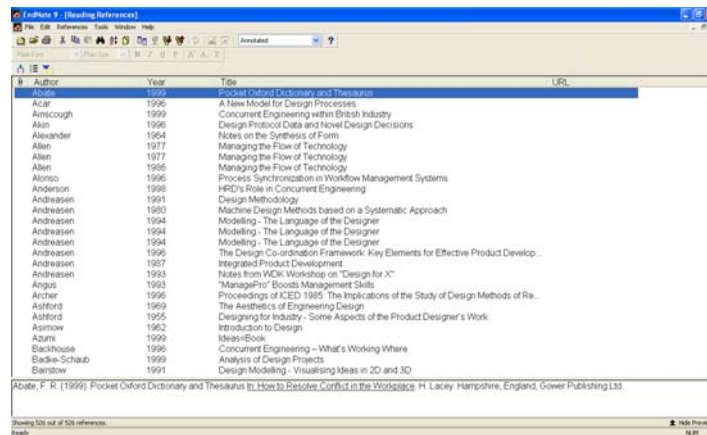


Figure 6: Screen-shot of the Endnote package

Undertaking the literature review identified that research on collaboration between industrial designers and engineering designers had been minimal. This led to Phase 3 with use of empirical methods including semi-structured interviews and participant observations to identify issues relating to collaboration between industrial designers and engineering designers during new product development. Phases Two and Three encompassed the first stage of data collection.

In the second stage of data collection, a more focused literature review was undertaken (Phase 4) to explore the use of visual design representations followed by further empirical research (Phase 5). The purpose of the empirical research was to assess the use of visual design representations among industrial designers and engineering designers during new product development.

Finally, Phase 6 compiled the knowledge into the CoLab system, and subsequent steps consisted of pilot testing, refinements and validation of the system. The validation was conducted by means of semi-structured interviews with practitioners, academics and students, as well as observing the use of CoLab during an industry project as a case study. The overall research strategy is illustrated in Figure 7.

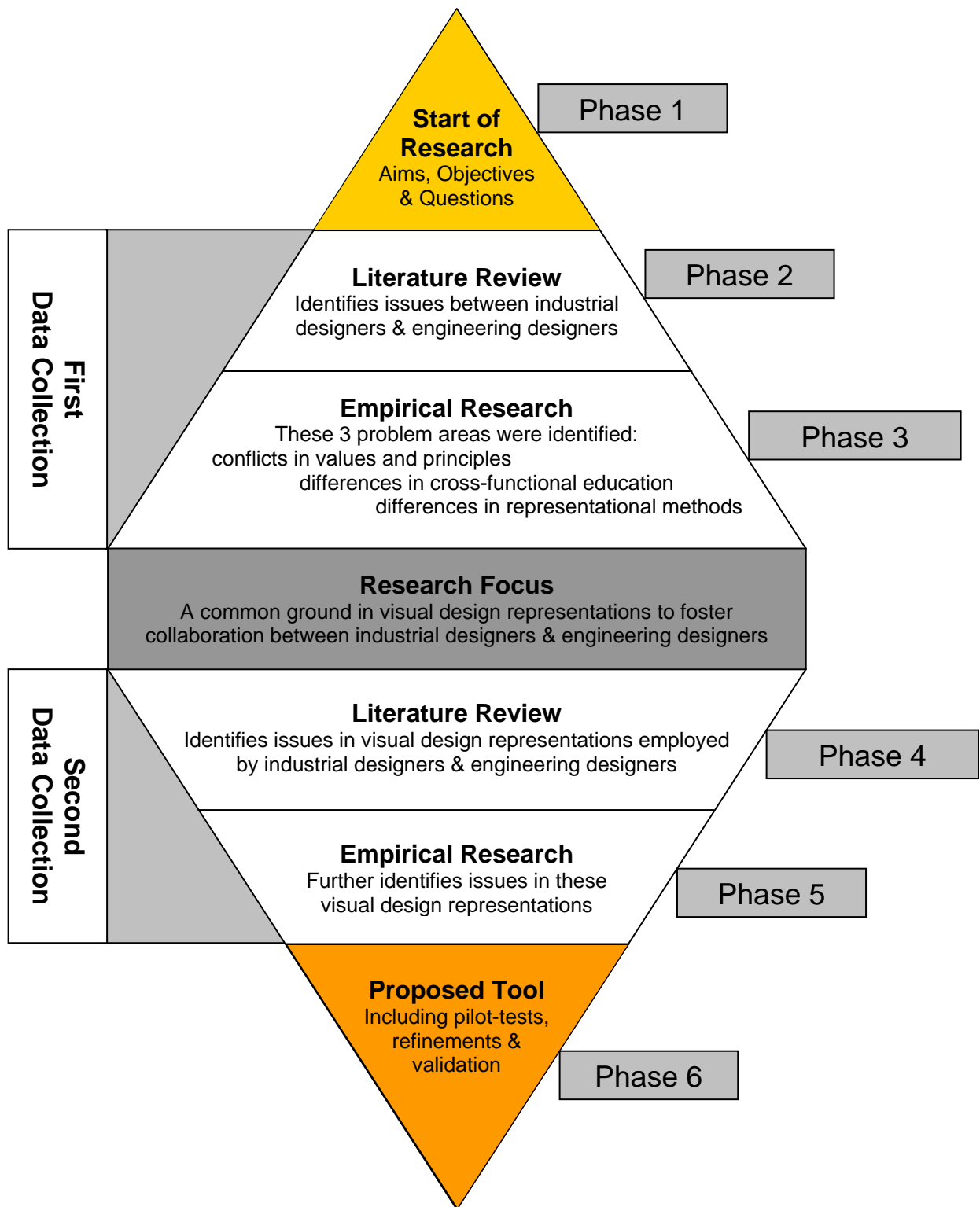


Figure 7: Overall research strategy

## **1.7 Data Collection and Analysis with Empirical Research**

According to the Merriam-Webster Dictionary (1994), empirical research relies on experiments or observations and may be divided into two categories:

Qualitative methods:        The collection of data in the form of words, images and sounds from observations, interviews and other documentary evidence

Quantitative methods:       The collection of data in the form of numbers and analysed with statistical methods

Quantitative methods concern measurable properties such as strength and weight that can be quantified. In contrast, qualitative methods take the form of a well-grounded and richly described approach of understanding processes that occur within a local context (Miles and Huberman 1985). It allows the researcher to examine and confirm a phenomenon taking place. Qualitative methods provide detailed information by being close to the field of study in the form of interviews or observations (Persson 2005b). It allows the researcher to have a holistic overview of events that occur in a natural setting (Miles and Huberman 1994). A qualitative approach works with small samples of people and is studied in-depth as compared to quantitative research that aims for a large number of cases for statistical significance (ibid).

For this research, qualitative methods in the form of interviews and observations were chosen to facilitate the collection of data including first-hand records of opinions, expressions, observations and comments. A general overview of the research methods employed is summarised in Table 2 and a more detailed description of the methods employed is found in Section 11.6. Although other methods such as real-time verbal protocols exist as compared to interviews and observations, they tend to be obtrusive as they



require respondents to verbalise their thoughts. Verbalisation may change the subject's behaviour and their cognitive performance. Also, what has been said may not be complete or true (Cross *et al.* 1996). In addition, the analysis requires transcribing and coding, which is lengthy to process (Culverhouse *et al.* 1992).

	Research Method				
	Literature Review	Semi-structured interviews	Participant observations	Case study	Use of design diary
Research Question 1	✓	✓	✓		
Research Question 2	✓	✓	✓		
Research Question 3	✓	✓			
Pilot Study		✓			
Validation		✓	✓	✓	✓

Table 2: Matrix showing research questions and research methods employed

It was decided that the qualitative methods would be used for data collection, followed by analysis (such as in Section 5.4.2) in the form of a coding scheme to categorise the information by topic and to seek out patterns (Brereton *et al.* 1996). The use of interviews and observations are easy to implement and were also less intrusive as compared to real-time verbal protocols. By using qualitative data collection methods with qualitative and quantitative analysis, it was possible to compare, contrast, catalogue and classify the object of the study (Miles and Huberman 1994). Several researchers have highlighted the advantages of linking qualitative and quantitative data analysis. According to Miles and Huberman (1994), the qualitative approach allows the validation, interpretation, clarification and illustration of the quantitative findings. Rossman and Wilson (1984) suggested that the use of both approaches of analysis enables 'confirmation, elaboration of details, or to initiate new lines of

thinking and to provide fresh insights'. In addition, Greene, Caracelli and Graham (1989) pointed out that linking qualitative and quantitative analysis allows the results of the first method to confirm the second method. A summary of the qualitative and quantitative methods used can be found in Section 11.4.

## **1.8 *Structure of the Thesis***

This thesis is divided into 13 chapters. Chapter 1 describes the research background and discusses the aims, objectives and research questions. By way of a literature review, Chapters 2, 3 and 4 provide an understanding of associated themes regarding the research context. The first theme on 'design' is discussed in Chapter 2 concerning the mental processes, models and stages of new product development. Chapter 3 defines the terms 'industrial design' and 'engineering design', describing the history, and similarities and differences in work practices. Chapter 4 discusses 'design management', examining how teams work in new product development and explores why collaboration is crucial for product success.

Having identified gaps in knowledge from the literature review, Chapter 5 discusses the execution of empirical research and highlights problem areas among industrial designers and engineering designers. A more focused discussion on the theme of visual design representations is presented in Chapter 6, following which Chapter 7 distinguishes the types of visual design representations and the key design and technical information employed by the two disciplines. Chapter 8 presents the empirical research findings on the use of representations by industrial designers and engineering designers during new product development. Chapter 9 describes the development of the tool and Chapter 10 describes the user trials, professional validations and refinements undertaken as well as presenting the final version of the tool. The research questions are addressed in Chapter 11, reflecting on the completed work with suggestions for future research. The references and appendices are found in Chapters 12 and 13 respectively. The overall thesis structure is shown in Figure 8.

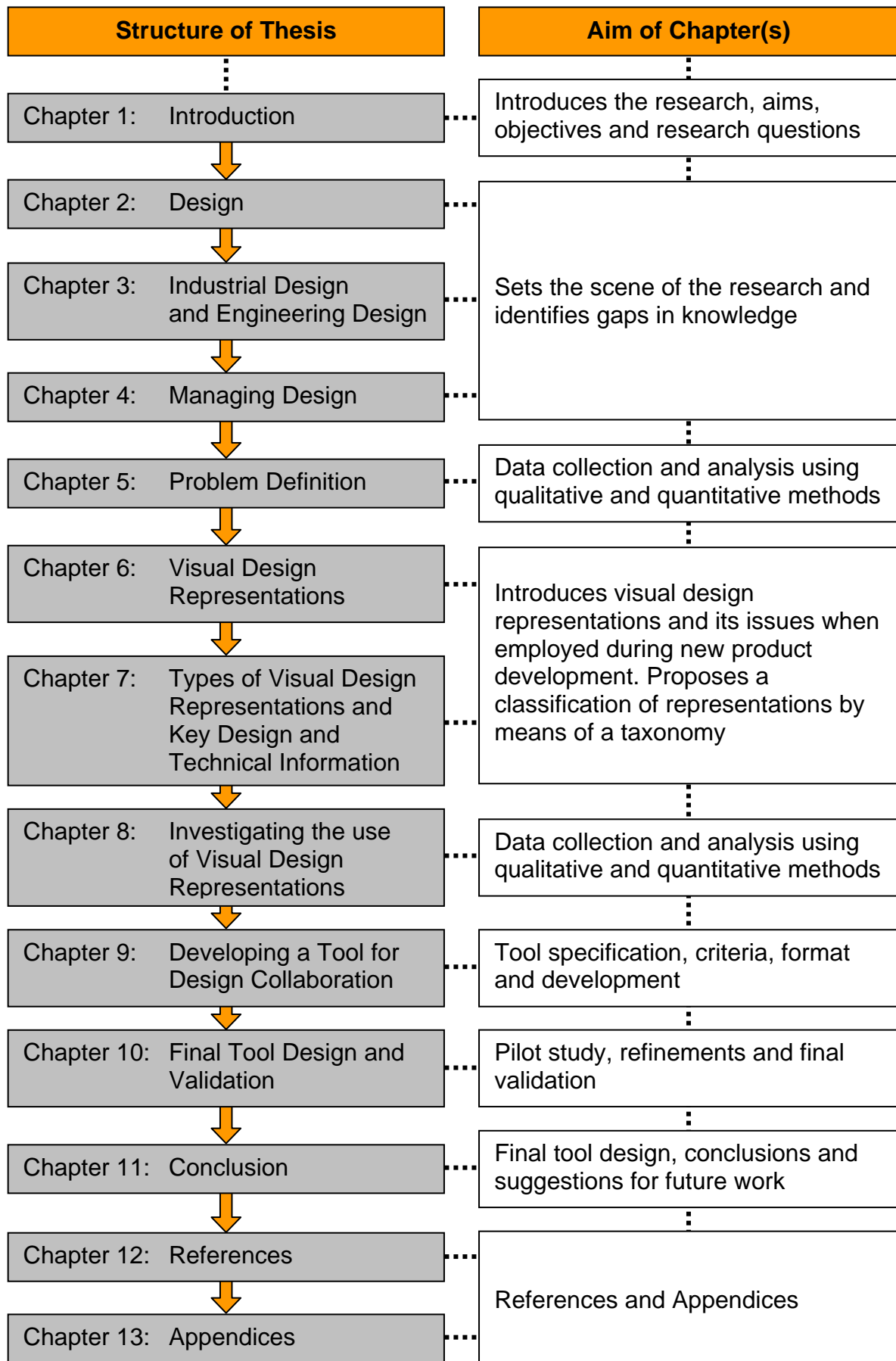


Figure 8: Map of thesis structure

## **2 DESIGN**

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### **2.1 Chapter Overview**

The aim of this chapter is to provide an understanding of design and the product development process. It explains what design is in the research context concerning thinking styles and differentiates left and right brain thinking. The next section introduces the concept of new product development and explains key models and stages of new product development, ending with a review of various design methods practiced in the industry.

### **2.2 What is Design?**

According to Bürdek (2005), design has been defined as a plan or scheme devised by a person to develop a man-made object with a specific purpose. It may also be used to refer to the arrangement of elements in a product or for a work of art (Dictionary of Art Terms 2003). Design has been used to add value to a product (Best 2006) and as a communication and retail strategy (Alexander 1964). In a wider scope, design brings various elements together rather than just a styling exercise (Pipes 2007). Design enhances lives with innovative solutions through use of appropriate forms, structure and manufacture that respond to technical, functional and cultural needs (Fiell and Fiell 2003a).

In this research, the term 'design' is concerned with idea-based disciplines, comprising of industrial design, engineering design, communication design, architecture, fashion and many others. In comparing design with science, the latter is ruled by formulas and constraints; and design, unlike art, is justified in being societal, functional, meaningful and concrete (Erlhoff 1987; Sparke 1996). It is concerned with mass-produced products or a system of artefacts (Gorb 1986; Feierabend and Erlhoff 2004). Nearly everything around us with the exception of the natural world has been designed by someone (Cross 2000).

Perks *et al.* (2005) characterised the role of design in new product development and provided a table showing the evolutionary role of design (Table 3).

Period	Design Role
1800s	Business-orientated
1920s – 1950s	Specialist
1960s – 1970s	Professional
1980s	Brand-dominated
1990s	Sub-process of New Product Development
Early 2000s	New Product Development Process Leader

Table 3: The evolution of the role of design in NPD (Perks *et al.* 2005)

In another study, Trueman (1998) summarised how design can be applied (Table 4) and acknowledged that good design enables a company to increase the perceived value of their products, to maintain a competitive advantage, and to portray the right image of the organisation to customers. In addition, design helps to improve processes and production (Hands *et al.* 2004). Kim and Kang (2008) also viewed design as a ‘bridge between technological expertise and customer needs’ and as a ‘central activity connected with other functions’.

Design Strategy	Design Attributes	Company Goals
Value	Product Styling Aesthetics Quality Standards Added Value	To add value for consumer and enhance company reputation
Image	Product Differentiation Product Diversification Product Identity Brand Identity Brand Creation	Company Image and Strategy
Process	Generate New Ideas Idea Communication Interrupt Ideas Integrate Ideas Promote Products	Culture for New Ideas, Creativity and Innovation
Production	Reduce Complexity Use New Technology and Materials Reduce Production Time	Improvement and Reduce Time to Market

Table 4: Levels of Design Strategy (Trueman 1998)

### 2.2.1 The Act of Designing

The act of designing involves creatively building the nature, appearance and social function of objects (Tjalve 1979). It entails the use of problem solving methods and creativity to produce desired properties of a product (Andreasen *et al.* 1988). As these design ideas are formulated in the mind, various elements and constraints are considered, balancing aesthetics with practical function (Cross 1996). When the mental images are produced through sketching, drawing and modelling (Goel 1995), they become part of the information used to generate the next idea. These representations assist in the mental sorting of information and allows the simultaneous consideration of other factors (Tovey 1989). The theme on representations is discussed in detail under Chapter 6.

Other researchers described design as a problem solving approach through a process of trial and error (Roozenburg and Eekels 1995). It involves iterations whereby steps are repeated as no firm decisions are made in the first time. These iterations occur throughout the design process and involve innovation, analysis, decision making and evaluation. During iteration, an approximate solution to a problem is initially worked out and then fed back into the process for an improved solution. This process is continued until the desired solution is achieved (Wright 1998). The iterative cycle can be regarded as a feedback loop (Figure 9) where the first designs are created and then improved as more information is made known (Gupta and Murthy 1980).

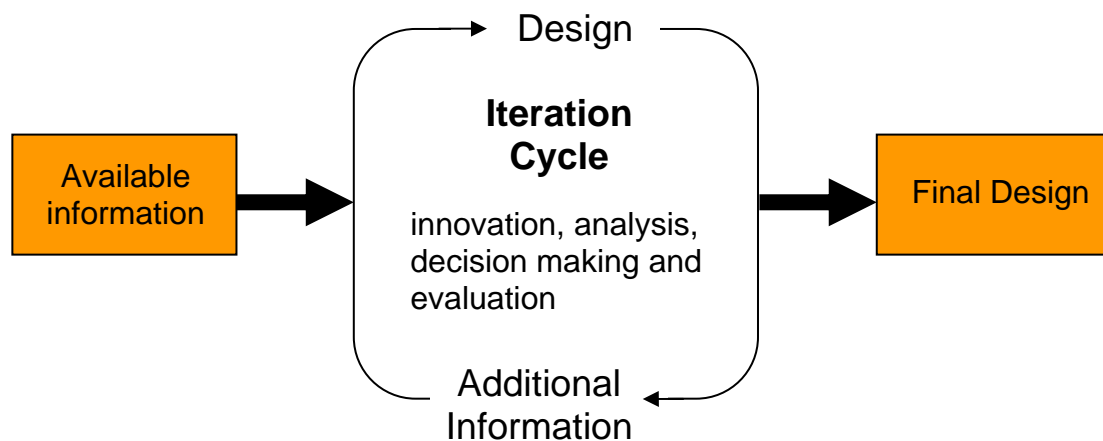


Figure 9: Design as an iterative process (Gupta and Murthy 1980)

Cross (1984) suggested that as design is an open-ended and ill-structured process, there are no clear solutions and answers cannot be obtained by formulas. As the goals, constraints and criteria are poorly understood and always change when more information is added, the problem set becomes messy, inconsistent and unstable. In addition, formulating the problem is difficult as there are no true or false answers and they can only be considered as good or bad, appropriate or inappropriate. Design problems are thus recognised as having ill-defined solutions (Dym and Little 2003) whereby a systematic approach is needed to counter the ill-structure, yet requiring the freedom for creativity (Hawkes and Abinett 1985; Stempfle and Badke-Schaub 2002). In light of this, designers aim to solve ill-defined design problems by improving the definition of the issue through questioning the client and

collecting more data. In addition, the use of sketches, drawings and other representations assist designers by structuring problems and solutions and finally converging on a matching problem-solution pair as the answer (Cross 2000).

Design at an individual level requires conveying the visual information clearly to others. It also requires personal characteristics such as flair, ability, intuition, creativity, judgment, reflection, feeling and experience (Schön 1983). To aid this, Pahl and Beitz (1996) have proposed guidelines in achieving good aesthetics, including use of recognisable style; structured and unified form; good use of colours; and with complementing graphics. In addition, Tjalve (1979) proposed a list of factors to be considered during designing as shown in Table 5.

<b>Factors influencing Form</b>  Structure Material Dimension Surface Other design factors include: The designer The company The target consumer Production factors Manufacturing feasibility Economic viability Assembly Distribution (eg stacking) Packaging Usability & operations Cleaning & maintenance Servicing Adjustment Repairs Psychological Appearance Product disposal	<b>Factors influencing Appearance</b>  Aesthetics Unity Order Visual balance Rhythm Proportion Lines and planes Joints
	<b>Factors influencing Means of Expression</b>  Lightness Weight & stability Movement
	<b>Other Influences</b>  Colour Texture Material Tactile feel

Table 5: Factors that influence design (Tjalve 1979)



It has been acknowledged that design occurs among individuals and as a shared inquiry and dialogue among a broad circle of stakeholders (Hack and Canto 1984). This has been confirmed by Mayall (1983) in that design is a social activity where members of different backgrounds should have a shared vision when working together. This social process involves negotiation and consensus, bringing the perspectives of individuals together to build the final product (Bucciarelli 1994). However, as different stakeholders have competing and conflicting objectives, design becomes more complicated (Sebastian 2005). An investigation of these multi-disciplinary issues among industrial designers and engineering designers is a central topic to this research and a dedicated discussion on managing design is presented in Chapter 4.

### **2.2.2 Visualisation and Thinking Processes in Design**

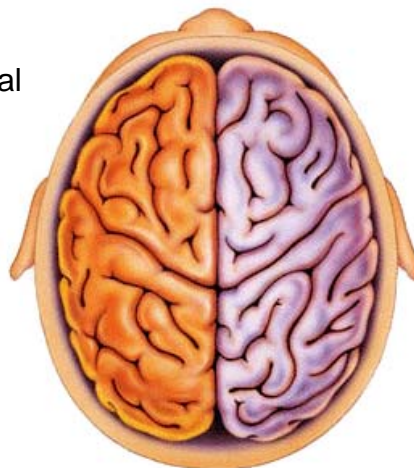
Thinking is the activity that sorts, juxtaposes and combines mental information derived from the five senses (Tovey 1989). This section concerns the area of visual thinking - thinking that uses visual information. Visualisation makes a mental image of an object visible through cognitive processes such as perception, imagination and communication (Persson 2002c). According to Rodriguez (1992), visualisation is regarded as an important ability for a designer and Rodriguez classified visualisations as those that can be seen; those imagined in the mind, and those drawn or modelled in a physical form. When constructing visual images, the developer introduces features such as form, proportions, orientation, material, colour, symmetry, contrast, repetition etc.

Research has supported that the visual system is the main way whereby stimuli reaches the brain and it signifies the importance of images and visuals for communication (Kosslyn 1994). In addition, it has been suggested that the three imageries of seeing, imagining and drawing are inter-related where imagination filters what we see and seeing stimulates our imagination that in turn produces the drawing (Dorta 2005). This is in line with McKim (1980) who established that visual thinking involves the interaction of mental (imagining), graphical (drawing), and perceptual (seeing) images.

Thinking styles can be classified into left and right hemispherical use of the human brain (Figure 10). Evidence from research has shown that facts, numbers and words are more associated with the left brain and aesthetics and creativity involve the right hemisphere (Burghardt 1999). The left hemisphere can be regarded as logical and systematic (Jones 1992). Information processing is serialised that investigates deep into a problem space with careful decisions at each stage. This rational, verbal and analytic thinking is known as serial thinking (Cross 2000). In contrast, the right hemisphere generates more alternative ideas and visuals that are associated with lateral thinking which seeks as many choices as possible and doing things out of sequence (Bradshaw and Nettleton 1983). This is known as holistic thinking (Cross 2000).

### Left Hemisphere

Facts, Numbers, Words  
 Logical, systematic, Rational  
 Sequential  
 Verbal  
 Analytic  
 Serialist  
 Vertical  
 Linear processing  
 Convergent  
 Narrows and filters  
 Logical / Linear / Digital  
 Time orientated



### Right Hemisphere

Ideas and Visuals  
 Out of sequence  
 Random  
 Non-verbal  
 Synthetic  
 Holistic  
 Lateral  
 Simultaneous processing  
 Divergent  
 Expansive  
 Intuitive / Spatial  
 Timeless / Diffuse

Figure 10: Left and right hemispheres of the brain (Cross 2000; Dominick et al. 2001)

The vertical approach of the left hemisphere is sequential whereby the individual evaluates information logically and objectively (Figure 11). It is analytical, judgemental, critical and selective. In contrast, the lateral thinking of the right hemisphere is random, simultaneous and generative where the

individual thinks in several directions by combining bits of information into new patterns and expands possibilities into new ideas. The key difference is that vertical thinking regards an idea as the goal, whereas lateral thinking generates ideas as the goal (Tovey 1984; Shetty 2002)

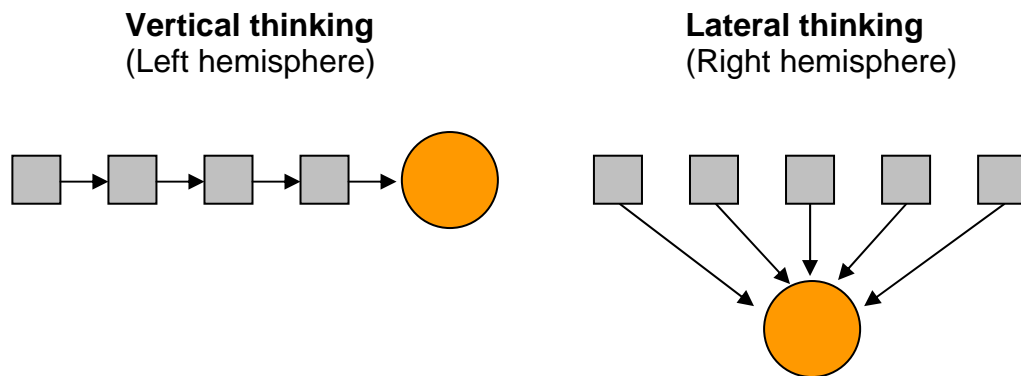


Figure 11: Vertical approach / Linear processing (left hemisphere) and Lateral / Simultaneous processing (right hemisphere) (Tovey 1991)

Left-brain convergent thinking narrows a design space by filtering the best alternatives with logical and structured methods. In contrast, right-brain divergent thinking is expansive and seeks to find more ideas and choices by thinking 'outside the box' (Figure 12) (Dym and Little 2003). Divergent thinking is associated with creativity where the use of brainstorming activities and ideation generates a large number of drawings and sketches that allows members to explore beyond conventional ideas (Eissen and Steur 2008).

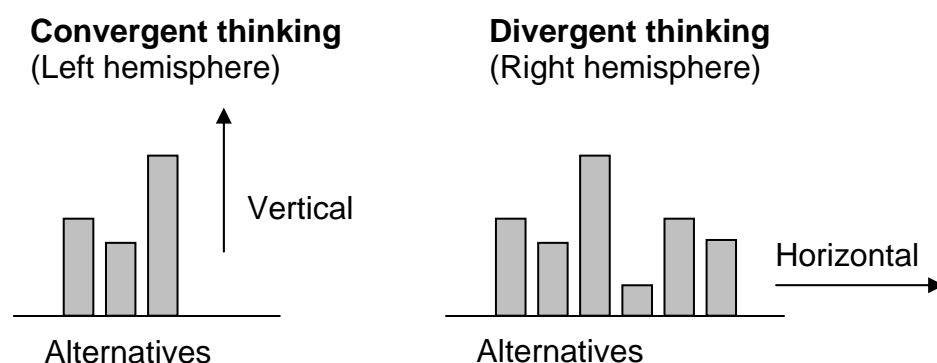


Figure 12: The vertical and horizontal thought process (Tovey 1984)

Cross (1983) suggested that these two approaches may be observed in the design process that begins with a divergent manner and then converges as the possible solutions are filtered down into a well-defined solution (Figure 13).

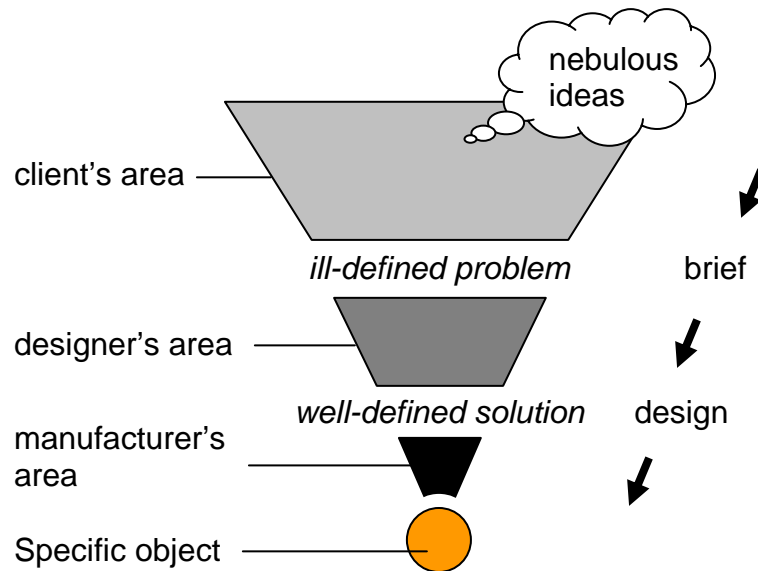


Figure 13: The convergent nature of the design process (Cross 1983)

Semmes' proposed another approach by separating the two hemispheres with a schematic representation of functions. He highlighted that the left hemisphere is strongly focused (Figure 14) whereas the right hemisphere consists of overlapping circles (Bryden 1982).

#### Left hemisphere Right hemisphere

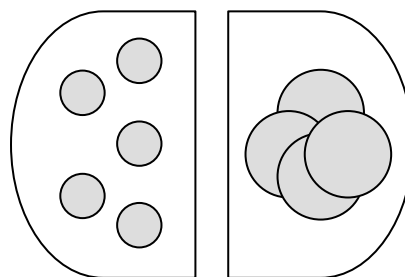


Figure 14: The distinct functions of the two hemispheres (Bryden 1982)

Despite the two distinct types of thinking, researchers have acknowledged that during higher levels of mental activities, both hemispheres operate in

parallel and exchange information (Tovey 1984; 1991). An example can be observed whereby the design process consists of analytically processed problems that are matched with visual solutions (De Bono 1970). After the initial information is processed independently in each hemisphere, the data is then moved to the other. As more information is added, it will then move back for evaluation. Where visual thinking is more required, the right brain will work harder. Where data needs to be analysed, the left will perform more work. It continues until there is an agreement between the two hemispheres over a solution and this is known as the dual processing model (Figure 15).

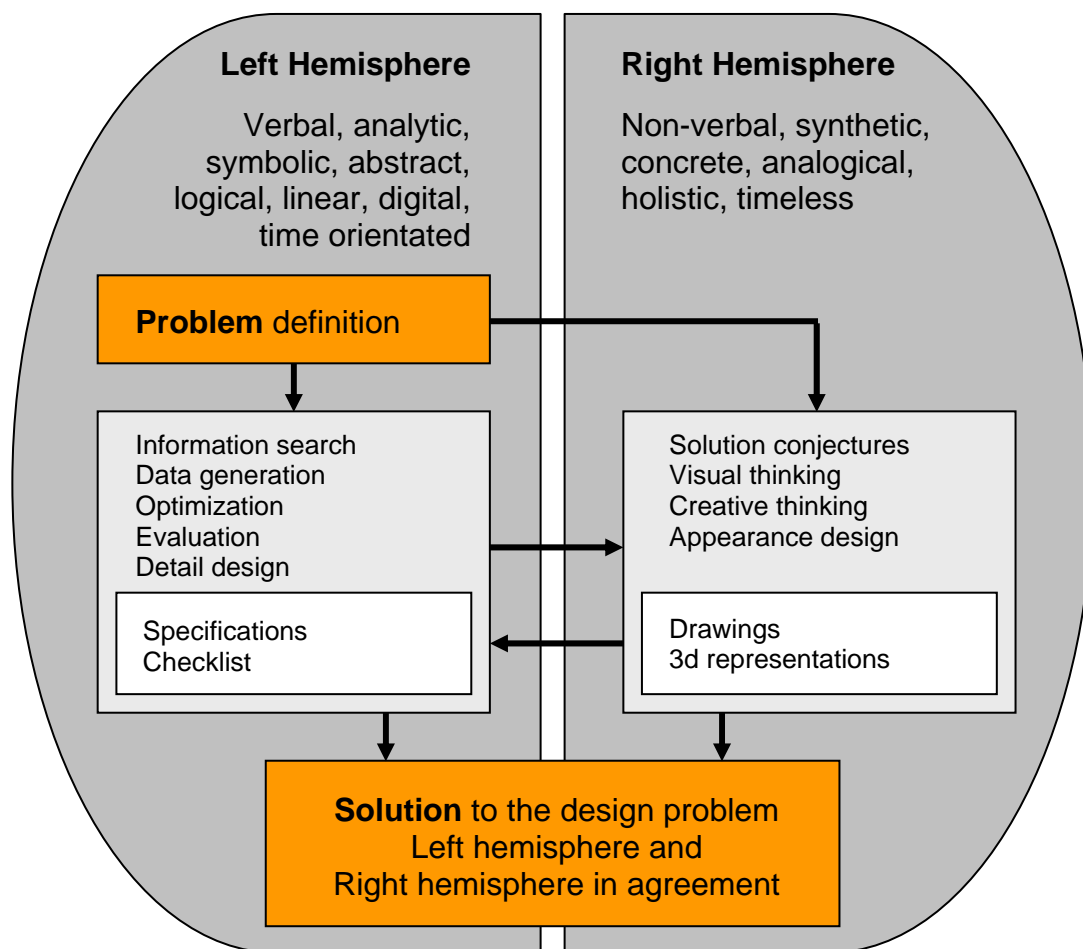


Figure 15: The dual processing model (Tovey 1984).

Having described the act of design and the different styles of design thinking, the next section brings the chapter forward by discussing models of the design process.

## 2.3 Models of the Design Process

The first generation of design models were those established by Horst Rittel in 1973 who cited that design should be broken into steps such as understanding, collecting, analysing, developing, assessing and finally testing of the solution (Erlhoff 1987; Bousbaci 2008). Other scholars contributed with a morphology of design (Morris Asimov in 1962); a formalised design checklist (Bruce Archer 1964); evaluating design solutions (John R. M Alger and Carl V. Hays in 1964) and general new product development process models by Christopher J. Jones (1969) and Nigel Cross (2000). According to Urban and Hauser (1993), the design process may be viewed as a series of steps or activities, including idea generation, product development, and product commercialisation. Other models of these activities include those by Tjalve *et al.* (1979b) and French (1985) that begin with an initial statement of a need and problem analysis (Figure 16). Next, the conceptual design phase generates and selects the idea. The embodiment stage allows the concepts to be worked further before detailing as the last phase whereby a large number of small but essential points are decided.

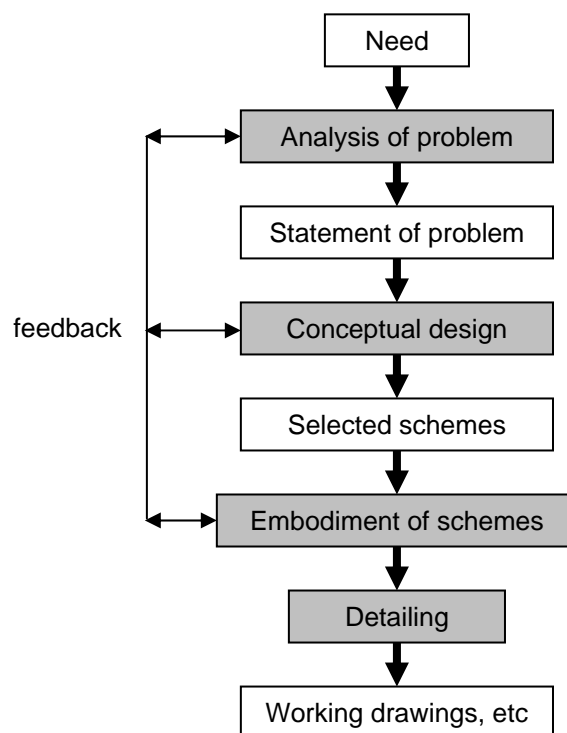
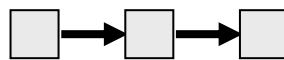


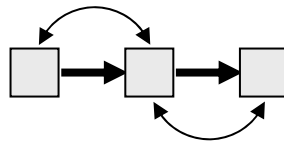
Figure 16: French's (1985) model of the design process

Boekholt (1985) added that by describing and clarifying design processes, stakeholders are able to better understand working relationships and tasks, as well as recognising the links between information, activities and systems with other members. From the literature review, five distinct groups of the design process models have been identified by the author (Figure 17).

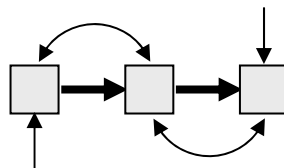
First Model: Basic with only key activities



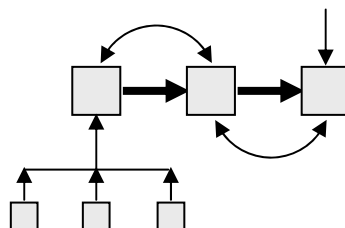
Second Model: Incorporating feedback loops



Third Model: External factors with feedback loops



Fourth Model: Sub-stages with feedback loops



Fifth Model: Combination of linear and spiral with feedback loops

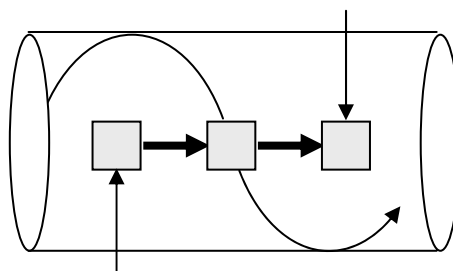


Figure 17: The 5 distinct groups of the design process models

### 2.3.1 First Model of the Design Process

The first type of design models are very basic and highlight key activities. This example is evident in the model by Jones (1992) as shown in Figure 18. The model begins with an initial analysis that examines the problem and then formulating the criteria. It follows with a synthesis stage to find possible solutions and to build the product based on structure, form, material, dimension and surface and finally ending with evaluation.

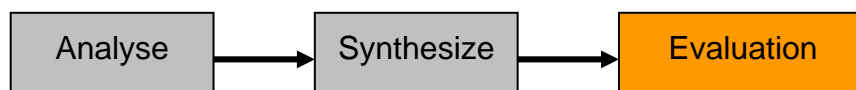


Figure 18: The design process according to Jones (1992)

Archer's sequential model (1965) (Figure 19) incorporates more details within each stage, such as observations and data collection occurring in the analytical phase. Archer's model has been considered to be 'first generation' and is similar to that proposed by Ulrich and Eppinger (2003) whereby the flow of activities are held sequentially (Figure 20). The key feature is that the creative phase present in the middle of the model is similar to the model proposed by Jones.

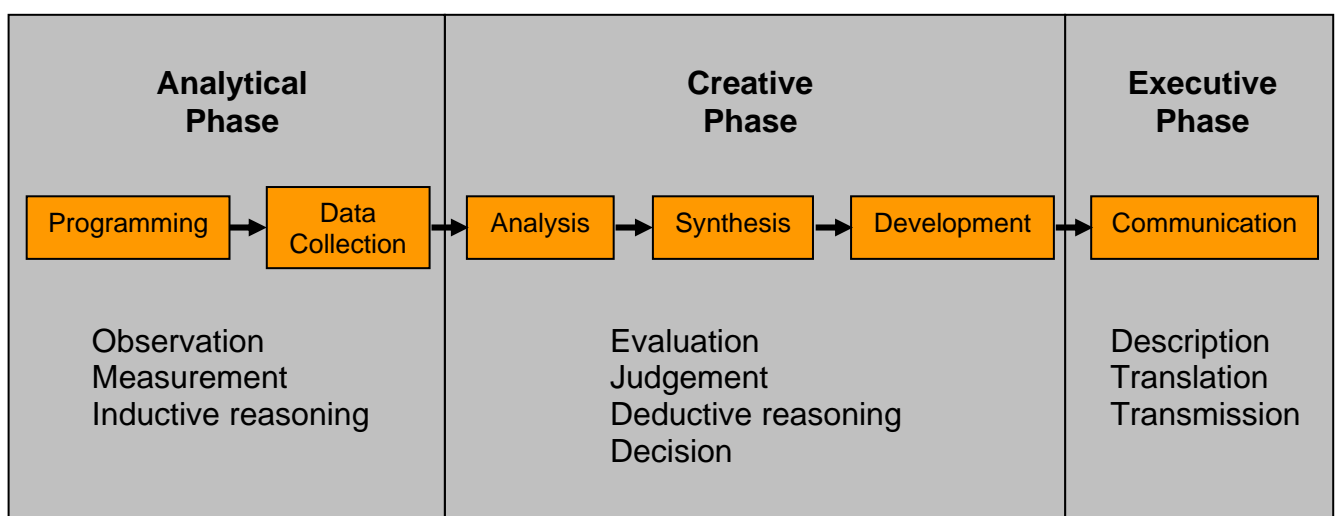


Figure 19: Archer's (1965) model of the design process



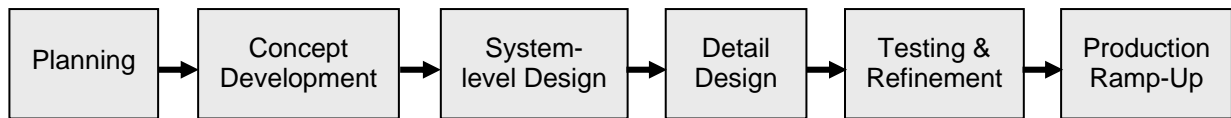


Figure 20: The design model according to Ulrich and Eppinger (2003)

It can be observed that the first type of design process models follow a pattern with three key phases that can be summarised with a simple diagram proposed by Boekholt (1985) (Figure 21):

Phase 1: Formulation of the design problem

Phase 2: Generation of solutions

Phase 3: Evaluation of solutions

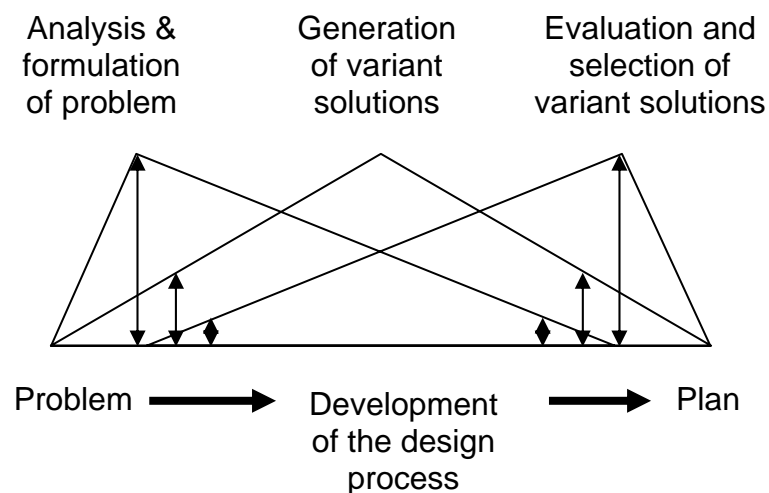


Figure 21: Boekholt's (1985) model

### 2.3.2 Second Model of the Design Process

The second type of design process models are those proposed by French (1985) (Figure 22) and Dominick *et al.* (2001) (Figure 23) who incorporated the use of feedback loops that allows possibilities for connections to be made between the stages. The return lines show that design is an iterative process with back tracking and parallel activities (Gupta and Murthy 1980).

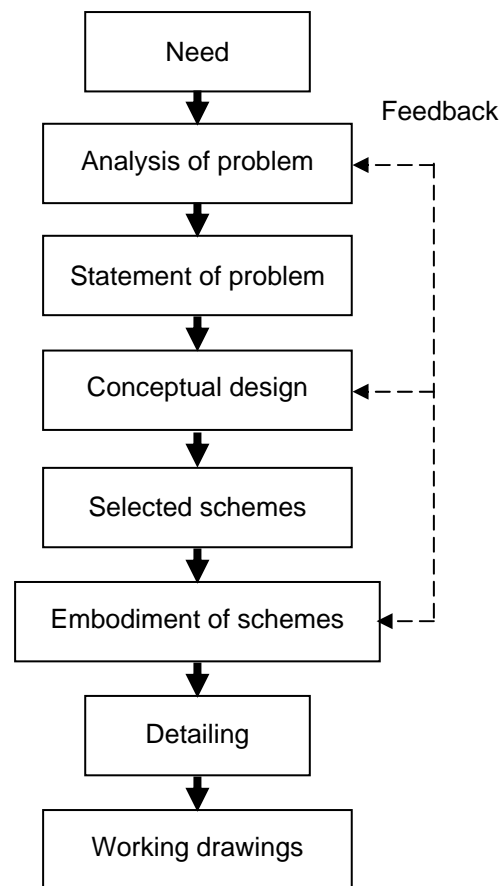


Figure 22: Block diagram of the design process (French 1985)

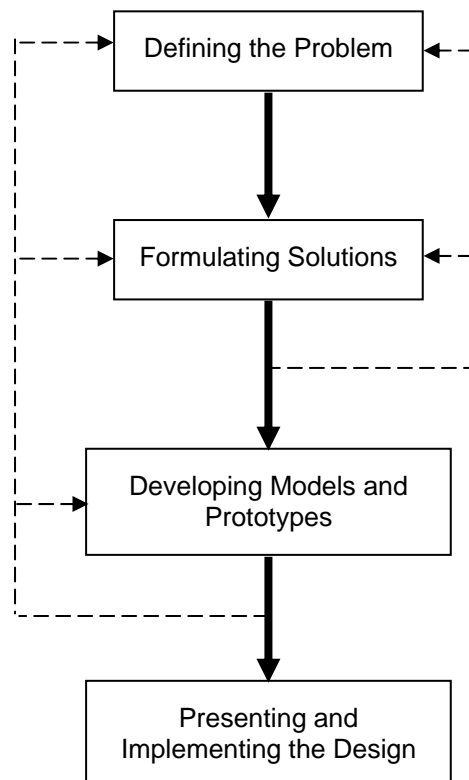


Figure 23: The Iterative phases of the design process (Dominick *et al.* 2001)

### 2.3.3 Third Model of the Design Process

The third type of design process model emphasises the external factors involved during the design process. This is shown in the prescriptive model proposed by Archer (1965) whereby external interactions are included such as client contributions, the designer's training and his experience (Figure 24). In his model, Archer identified six activities: programming to establish issues; data collection and storing information; analysis of sub-problems; synthesis by outlining the design proposals; development, preparation and execution of prototypes; and the communication and documentation for manufacture.

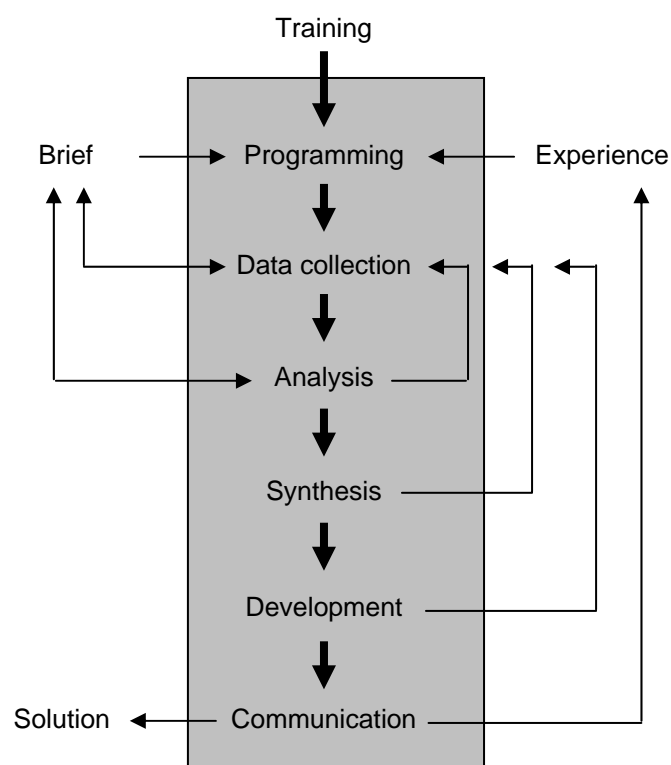


Figure 24: Archer's (1965) model of the design process

### 2.3.4 Fourth Model of the Design Process

The fourth design process model is evident by those proposed by Pahl and Beitz (1996) and those of the German professional designer's society, Verein Deutscher Ingenieure (VDI). Similar to Pahl and Beitz's model (Figure 25), the VDI 2221 guideline (Figure 26) described a more systematic approach towards the design of technical systems and products. The guideline breaks down complex problems into sub-stages that are solved individually. It also

recognised that because sub-solutions need to be compatible, the interface between them must be considered. VDI 221 is interpreted in a different way in Figure 27 by having converging and diverging lines among each phase.

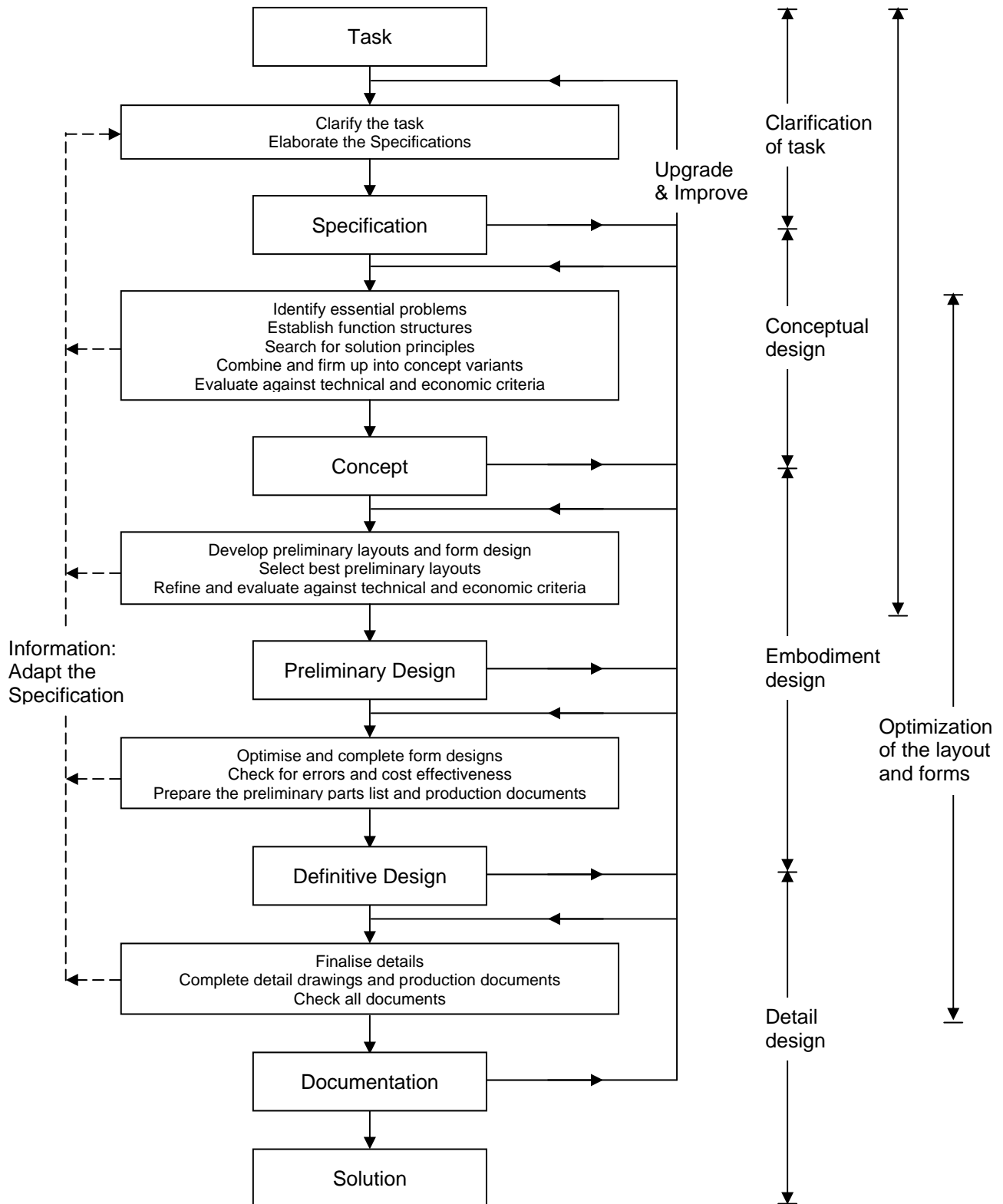


Figure 25: Phases of the design process according to Pahl and Beitz (1996)

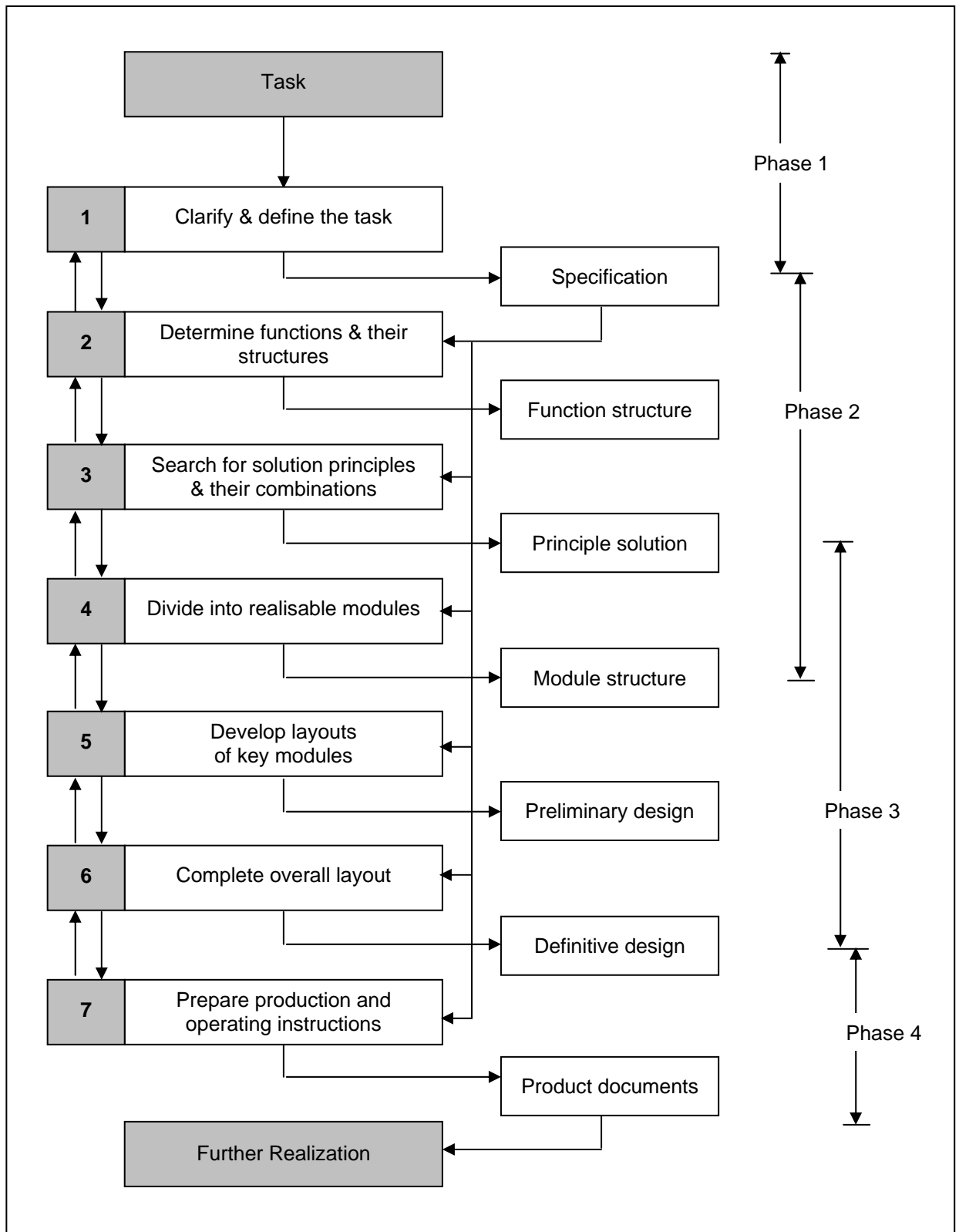


Figure 26: General approach to design according to VDI 2221 (Dominick *et al.* 2001)

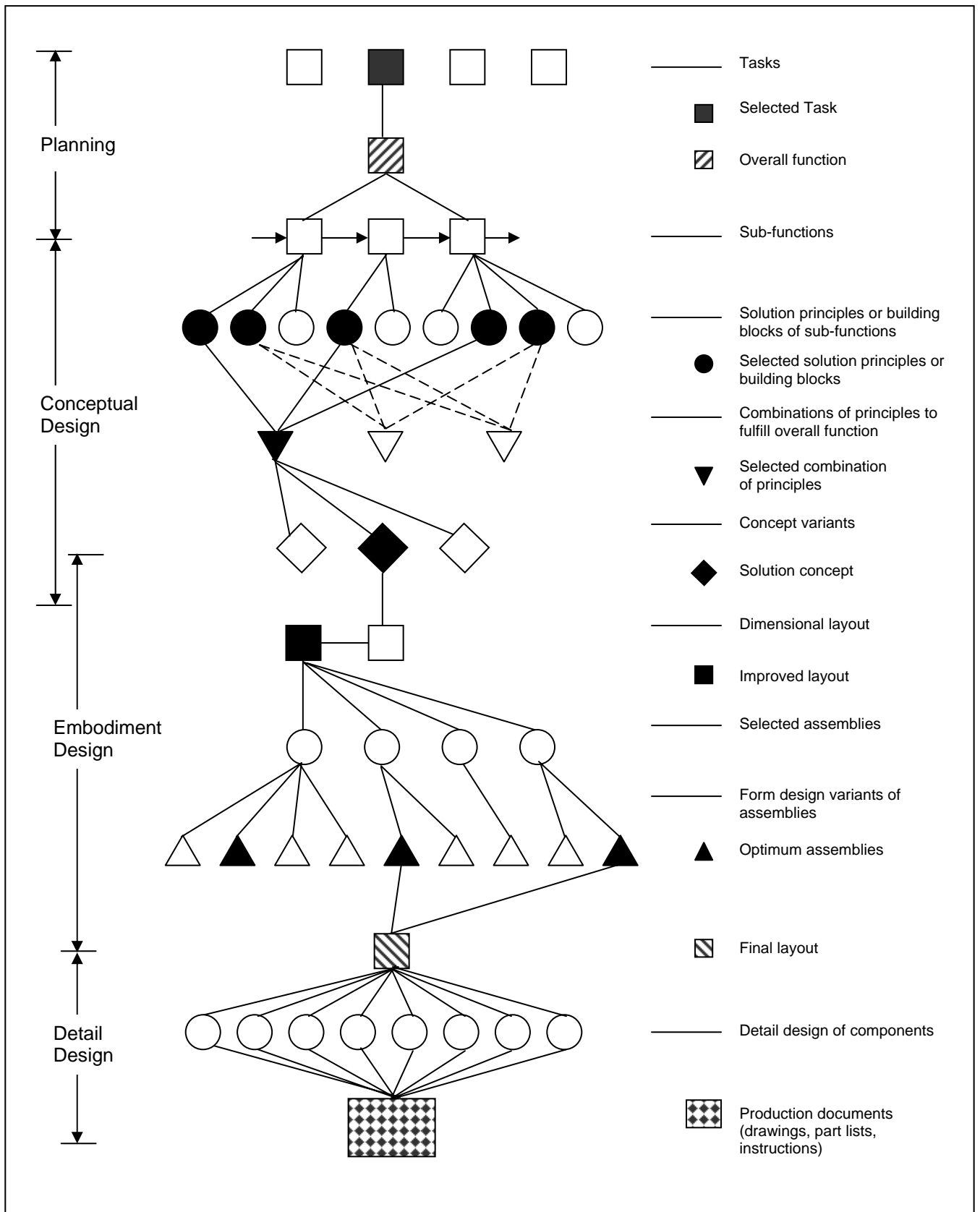


Figure 27: Divergence and Convergence in the design process of VDI 2221  
(Dominick *et al.* 2001)

The VDI 2222, known as the ‘guideline to conceive technical products’, describes the development process from problem statement to manufacture (Figure 28). As there are no stakeholders included in the model, it allows the model to be freely applied to relevant projects. Another element is the use of key points that separate project, concept, order and the execution (Wright 1998). Despite having a systematic approach, VDI guidelines have been criticised as having an engineer’s problem-focused approach rather than a designer’s solution-focused approach (Cross 2000).

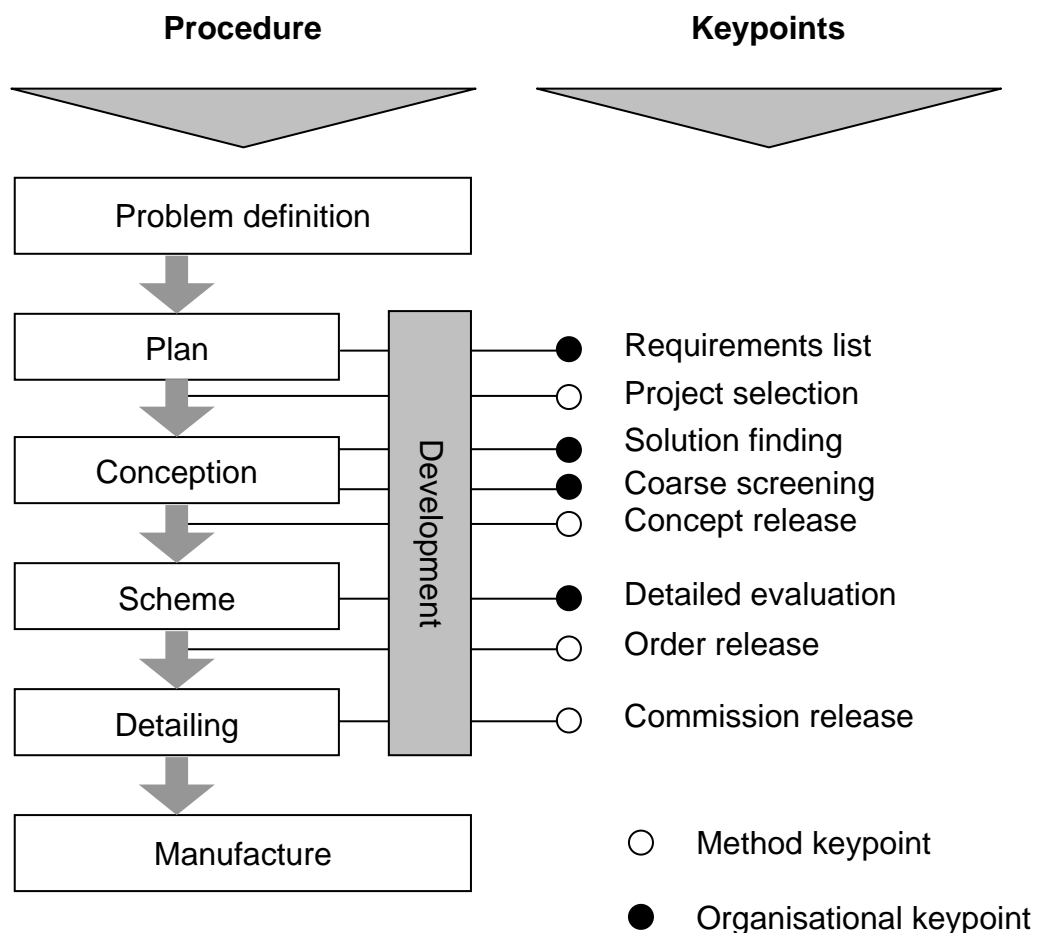


Figure 28: Method and organisation key points of VDI-2222 (Wiendahl 1981)

### 2.3.5 Fifth Model of the Design Process

The last category of design process models comprise those of Pugh (1991) who differentiated that engineering models are prescriptive and show stages in a linear manner (e.g. concept-embodiment-detail stages); and design

models are shown as descriptive and emphasise cognitive processes in a spiral and cyclical way (e.g. productive-deductive-inductive thinking). As a result, Pugh (1996) proposed a 'Total Design' model (Figure 29) that combined the linear and spiral elements as well as the flow of information. The model also illustrates the links between the stakeholders with other departments and how tasks are inter-related.

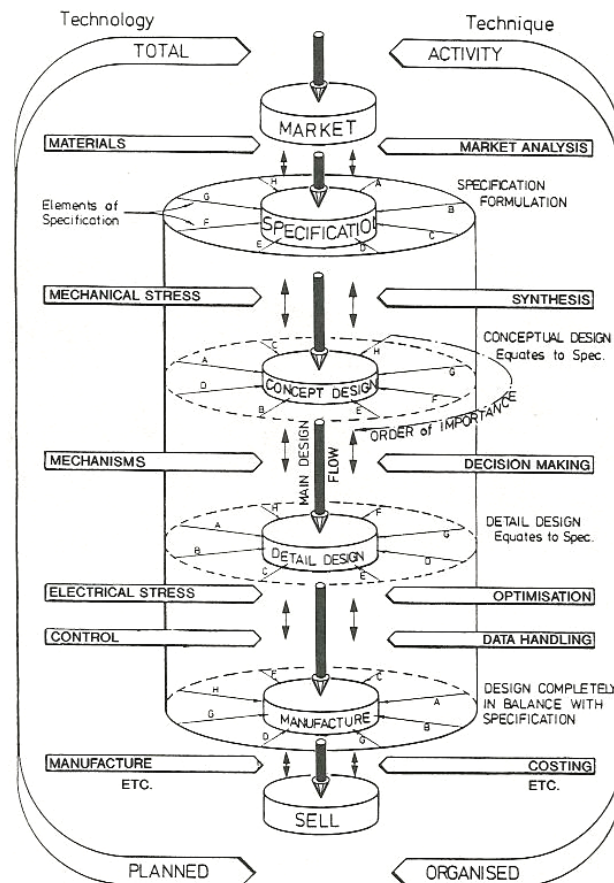


Figure 29: The Total Design activity model by Pugh (1991)

This spiral element is also visible in Acar's (1996) model (Figure 30) that consisted of a triple helix highlighting the ongoing interaction between specification, conceptual design and embodiment at any given time throughout the process. The five design models described in this section are summarised in Figure 31. The next section discusses the concept of new product development.



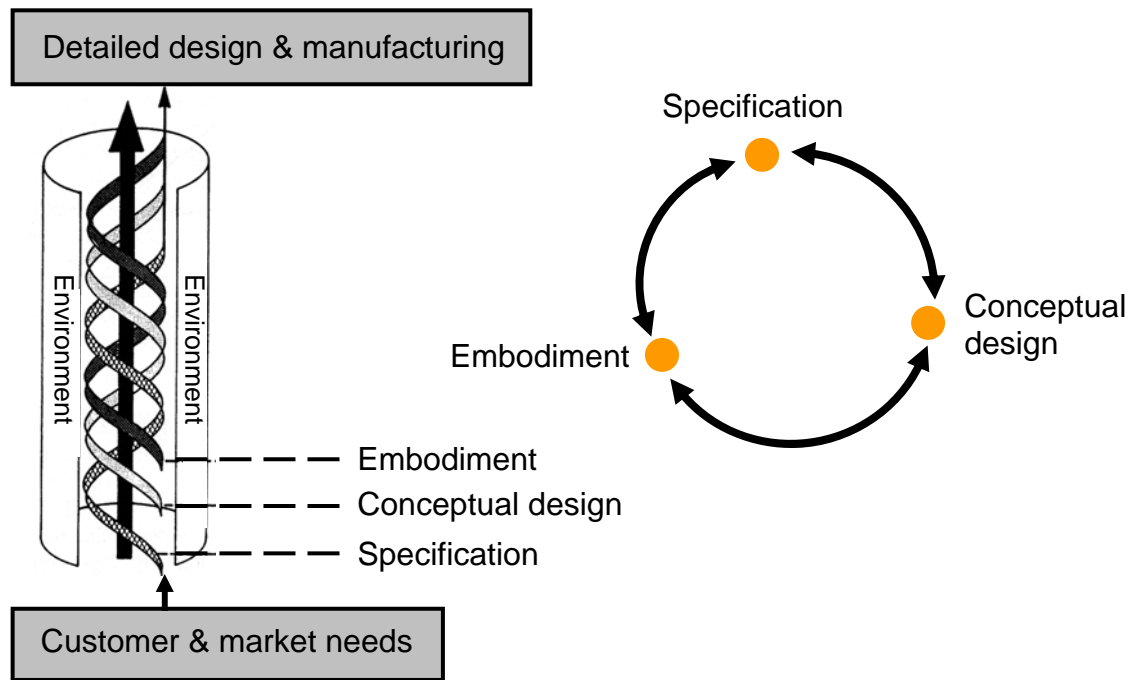


Figure 30: Acar's (1996) triple-helix model of the design process

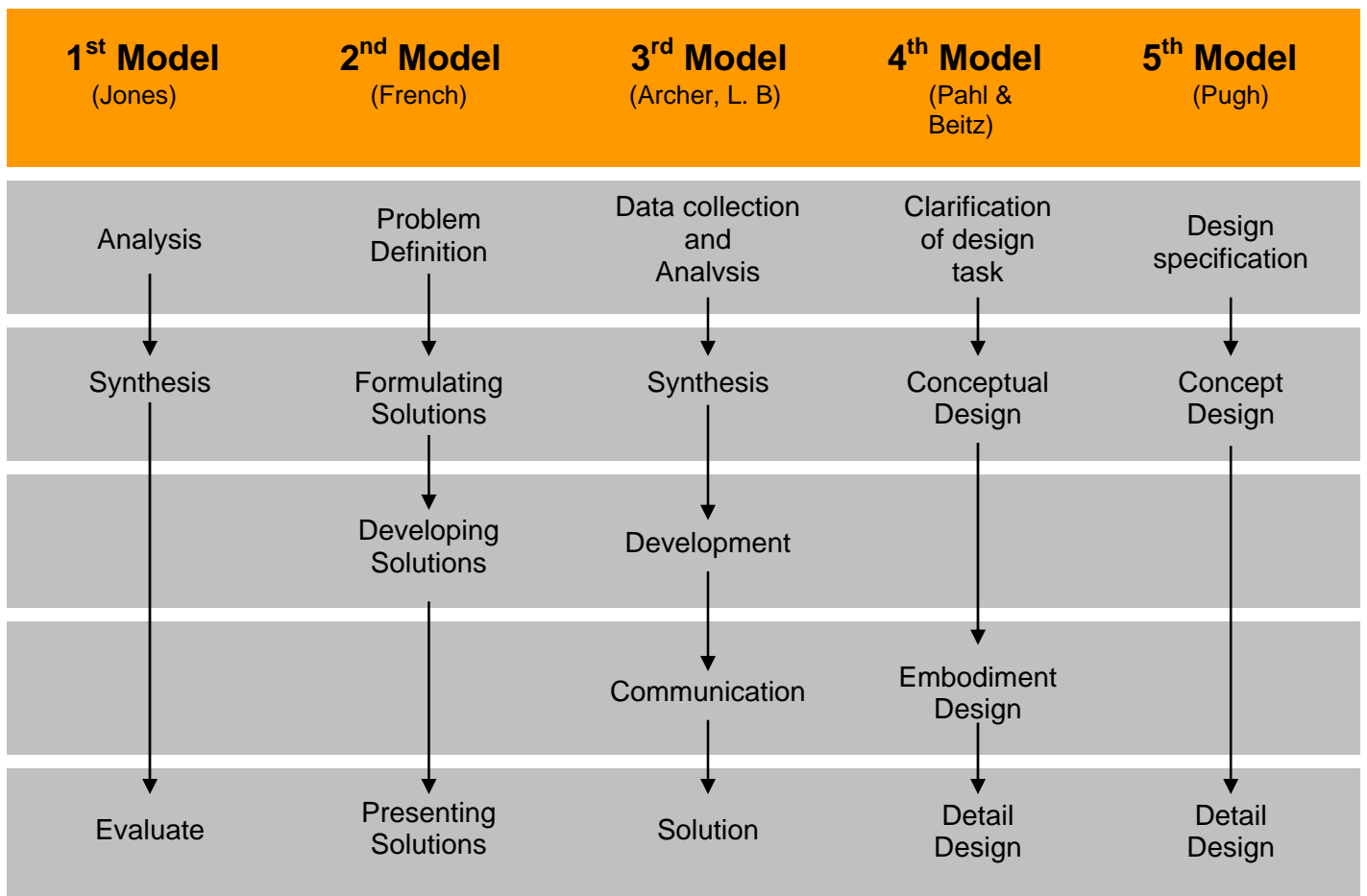


Figure 31: Models of the design process

## **2.4 New Product Development**

The term 'product' has been described by Ulrich and Eppinger (2003) as 'something sold by an enterprise to its customers' or 'a device that provides a service which enhances human experience (Cagan and Vogel 2002; Junginger 2008). New product development is a central activity that involves stakeholders working together to reduce uncertainty and to improve the quality of products (Moenaert and Souder 1990; Backhouse and Brookes 1996). In addition, Ulrich and Eppinger (2003) defined product development as 'a set of activities beginning with the perception of a market opportunity and ending with the production, sale, and delivery of a product' and is sometimes referred as a sales strategy that seeks to improve current products or to develop new products for the market (Kotler and Armstrong 2003).

Paashuis (1997) stated that the aim of new product development is to create, define and select superior products by integrating and coordinating tasks, improving the company's competitive advantage; and to translate the steps into an effective and efficient process. In turn, new product development is achieved by simplifying processes, eliminating delays, abolishing steps, speeding up operations and conducting simultaneous, concurrent and overlapping operations (Souder 1987). For manufacturers to remain profitable, they are constantly reducing production costs, shortening lead-times and improving product quality (Maffin 1998).

In new product development, effectiveness is assessed through the company's degree of success, its performance in meeting the objectives, the product span and quality, and whether the firm is able to meet the budget. In contrast, product efficiency is measured by the timeliness of a product's introduction into the market (Song *et al.* 1998). To stimulate or foster cooperation between stakeholders, companies have implemented mechanisms such as reward systems (Song *et al.* 1997) and co-location of members (Clark and Fujimoto 1991; Tassarolo 2007). Another approach involves the implementation of organised teamwork with good internal communication and effective collaboration across functions (Rothwell 1992).

To achieve effective collaboration, multi-disciplinary barriers must be first broken down (Erhorn and Stark 1994). However, this is difficult as different functional members have diverse orientations, goals and values that lead to conflicting expectations, disrupted work patterns and decreased productivity.

The discussion on multi-disciplinary conflicts between industrial designers and engineering designers will be discussed in Chapter 4, Managing Design while subsequent sections in this chapter continue the discussion on new product development by reviewing the models and stages of the development process.

## **2.5 *Stages of the New Product Development Process***

There have been several overlapping definitions used for the terms concerning the stages of new product development. For example, the embodiment stage is also referred as the system-level phase (Ulrich and Eppinger 2003). To provide clarity, the following sections aim to formalise the terms that altogether make up the stages of new product development. Examples of visualisation used at each stage are also given.

### **2.5.1 Concept Design**

As the first phase of new product development, the concept design stage is mainly associated with idea generation activities even though the problems may be unclear. A large portion of this phase involves clarifying ideas through searching, establishing and selecting suitable concepts against technical and economic criteria (French 1985; Pahl and Beitz 1996). More importantly, this phase brings industrial design, engineering design and marketing together for the first time to make important early decisions (Haskell 2004). Once the function structures and system architecture are finalised, the physical design then takes place (Rosenthal 1992). This involves exploring design solutions usually with use of pencil and paper to record quick, spontaneous conceptual thoughts (Lawson 1984; Roozenburg and Cross 1991) such as those shown in Figure 32. For this research, concept design is defined as the first phase

of new product development that involves generating ideas based on form, function, features, specifications and benchmarking with economic justification.

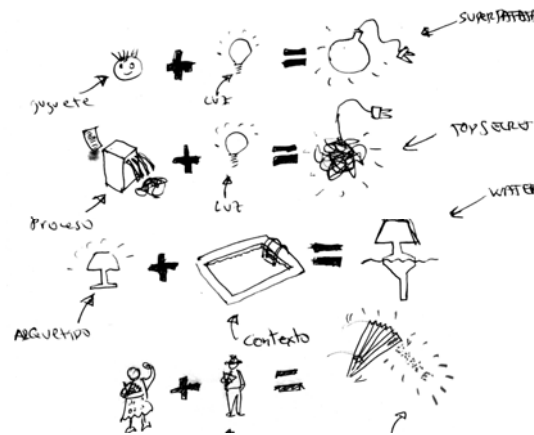


Figure 32: Concept sketches showing the thoughts behind the ideas (Pipes 2007)

## 2.5.2 Concept Development

In the second phase of new product development, the concept development stage follows up ideas that have been selected from concept design. This stage develops the initial ideas through a series of activities and refining them through extensive use of sketches and models to establish the feasibility of the overall concept (Cooper *et al.* 2000; Ulrich and Eppinger 2003). A large portion of this stage involves visualisation such as the sketch shown in Figure 33, and developing and evaluating ideas that meet the design specifications (Pipes 2007). For this research, the concept development phase is defined as the second stage of new product development that involves the selection, development and evaluation of suitable concepts based on set specifications.

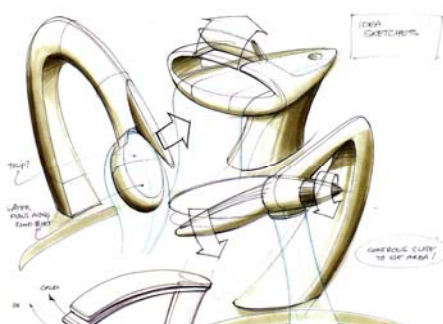


Figure 33: These sketches include directional arrows and texts to effectively communicate function (Olofsson and Sjöln 2005)

### 2.5.3 Embodiment Design

The embodiment or system-level design phase is the third stage that aims to produce a concrete form of the developed idea (Wright 1998). The output may be a technical description such as general arrangement drawings that incorporate both layout design (arrangement of components) and form design (aesthetics) in consideration to technical and economic constraints (Rosenthal 1992; Dym and Little 2003). Other representations frequently used in this stage include physical models (Figure 34) and prototypes that define the developed arrangement and shape of the product. For this research, the embodiment design phase is the third stage of new product development that creates a fixed layout by selecting the most desirable configuration, evaluating against technical and economic criteria.



Figure 34: An appearance model of a lawnmower (Garner 2006)

### 2.5.4 Detail Design

At the fourth stage of new product development, the detail design phase is concerned with many small but important aspects of the product (Haskell 2004). This phase produces a final and highly detailed technical description of each component including the materials, surface properties, tolerances, positioning and assembly (Figure 35). Other activities include checking and testing prior to manufacture (Pahl and Beitz 1996). For this research, the detail design phase is the fourth stage of new product development that realises the physical product through the specification of details such as material, size, assembly, etc., with final testing before production.

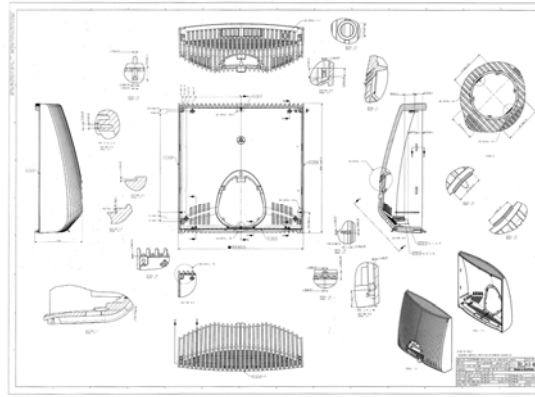


Figure 35: A technical drawing for the Bang & Olufsen CD player (Pipes 2007)

The next section continues the discussion on new product development and examines the design methods employed during new product development.

## 2.6 *Design Methods*

According to the Merriam-Webster dictionary (1994), a method is an orderly arrangement, procedure or plan employed so as to achieve something. The use of design methods emerged in the 1960s where design problems became too complex with the large amounts of data that industrial designers and engineering designers had to consider (Erlhoff 1987). By formalising activities (French 1985) and externalising thinking, all members are able to better understand the situation and act accordingly (Cross 2000). The use of methods within a multi-disciplinary workspace allowed stakeholders to gain a common ground for better communication among themselves (Löwgren and Stolterman 1999) and to ensure that work processes are uniform throughout the organisation (Pitts 1973; Syan and Menon 1994). Methods are usually represented as words and symbols in a diagram showing the relationship of processes and are graded according to their effectiveness, relevance, convenience, familiarity and limitations (Jones 1992).

Hubka (1983) defined design methods comprising a system of rules and directives to support and enhance the regulation of activities and resources; and a single element of a method is a 'working principle'. In the bigger picture, a set of methods comprises a 'methodology' (Roozenburg and Eekels 1995).

The term 'strategy', refers to planned methodical list of actions with use of specific methods or working principles to achieve goals (Cross 2000). Design strategy is a higher-level structure of how things should be carried out during the design process by means of assessing, evaluating routes, setting priorities and monitoring costs (Joseph 1996). Key strategies for new product development include implementing concurrent activities, simultaneity of procedures and integration (Duffy *et al.* 1993). These key definitions are summarised in Table 6.

Term	Description
Working principle	A single element of any method
Method	A system of systematic working principles or procedures used to accomplish something
Design method	A system of rules and directives to determine the performance of design activity and to regulate resources
Methodology	A set of methods or working principles
Design methodology	The set of methods that can be applied towards design
Design Strategy	Achieving goals through use of use of specific design methods or working principles

Table 6: Definitions of guidelines, methods and methodology

Design methods started off by collecting observations of best practices in the industry (Roozenburg and Eekels 1995; Frost 1999). Different design methods have different purposes and may be relevant to different aspects and stages in the design process. Shetty (2002) suggested that certain methods could be more effective when used during a particular phase during new product development as shown in Table 7. Although some design methods have been criticised as being over-formalised and hindering creativity, it has been argued that because many projects are complex, the use of methods would still help towards a structured approach to reduce errors (Cross 2000). Guidelines are a more organised and systematic way of working. Gouvinhas and Corbett

(1999) emphasise that although design guidelines may increase the complexity of tasks, they still offer significant benefits, for example a checklist straightforwardly shows factors that are to be considered. In contrast, Naylor and Ball (2005) argue that because guidelines produce predictable results, they are hardly creative or inventive and do not work for design.

Phase	Recommended Method
Concept Development	Market Studies Voice of the customer House of Quality (QFD)
Design & Development	Function analysis Design for Manufacture Design for Assembly / Disassembly CAD/CAM product modelling Simulation Optimisation 6-Sigma analysis Rapid Prototyping Design for Environment & Service
Analysis & Testing (Embodiment Design)	Failure Mode and Effects Analysis Robust Design Statistical Reliability Analysis Design for Life-Cycle
Product Creation (Detail Design)	Workplace Design Flexible Automation Tools Value Stream Mapping

Table 7: Recommended product development methods (Shetty 2002)

It must be stressed that methods and working practices are not strictly limited to design or engineering applications. They may be used interchangeably depending on the circumstance of the situation. Attempts to categorise methods have been difficult because there are so many available and they may serve multiple purposes and may be used at several stages (Trygg 1993b). An example is that proposed by Hein (1994) in Table 8, showing numerous strategies, procedures and methods overlapping in terms of use in the application of problem solving, product synthesis and in product development.



Use Type	Problem Solving	Product Synthesis	Product Development
<b>Strategies</b>	Learning Strategy General Problem Solving Strategy	Trial & Error Abstraction Combination	Integrated Product Development Concurrent Engineering Total Design
<b>Procedures</b>	Chris Jones	VDI2221 Tjalve	IPD Pugh
<b>Methods</b>	Brainstorming Synectics Sketching	Evaluation Methods 635 Morphology Variation	Functional Reasoning Design Catalogues Specifications Need Analysis Competitor Analysis Business Search Team Milestones
<b>Models</b>	Sketch Photo Writing Drawing	CAD Experiments Mathematical Model Simulation	Design Model Products for Experiments Prototype Mockup Functional Model Zero series production
<b>DFX</b>		DFA DFEnvir. DFM DFQ DFC	
<b>Technical Means</b>		FEM CID CAD CADCAM Workbench	

Table 8: Primary application of tools (Hein 1994)

In terms of classifying methods, Jones (1992) proposed a system categorising methods to be divergent and convergent, while Gupta and Murthy (1980) added transformation as a third category (Figure 36). Divergent methods establish the need and expand the solution space, while transformation methods involve creativity and ingenuity. Consequently, convergent methods narrow down solutions with evaluation.

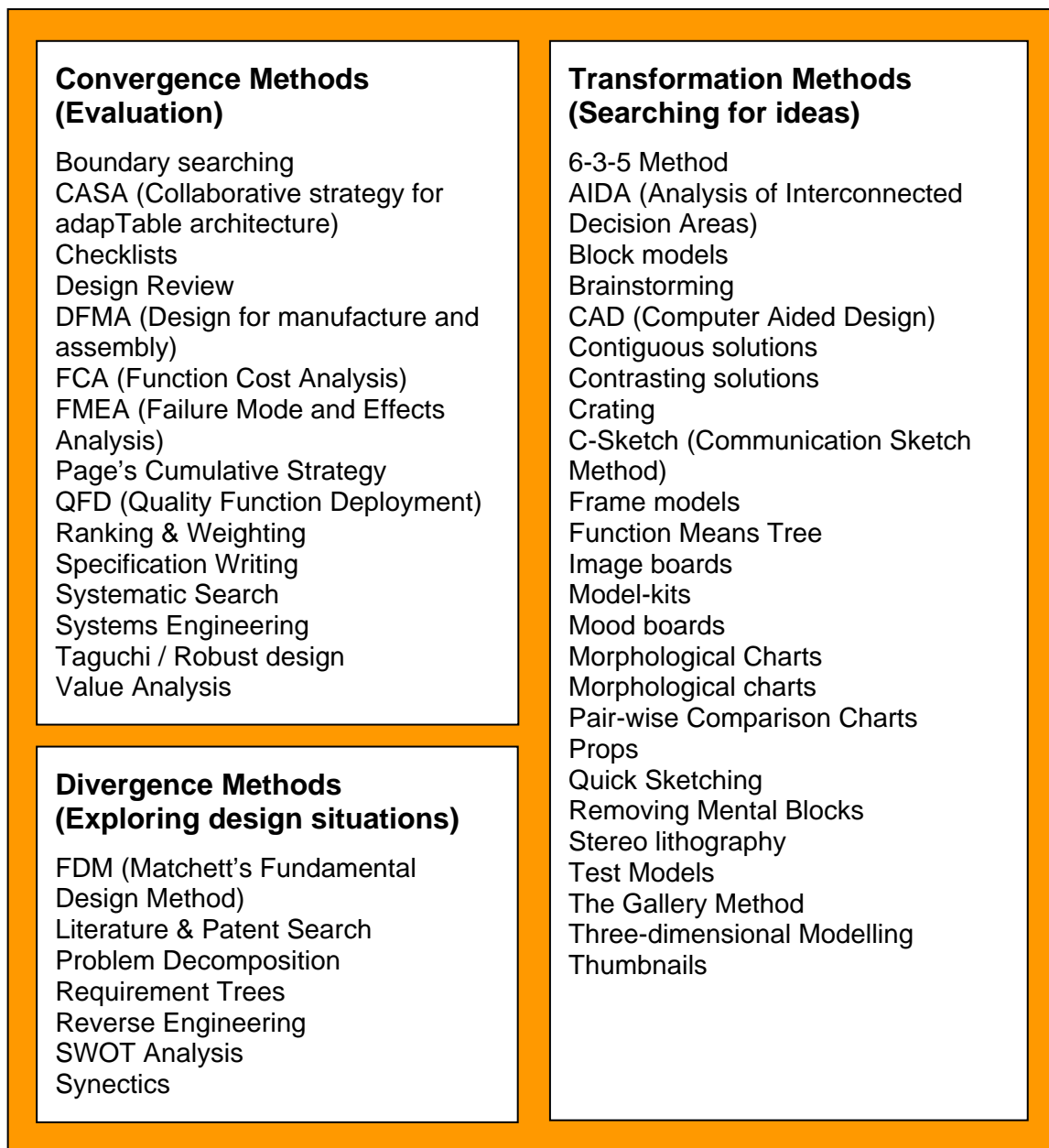


Figure 36: Classification of methods (Gupta and Murthy 1980)

Cross (2000) proposed another categorisation by grouping design methods (Table 9) as being creative or rational. Although both methods complement each other, rational methods cover all aspects of the design process but creative methods are limited to tasks that require help in removing mental blocks. An overview of the categories of methods is located in Appendix 13.1 and a list of methods used during new product development may be found in Appendix 13.2.

Design Method	Purpose	Example
Creative Methods	Provide ideas by removing mental blocks that prevent creativity, or by widening the search space	Brainstorming Synectics etc
Rational Methods	Improves quality of decision making including problem clarification and detail designing	Objectives tree Morphological chart Performance specification etc

Table 9: Creative and rational methods (Cross 2000)

## 2.7 Chapter Summary

This chapter has set the first level of groundwork, providing an overall understanding of design and the cognitive processes. It highlighted that through well-thought solutions with a balance of good aesthetics, engineering and manufacture would enable the creation of better-designed products. The act of designing involves creatively building the nature, appearance and social function of objects through problem solving that involves iterations throughout all stages of the product development process - concept design, concept development, embodiment design and detail design. The chapter also classified five distinct groups of design process models in new product development and introduced different design methods used during new product development. The next chapter will provide an introduction to the industrial design and engineering design disciplines.

### **3. INDUSTRIAL DESIGN & ENGINEERING DESIGN**

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#### **3.1 Chapter Overview**

Before discussing how industrial designers and engineering designers collaborate in new product development, it is important to first understand both disciplines in terms of their history and work practices. This chapter also compares differences between them and links this to the next chapter that discusses the issue of design management including teamwork and collaborative design.

#### **3.2 Industrial Design**

According to the Dictionary of Art Terms (2003), industrial design is the reasoned application of aesthetic and practical criteria for the design of machine-made artefacts, in the hope of creating a successful marriage between aesthetics and functionality. Goldschmidt (1995a) acknowledged that the field of industrial design lies in between engineering and other artistic design disciplines and its work is to create artefacts that deliver engineering and science. For example, the telephone was invented by Alexander Graham Bell but it was the industrial designer who gave the phone its form (Hannah 2004). Well-designed products provide a feeling of aesthetic and emotional experience through their use (Billings 2006). By providing good aesthetical experience, manufacturers are able to increase their competitive advantage, and make products usable and acceptable for consumers (Ashford 1969a; Bohemia 2002). In addition, industrial design can be used to communicate the manufacturer's image and promote the integrity of the product to enhance sales (Yamamoto and Lambert 1994).

In one of the earliest interpretations still relevant today, the goal of the industrial designer is to understand and achieve the requirements of both user and manufacturer (Holme 1934). The industrial designer plans and creates physical artefacts suitable for mass production by synthesising engineering, technology, materials and aesthetics, balancing the needs of users within

technical and social limitations (Heskett 1980; Gemsera and Leenders 2001; Fiell and Fiell 2003b). Apart from aesthetics, the industrial designer is also required to have a sound knowledge of manufacturing methods, issues and limitations (Holme 1934).

For this research, in line with the Industrial Designers Society of America (IDSA), industrial design (ID) refers to the professional service of creating and developing concepts and specifications that optimises function, value and appearance of products and systems for the mutual benefit of both user and manufacturer (IDSA 2006). The terms product design and industrial design have often been used interchangeably in the literature. However, the term 'product design' has also often been used to refer solely to products and has been felt to be too limiting (Dictionary of 20th Century Design 1990). To add to the confusion, the Corfield report (1979) defined product design to comprise both engineering design and industrial design. Even today, the British Design Council also uses both product and industrial design terms when describing product creation activities. To achieve consistency and to avoid misunderstanding, only the term industrial design will be used for this research.

### **3.2.1 A Brief History of Industrial Design**

Industrial design has a young history and its roots stem from the Crafts movement and the Bauhaus in Europe. The term 'industrial' is used because products are manufactured by industrial processes (Hirdina 1998).

Aesthetic design has long existed since the ancient civilisations with products such as Greek pots, Byzantine ornaments and artefacts in Egyptian temples. For centuries, objects were created by craftsmen who planned and produced artefacts from start to finish. It was the early 19th century that witnessed the industrial revolution where mechanical production and a divided labour system superseded the use of hand-production (Heskett 1980). The difference between the craftsman and an industrial designer lies in the fact that the craftsmen planned and created the product, while the industrial designer does

not produce the product (Sparke 1983). Consequently, when an industrial designer designs a one-off product, the term 'industrial' is dropped and he is acknowledged as a 'craft designer' (Campbell *et al.* 2006).

The outbreak of the First World War saw the implementation of standardised and mechanised production, but with very little emphasis on aesthetics. In the 1930s, a saturated market and the Great Depression made manufacturers realise that they could boost sales and seek a competitive advantage by improving the appearance of products. These visually trained individuals were tasked to make things irresistible, and to fill the gap between art and manufacture (Woodham 1983).

Considered as among the pioneering professional industrial designers, Peter Behrens, originally an architect, was engaged by the AEG company as an artistic advisor to enhance the company's products. He worked by varying finishing, form and sizes based on a standard component. It made his work novel, distinguishing himself as one of first modern industrial designers (Heskett 1980). Since then, industrial designers have now extended their responsibilities to include market trend analysis, ergonomics and usability studies, etc. The key activities of modern industrial design also include innovating and developing concepts. To do so, the industrial designer must be adept in externalising thoughts, to communicate and sell the idea to the client (Pipes 1990). In addition, the industrial designer should be skilled in visual design representations, from creating simple sketches to modelling detailed prototypes that are essential to communicate the design idea (Garner 1999).

Tovey (1989; 1997) cited that the industrial designer has a particular concern towards the appearance of products and in representing design concepts and should also have a good grasp of the market, the user and engineering requirements and condensing these into a holistic solution. In terms of aesthetics, the industrial designer should provide the product with a sense of unity, coherence and individuality to produce a distinct product personality. An example is the German company, Braun that has been developing products such as shavers (Figure 37) by jointly working with designers, engineers and

marketing experts, combining technological innovation with clear aesthetic expression, and creating products that are distinctive, desirable, functional and beautiful (Fiell and Fiell 2003b).



Figure 37: Braun 570 PocketGo

Good designs provide the best balance between functional, emotional, aesthetic, manufacture and ethical needs of the consumer, and bears in mind efficiency, economy and ease of maintenance (Kristensen 1995). As manufacturing becomes more advanced, industrial designers are also expected to be proficient in the use of computer-aided design (CAD), and to be able to work with various disciplines to develop products (Hannah 2004).

### 3.2.3 Working Approaches of Industrial Designers

In a survey conducted in Australia with 134 responses, Bohemia (2002) found that industrial design has been used for a number of reasons with work on appearance being the most common among companies (Table 10).

1. Appearance	6. Value	11. Flexibility
2. Quality	7. Market Share	12. Operating Cost
3. Product Cost	8. Time	13. Reduces Number of Parts
4. Efficiency	9. Durability	14. Integrates Various Functions
5. Product Differentiation	10. Safety	

Table 10: Ranking of reasons for using industrial design from highest to lowest (Bohemia 2002)

Persson (2005b) established that the industrial designer's work is focused on aspects experienced by users, including the outlook, usability and identity of a product. They work by first creating an overall solution and then working on the details (Tovey 1997). In terms of language, industrial designers use graphic codes that take the form of sketches and drawings which are considered to be the most convenient form of representing ideas (Robertson 1996; Kavakli *et al.* 1998; Verstijnen *et al.* 1998) such as those shown in Figure 38. Even more so, the professional industrial designer should be skilled in communicating how the final product should look and to ensure that the design intent is accurately conveyed (Cross 2007).

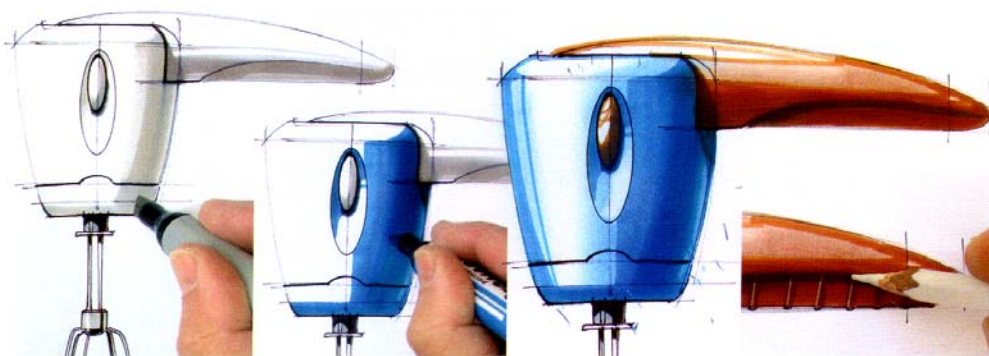


Figure 38: The use of marker techniques to communicate the suggestion of colour (Eissen and Steur 2008)

It must be noted that the simplicity and spontaneity of representations such as sketches should not be restricted only to 2D paper. Where form and surfaces need to be further explored, industrial designers may use physical materials to create 3D forms, more popularly recognised as the act of 3D sketching or sketch modelling. Also, 2D representations lack the tactile experience and do not provide confidence for stakeholders to proceed directly to manufacture. This justifies the need to produce a non-working block model or a working prototype as a close representation of the final product (Evans and Wormald 1993). They allow ideas to be seen and tested in a tangible way at a low cost (Frishberg 2006). Consequently, the delivery of a final prototype signifies that the input of industrial design decreases and subsequent follow-ups are limited to fine detailing and production support.



Apart from creating physical representations, Computer-aided Industrial Design (CAID) has also gained importance because it allows ease of modelling, manipulation and visualisation of 3D forms (Evans and Wormald 1993). Digital methods also allow information to be sent directly to the manufacturer for production, thus saving time.

The process of using pencil and pen sketches and then moving into solid models with use of CAD, CAM, and rapid prototyping technologies is a popular approach that has been adopted by most industrial designers (Utterback *et al.* 2006). When asked about one's design approach, principle industrial designer, Mario Turchi of ION Design described that the moment begins by thinking and looking for references and then forming these ideas by sketching on paper. A meeting then takes place to bring project members together for discussion. The design team goes back and returns after a few days to present the developed ideas. After more brainstorming sessions, the design concept is born (Hannah 2004). Other industrial designers prefer to adopt a more hands-on approach, such as Mark Lim of Conair Corporation in Connecticut who described his work as involving study and research, drawing form sketches and creating 3D CAD models. Other industrial designers preferred a thinking approach, such as Tucker Viemeister of Springtime-USA who described that his work involves carefully analysing problems, looking for improvements to daily life, looking for added features, finding applications for technology, and dreaming of ideas (*ibid*).

In terms of corporate working approach, most European industrial design consultancies work up to the delivery of the layout or general arrangement drawing and are rarely involved with technical details (Pipes 2007). However, British and American companies ensure that their designs are seen right through to production, certifying that the original design intent has been retained (*ibid*). Most large corporations have an internal industrial design department and small companies usually contract design services from consultancies. In all cases, industrial designers are always required to work with other disciplines, including engineering designers, to generate, develop

and evaluate concepts for the product throughout the stages of new product development.

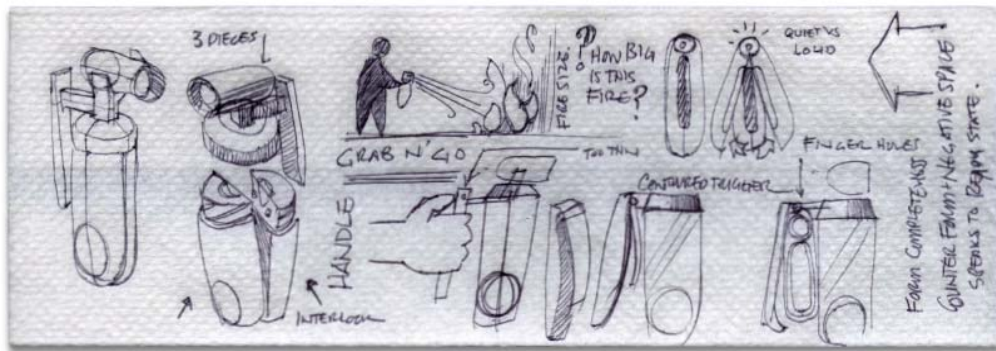


Figure 39: Sketches on a napkin showing quick evolution of concepts of a fire extinguisher (Baskinger 2008).



Figure 40: Examples of foam models for a bottle stopper (IDSA 2003)

In terms of working on 2D representations, industrial designers often vary the structure or form to try out suitable appearances that may suit the product outlook (Tjalve 1979). Pahl and Beitz (1996) also proposed embodiment guidelines that recommend ways to show expression, structure and the form of a product. For example, one of the guidelines shows how the structure of an automatic tea maker can take on different variations (Figure 41).

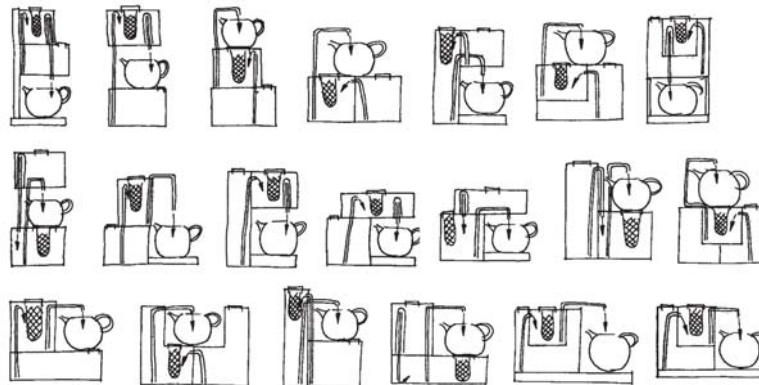


Figure 41: Variation of the structure of an automatic tea maker (Pahl and Beitz 1996)

Another guideline is the Principles of Formal Design proposed by Dieter Mankau (Bürdek 2005) encompassing additive design, integrative design, integral design, sculptural design, organic design, as well as employing visual markings that highlight the function of a product. Additive design can be seen

in the video camera, mail wagon and bathtub (Figure 42) where components are strategically arranged to highlight their practical functions.

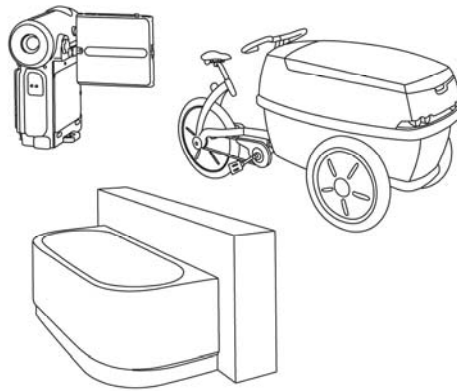


Figure 42: Products that use additive design (Bürdek 2005)

Integrative design can be seen in the shower stall, nutcracker and spotting scope (Figure 43) that use uninterrupted lines to show continuity and uniform use of material or colours as a wholesome product.

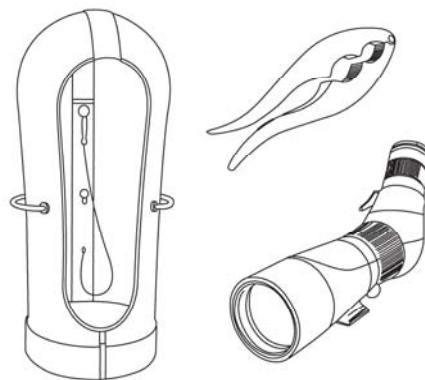


Figure 43: Products that use integrative design (Bürdek 2005)

Integral design is an approach that employs very basic shapes, as shown in the ICE Train, the Cube armchair or the camera housing (Figure 44). Sculpturally designed products can be seen in the kitchen table, industrial robot and fan (Figure 45) that have parts put together in a very expressive manner.

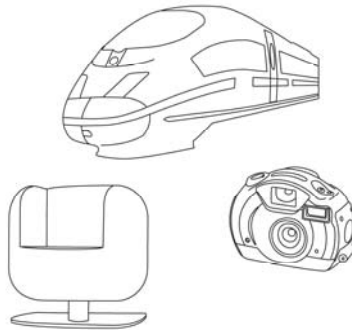


Figure 44: Products that use integral design (Bürdek 2005)

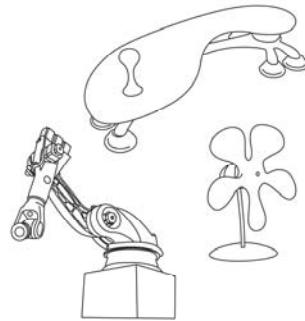


Figure 45: Products that use sculptural design (Bürdek 2005)

Organic design uses natural references to give meaning to products such as a roof construction, public lighting and the fruit bowl (Figure 46).



Figure 46: Products that use organic design (Bürdek 2005)

Visual practical functions highlight the functionality of a product (Bürdek 2005). The products in Figure 47 show (clockwise, from top left) a power screwdriver highlighting orientation, the iMac computer showing an interface function, a CD player showing precision, a window cleaner showing orientation to the

human body, an electric toothbrush showing operation, garden shears showing changeability, and an office table that shows stability.



Figure 47: Visual practical functions in products (Bürdek 2005)

In summary, industrial design is concerned with the creation of products that are manufactured with industrial processes. The industrial designer focuses on the form, usability and identity of a product by employing the use of visual design representations to externalise and communicate ideas with the client. The next section discusses aspects of engineering design.

### **3.3 Engineering Design**

Engineering design in its simplest form has been considered as a problem solving process (Hurst 1999). Fielden (1963) defined engineering design as ‘the use of scientific principles, technical information and imagination to define the mechanical structure, machine or system to perform specified functions with maximum economy and efficiency’. Another formal definition has been provided by the Accreditation Board for Engineering and Technology (ABET) who stated that it is an activity involving the ‘devising of a system, component, or process to meet desired needs through iterative decision-making where science, mathematics, and engineering are applied to convert resources optimally to meet objectives (Crosby 1979).

In new product development, both engineering design and industrial design work in parallel, with engineering design focusing on the product functions and its production (Kimura 1997; Persson 2005b). The process of engineering design follows a series of steps that include problem definition, conceptualisation, embodiment, and detail design (Shigley and Mischke 1989; Pahl and Beitz 1996; Ullman 2003). The engineering design process is identical to the proposed product development process (Section 2.5) that comprises concept design, concept development, embodiment design and detail design.

Engineering design began primarily as a military activity until new technologies grew and divided the discipline into segments (Ledsome 2006). It is different from other engineering disciplines because it is not required for them to create artefacts but to produce only a detailed description of a design proposal for manufacture (Dym and Little 2003). In addition, engineering design is a trans-disciplinary group possessing the knowledge of traditional, mechanical, electrical and electronic engineering which combines the fields of science, mathematics, social sciences and humanities (Burghardt 1999).

For this research, in line with Hurst (1999), engineering design is referred as the technical activities that establish and define solutions to problems through applying scientific knowledge and to ensure that the product satisfies the market needs, design specifications and is produced through optimum manufacture

### **3.3.1 Concurrent Engineering**

Concurrent engineering started in America in the early 1980s where the Defence Advanced Research Projects Agency (DARPA) began a study to improve concurrency in the design process. It was later called 'concurrent engineering' and referred to the systematic method of product and process design (Syan and Menon 1994). Up to the early 80s, design and manufacture was considered a sequential process where production teams became involved only when the product engineering was complete (Lorenz 1986).

When an error was discovered during the later stages, changes were costly and time-consuming to rectify. When companies demanded products to be produced more cheaply and quickly, it required both design and production teams to work in tandem during the development process (Dominick *et al.* 2001). This is the use of concurrent engineering and is considered as a key initiative required of a world-class manufacturer (Miller 1993). The term 'concurrent engineering' has also been known as 'simultaneous engineering' or 'synchronous engineering'. Other similar terms used are found in Figure 48.

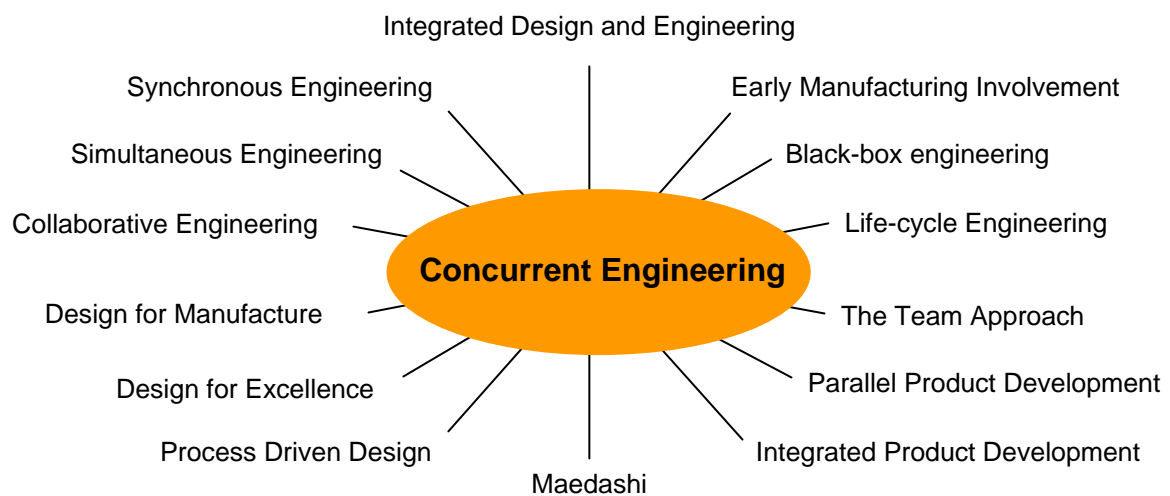


Figure 48: Other terms used for concurrent engineering (Trygg 1993b)

In describing how concurrent engineering works, Rosenthal (1992) used the analogy of a relay race similar to a sequential approach where the runner passes his baton to the next person. If a delay occurs at any point, the entire race is affected. Simultaneous engineering on the other hand, is comparable to a game of rugby where the ball is repeatedly passed around, requiring team effort and constant interaction at all times. Therefore, concurrent engineering requires teamwork, information sharing, and timely decision-making. The multi-disciplinary members must work together collectively and concurrently (Hague *et al.* 2002; Klein *et al.* 2003). A close link between them ensures that they can perform their work in parallel and with a heavy emphasis on interpersonal and intra-team communication and coordination (Fleischer and Liker 1997). Trygg (1993a) also acknowledged that early concurrent engineering developments were aimed at improving quality or minimising



product acquisition costs, whereas more recent programmes have emphasised reductions in product development time.

By bringing multi-disciplinary teams together, concurrent engineering aims to get the design correct at the start and to reduce downstream difficulties in the workflow (Erhorn and Stark 1994; Paashuis 1997). However, despite the fact that teamwork is important, Rosenthal (1992) highlighted that there is no assurance that members are able to work well together. Huang (1996) proposed that to achieve successful teams in concurrent engineering, there needs to be organisation and management support, use of efficient methods and application of effective information transferring systems as summarised in Figure 49.

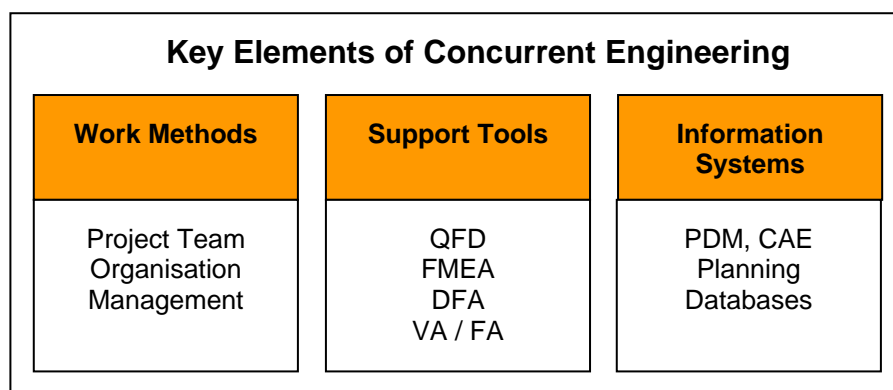


Figure 49: Key elements of concurrent engineering (Huang 1996)

### 3.3.2 Working Approaches of Engineering Designers

The work of engineering designers centres on problem defining and solution gathering activities supported by other specialist engineers. Holt, Radcliffe *et al.* (1985) identified two distinct interpretations of engineering design: the problem solving approach that seeks to solve well-structured problems through formal techniques based on “hard” systems thinking; and the creative approach that combines analytical and systems thinking with human factors. A hard approach is useful when a ‘need’ is given, while a soft approach allows for creative and unexpected answers.

The work of engineering designers start as images in the mind which are communicated visually with use of engineering graphics taking the form of technical sketches or calculations (Lueptow 2000). Although they may also use sketching, their focus is towards the functional, assembly or production aspects of the product rather than the aesthetic outlook that industrial designers focus on. In addition, drafting and 3D CAD modelling such as the assembly drawing in Figure 50 constitutes the main job for most engineering designers (Ullman *et al.* 1990). Both industrial designers and engineering designers use representations to better understand the problem and to communicate with others (Burghardt 1999). However representations made by engineering designers tend to involve calculations, technical data and are usually very precise.

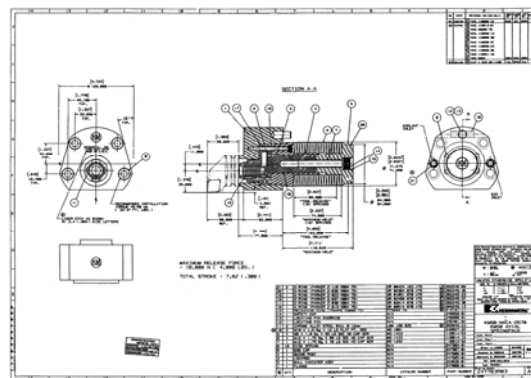


Figure 50: Multi-view assembly drawing of a spring pack (Bertoline 2002)

Engineering designers work by first defining the problem, after which they then accumulate more data and verify its accuracy. At this point, the working approach may be viewed as being similar to that of industrial designers where design problems are usually ill-structured and open ended. Solutions through the use of mathematical formulae are usually also inapplicable during these early stages of the design process (Dym and Little 2003). After the facts have been verified, an appropriate theory or principle is then selected that may possibly assist towards problem solving (Crosby 1979). The engineering design process is also highly networked with different partners including subcontractors, manufacturers, toolmakers and other engineering specialists (Rouibah and Caskey 2003).

### 3.4 Differences between Industrial Designers & Engineering Designers

Although both industrial design and engineering design are concerned with the creation of man-made objects (Tovey 1989), there are also major differences between them. Industrial design is concerned with user-related aspects such as product appearance, yet engineering design is concerned with the structure, function and manufacture of the product (Oakley 1990; Wikström 2001; Kim *et al.* 2006). Cagan and Vogel (2002) suggested that these differences arise due to perceptual gaps or differences in perspective and arise because industrial designers are visual thinkers concerned with aesthetics, whereas engineering designers think in terms of function and cost. Figure 51 shows a sketch by an industrial designer as compared to Figure 52 showing a technical drawing drawn by an engineering designer showing the manufacturing details of the same product.

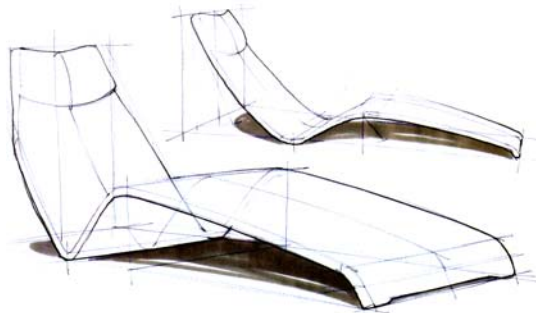


Figure 51: A concept sketch by an industrial designer (Eissen and Steur 2008)

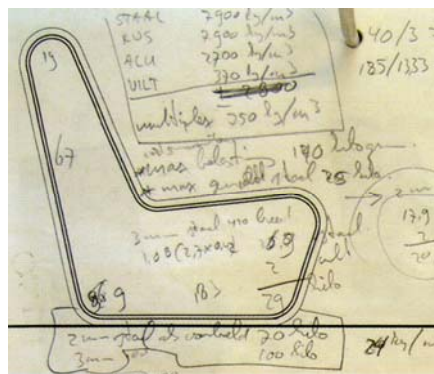


Figure 52: A technical diagram by an engineering designer (Eissen and Steur 2008)

If several engineers did a mathematical calculation, all of them would obtain the same answer. However, if industrial designers were asked to design a certain product, not all of them would come up with similar solutions (Eekels 1994). In terms of deliverables, Persson (2002b) revealed that engineering designers tend to use 2D technical drawings and preferred a formal approach, whereas industrial designers create 3D renderings or other visual representations to explain a theme or an idea. These 'soft' representations may be inaccurate, ambiguous and difficult for engineering designers to understand how they work in relation to the technical aspects of the product.

When solving problems, engineering designers prefer to work out the details, whereas industrial designers approach problems in a holistic manner (Purcell and Gero 1996). In addition, engineering designers tend to select a single solution, whereas industrial designers prefer to suggest several proposals (Muller 2001). This is clearly presented as an illustration in Figure 53 that shows engineering designers have limited but specialist skills, whereas industrial designers possess a large range of skills (Lofthouse and Bhamra 2000).

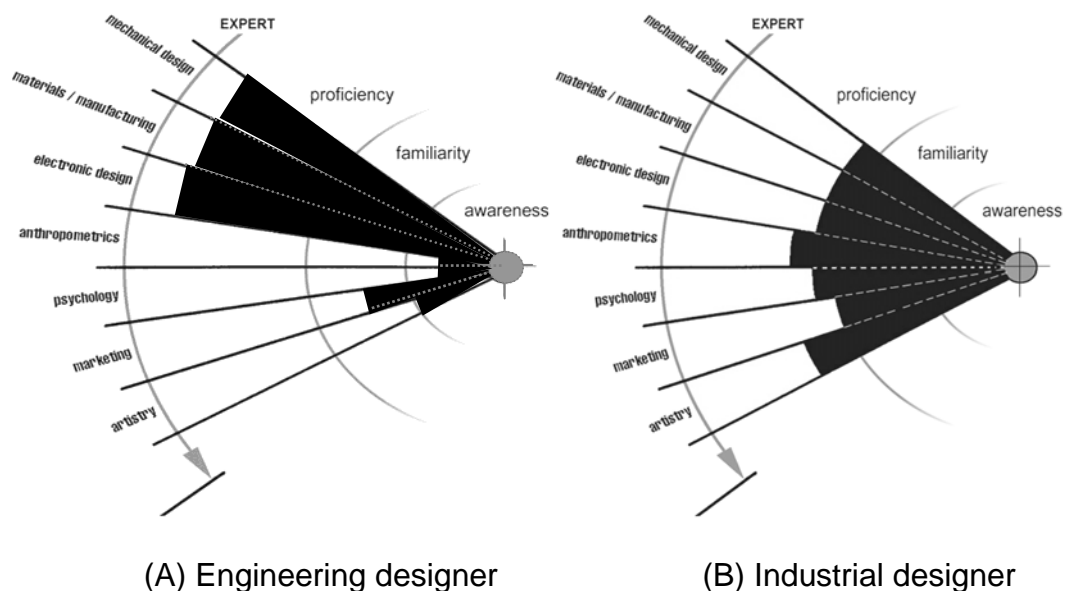


Figure 53: Skills of the (A). engineering designer and (B) industrial engineer (Lofthouse and Bhamra 2000)

Another key difference is the 'object world' of members. It was termed by Bucciarelli (1988) who described it as a domain of thought containing the individual beliefs, interests, knowledge and experiences, as well as the methods and techniques used; all of which are built from education and shaped through professional experience.

As members in a multi-disciplinary team have different object worlds, understanding each other and seeing the product in the same way may be difficult (Bucciarelli 1994; Bucciarelli 1999; Kalay 2002; Kleinsmann *et al.* 2005). Object worlds have their own unique language, codes and rules (Schön 1963). For example, a structural engineer speaks of load stress and strain, whereas an electronics engineer speaks about power, voltage and current (Bucciarelli 2002). Yet another example of an object world barrier occurs when an engineering designer cannot interpret information from an industrial designer's sketch. It highlights a communication problem between the two disciplines (Kleinsmann and Valkenburg 2003). These differing 'viewpoints' can be resolved through negotiations (Détienne *et al.* 2005). Members must be able to communicate, negotiate, and compromise which is the aim of the next section concerning design management.

### **3.5 Chapter Summary**

In this chapter, several interpretations have been offered to define industrial design and engineering design. While both are concerned with the creation of man-made objects, there are also a number of differences between them in terms of perceptual gap, their contribution towards the design process, their problem solving approach and dissimilarities in their worldview. It is intended that this chapter has provided a clear definition of the two disciplines prior to a continued discussion in the context of design collaboration. The next chapter looks at the concept of teamwork, following which the aspects of communication, participation, coordination and communication are discussed.

## **4. MANAGING DESIGN**

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### **4.1 Chapter Overview**

The previous chapter introduced the disciplines of industrial design and engineering design, highlighting key differences between them. In new product development, these disciplines must work together to improve the company's competitive advantage with better designed products. According to Bruce and Bessant (1995), having an efficiently managed design process is key to product success and it 'fuels new levels of interaction between design and other stakeholders involved in new product development'. The aim of this chapter is to provide an understanding on the concept of teamwork and to clarify the terminologies used regarding the phenomenon of people working together (coordination, cooperation, integration, interaction and collaboration). The chapter also brings to attention the key topic of collaboration which is central to this research and discusses factors and solutions that influence collaborative work.

### **4.2 Multi-disciplinary Teams**

A team is defined as a group of people associated together at work or through activities (Merriam-Webster Dictionary 1994). Bucciarelli (1994) described designing in a team as a social process between members with complementary skills. For product development to become effective, each discipline must bring their knowledge to the group and develop the best definition of the product (Cagan and Vogel 2002). Teams allow sharing of discipline-specific knowledge and members benefit from cross-fertilised ideas (Best 2006). However, as members have different backgrounds, interests and expertise, it is important that they remain unified towards the project objectives (Thamhain 1990). Another key element that keeps members together is the presence of trust (Dyer 1995). An example where teams have been used successfully is evident in the development of the Boeing 777 aircraft. The company chose the project name "working together" to create

awareness and to reflect on the open and good communication policy among the 10,000 employees involved (Swink *et al.* 1996).

A team may consist of individuals working interdependently in their tasks and sharing joint responsibility for outcomes and they may see themselves as a wholesome social entity (Cohen and Bailey 1997). Several authors have provided different names for design teams such as multi-disciplinary design teams (Denton 1997) and cross-functional design teams (Griffin and Hauser 1996a) that are used when members of a team come from different backgrounds. The term 'multi-disciplinary' is used when the origin of the members is not taken into account. They are 'a group of people who apply different skills with a high degree of interdependence, to ensure the effective delivery of a common organisational objective' (Holland *et al.* 2000); while 'cross-functional' refers to the fact that members originally come from different functional areas (or departments) within the organisation (Kleinsmann 2006). A multi-disciplinary team consists of members from different departments and / or disciplines being brought together under one manager to make development decisions (Ancona and Caldwell 1992). For this research, the term 'multi-disciplinary team' shall be used throughout this thesis

In comparing differences between multi-disciplinary teams and conventional teams, Denison *et al.* (1996) cited that multi-disciplinary teams are often temporary and have competing social identities and loyalties whereby members tend to associate themselves with their function rather than the organisation unit. Despite their differences, both multi-disciplinary teams and conventional teams work towards goals, seek improved performance at work and build relationships with others (Montoya *et al.* 2009). While having a variety of members from different backgrounds and with different education may be an advantage, it also increases the occurrence of conflict (Joshi *et al.* 2002). Reasons for conflict may be due to individual differences, opposing interests, disagreements or incompatibilities (Rahim 1992). While too much disagreement may disintegrate a group, too little conflict may lead to

stagnancy and groupthink. Other reasons for team failure include mismatched members, incompatible goals, bad decision making and poor leadership (Castka *et al.* 2001). Poorly managed teams result in ill-feelings, misunderstanding, communication failure and low morale (Blake *et al.* 1964). The tables below show the sources of conflict (Table 11) and the four general levels (Table 12) as proposed by Rahim (1992).

Type of Conflict	Description
Affective conflict / Psychological conflict	Occurs when feelings and emotions regarding issues are incompatible
Conflict of Interest	Occurs when members seek different and incompatible solutions
Conflict of Values / Ideological conflict	Occurs when members have different values or ideologies
Cognitive Conflict	Occurs when members have different perceptions or judgement
Substantive Conflict	Occurs when members disagree on their task or content issues
Issue Conflict	Occurs when members disagree about the facts in a case
Retributive Conflict	Occurs when members seek a drawn-out conflict to penalise the opponent
Misattributed Conflict	Occurs when there has been an incorrect assignment of cause to the conflict (behaviours, parties or issues)
Displaced Conflict	Occurs when members direct their frustrations to non-members

Table 11: Sources of Conflict (Rahim 1992)



Level of Conflict	Description	Resolution
Intra-personal or intra-individual conflict	Occurs when tasks or roles do not match members' expertise, interests, goals or values	Assigning a task according to one's expectations, position and personality, role analysis and job redesign
Inter-personal conflict / dyadic conflict	Occurs when there is an incompatibility, disagreement, or difference between members	Techniques include integrating, obliging, dominating, avoiding and compromising
Intra-group conflict / intra-departmental conflict	Occurs when there are incompatibilities or disagreements among members or subgroups regarding goals, functions or activities	Techniques include teambuilding, changing the group composition or size, bringing new members, restructuring tasks, altering the reward system and rules
Inter-group conflict / inter-departmental conflict	Occurs between two or more groups or departments within an organisation in connection with tasks, resources or information	Techniques improving staff relationship, transferring members, clarifying rules, altering the communication and providing accurate information

Table 12: Levels of Conflict (Rahim 1992)

In resolving conflicts, Dym and Little (2003) proposed five basic strategies including avoidance, smoothing, forcing, compromising and constructive engagement. It is also important that individuals are inspired, empowered, given respect and trust so that the group will be able to perform well. In addition, formal agreements on roles or having concordance allow members to be aware of what is happening and what is expected (Pawar *et al.* 1999). This workspace awareness further helps towards coordination and in managing the process that increases efficiency and reduces errors in teamwork (Clark and Brennan 1991; Tang 1991a; Tatar *et al.* 1991). Hauptman and Hirji (1999) also found that group rewards, job rotation, use of

information technology and empowered project leaders had enhanced key attributes of the team process and were linked to successful project outcomes. However, Menon *et al.* (1996) argued that not all conflict is harmful and they viewed functional conflict to be beneficial; and dysfunctional conflict harmful. Functional conflict comprises of healthy and vigorous challenging of ideas where stakeholders are willing to consider suggestions. In contrast, dysfunctional conflict hurts stakeholders and creates distrust by distorting and withholding information.

Teamwork is not only limited to technical problem-solving, but also involves communication between members (Bucciarelli 1988). The topic of communication is a fundamental aspect in teamwork and is discussed in the next section.

### **4.3 Communication**

Communication is the exchange of information between individuals (Bstieler 2006). According to Wiio (1973), the purpose of communication is to transfer information between members or groups and to seek the perspectives of others. For communication to be effective, it needs to be open, structured, clear and accessible (Pinto and Pinto 1990).

Successful teamwork is closely linked to the content and quality of communication (Mohr and Spekman 1994). It requires both sender and receiver to have the same meaning of the message (Gudykunst 1998) and necessitates members to select the most appropriate medium with an optimal amount of information (Daft and Lengel 1986). While too little communication causes misunderstanding, too much communication means members have to spend time sorting the data leading to counter-productiveness (Goodman *et al.* 1986; Boisot 1995; Hutchins 1995). Having a common language would also reduce misunderstanding and provide more efficient communication among members (Hardin and Higgins 1996; Carlson and Zmud 1999; Finger *et al.* 2006).

Communication may take the form of audio, visual or text (Tavcar *et al.* 2005) and some common representations include sketches and models that physically describe the design that are discussed in Chapter 6. It has been acknowledged that face-to-face meetings supported with speech, sketches and gestures represent the most effective way for members to develop shared understanding (Table 13) (Scrivener *et al.* 2000).

Type of Communication Support	Description
Sketching	Making marks on paper
Figural gesturing	Gestures in the air clearly meant to depict shape and / or motion
Figural pointing	Traces and / or points around a sketch without making marks on the page.

Table 13: Types of communication support (Scrivener *et al.* 2000)

Earlier studies by Bly (1988b) and Minneman and Harrison (1997) also confirmed the importance of gestures in face-to-face meetings that contributed towards successful collaboration. Hand gestures are used to convey meaning and clarify subjects such as pointing to locations, using the gesture to suggest a form or a mechanism, experiencing an object through manipulation, or acting with an object to suggest its use (Harrison and Minneman 1991). Another popular method for visual communication is the use of mood boards that support discussion with non-designers (Kosslyn and Storer 2006). Other communicative methods include meetings, phone calls, e-mails, forms and reports (Adler 1995). Table 14 by Ulrich and Eppinger (2003) lists types of communication ranked in order of increasing richness of information.

	Communication Type	Description
Increasing Richness of Information Conveyed ↓	Verbal description	A short paragraph summarising the product concept is verbally read out
	Sketch	Marks on paper showing the product in perspective
	Photos and renderings	Photos show pictures of appearance models of the product concept. Renderings are realistic illustrations achieved by marker or CAD tools
	Storyboard	Images showing a series of actions involving the product
	Video	A way of showing the product captured in motion
	Simulation	Use of software to show the function or interactive features of a product
	Interactive multimedia	Combination of interactive visual and audio sources to show the product function or features
	Physical appearance models	A non-working artefact displaying the appearance of a product
	Working prototypes	Working artefacts that display the function and appearance of a product

Table 14: Ways whereby a design concept can be communicated (Ulrich and Eppinger 2003)

Communication breakdown occurs when the received meaning does not match the original intention of the sender (Fischer *et al.* 1995). This could be due to physical disturbance from outdoor noise; semantic disturbance such as language difference; or psychological disturbance such as personal attitude (Nilsson and Waldemarson 1990). In addition, communication quality drops when physical distance increases (Moenaert *et al.* 1994b). Misunderstandings also arise when the norms and rules of people from different groups are not understood (Gudykunst 1998). Other factors affecting communication include language and culture, gender, personality, individual values, attitudes and stereotyping (ibid). For example, in terms of gender, women see questions as a way of keeping a conversation going, whereas men view questions as a way to obtain information (Beck 1988). In terms of culture, the Japanese prefer to

communicate more within their own groups, whereas Americans communicate more openly (Gudykunst and Hammer 1988). These differences should be recognised so that individuals are able to understand the perspectives of others in order to improve the quality of communication.

Chiu (2002) summarised four elements involved in communication (Table 15). First, the choice of media affects how the communication is to be transmitted. Second, the semantic aspect relates how the transmitted information can retain its original meaning without interference. Third, the performance of communication is associated with receiving messages effectively. Finally, in terms of organisation, communication needs to be sent to the right person through good distribution.

Communicative elements in Collaborative Design			
Media	Semantics	Performance	Organisation

Table 15: Communicative elements in Collaborative Design (Chiu 2002)

In conclusion, although miscommunication cannot be eliminated, it can be well-managed through communication strategies and support. The next section examines the areas of coordination and cooperation.

#### **4.4 Coordination and Cooperation**

The previous chapters discussed how concurrent engineering brings activities together in parallel. Design coordination takes a step further by incorporating planning, scheduling, representing, decision-making and information control with respect to time, tasks and resources (Duffy *et al.* 1993). According to the dictionary, coordination refers to how people or things are organised so that they work harmoniously together (Merriam-Webster Dictionary 1994). Coordination integrates and links various stakeholders so as to accomplish

tasks through the use of rules and procedures (Van de Ven *et al.* 1976; Coates *et al.* 2000).

To cooperate means to work jointly with another so as to achieve something that both parties want (Longman Dictionary 2005). Cooperation requires the pooling of resources so that objectives can be attained (Maranzana *et al.* 2007). Cooperation has been defined by Johnson (1975) as 'coordinating behaviour among individuals to achieve mutual goals' and is linked to the success of new product development (Eisenhardt and Tabrizi 1995; Griffin and Hauser 1996a; Jassawalla and Sashittal 1998). Similarly, Anderson and Narus (1990) stated that the key objective of cooperation is to help other members and it involves coordinated actions that are complementary. According to Kim and Kang (2008), successful multi-disciplinary cooperation is a key factor that helps achieve high performance in new product development.

In differentiating cooperation and coordination, the former requires shared goals and relies on the participants' attitudes; whereas coordination only links stakeholders together (Boujut and Laureillard 2002). It is also important to acknowledge that new product development requires both cooperation and coordination to be in place within the organisation so as to achieve an integrated development process.

#### **4.5 *An Integrated Development Process***

In the traditional sequential environment, activities were prone to problems due to insufficient communication across departments (Erhorn and Stark 1994). This has been superseded with the concept of integration and the use of digital infrastructure that allows various departments to cooperate together in maximising their contribution and to develop products faster and cheaper (Griffin and Hauser 1996b; Pisano 1997). An integrated development process is a highly systematic activity performed by a multi-disciplinary team (Hoegl *et al.* 2004; Buijs and Valkenburg 2005). Members have strong

‘interdepartmental connection’ where there is a presence of formal and informal direct contact among members across departments (Kohli and Jaworski 1990; Tjosvold 1990).

Integration forms, coordinates and blends people or objects into a functioning whole, incorporating them into a larger unit (Souder 1987). This requires shared values, mutual goals and collaborative behaviours (ibid). For this to take place, it is essential to have good communication, coordination and cooperation (Pinto and Pinto 1990). Without integration, each department would have deviating goals and fragmented tasks that would reduce efficiency Persson and Warell (2003c).

Concurrent engineering, integrated product development, integrated design and engineering and life-cycle engineering are all synonymous with the concept of integration as a pillar for product success (Paashuis 1997). Through sharing goals and obtaining information early, departments can plan for contingencies and minimise downstream issues. In addition, studies by Clark and Fujimoto (1991) and Brown and Eisenhardt (1995a) showed that integrated teams are better able to understand technical constraints and seek joint opportunities. Although the departments may be integrated, they still retain their individual orientations and functional specialisations. Despite these advantages, integration introduces conflict as individuals can have dissimilar orientations, goals and values (Parry and Song 1993), whereby the main difficulties and problems in integration are usually related to managing people and their roles and responsibilities (Paashuis 1997). Integration has also been hampered by distinct ‘worlds’ where members of each discipline have different views of each other (Dougherty 1992a). Therefore, for integration to be effective, perceptual gaps among departments must be closed (Cagan and Vogel 2002). According to Vajna and Burchardt (1998), an integrated product development brings together human factors that comprise of planning and organising, technical support, and procedures and methods, which are in turn

united by the workplace environment such as infrastructure, location and the physical environment (Figure 54).

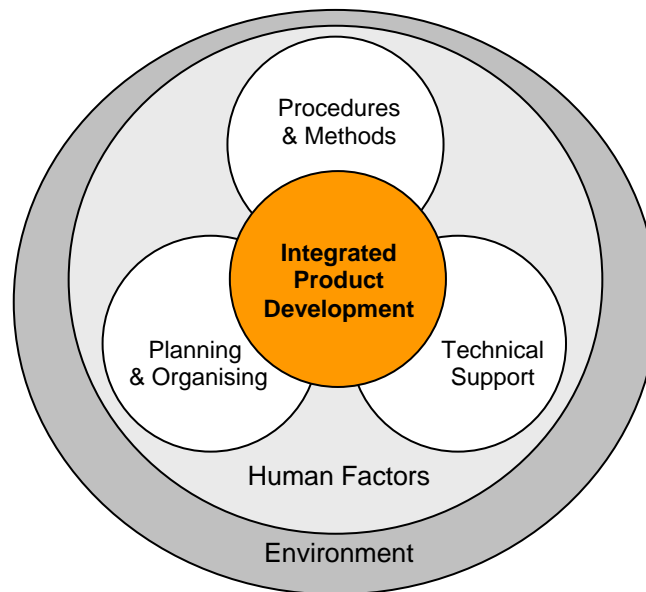


Figure 54: Elements of an integrated product development (Vajna and Burchardt 1998)

Paashuis (1997) identified seven influential factors in integrated product development. Firstly, the team should possess healthy interaction and good formal and informal communication. Secondly, management affects the way roles and activities are integrated. Members of staff are empowered to act on events and the management takes on a supporting and guiding role. Thirdly, there should be formal procedures to structure and discipline the responsibilities and interaction among members which may be in the form of stage-gate tools. Fourthly, roles, responsibilities and authorities need to be clear through guidelines and having coordinated tasks. Fifthly, there may be members who might resist change and resist integrative efforts. Next, creativity within the group might be affected when there are over-stringent standards (Maddux and Souder 1993). Lastly, inadequate rewards may lead to poor performance because members become individualistic (Clark and Wheelwright 1992). The next section discusses the concept of integrating mechanisms that enable the process of bringing people together successfully.



#### 4.5.1 Integrating Mechanisms

Research has shown that integrating mechanisms are key pillars for effective product development (Song *et al.* 1997). They enable, facilitate and improve collaboration and communication between members in terms of physical, psychological and organisational benefits (Norrgrén 1992). Some examples of multi-disciplinary integration that have been employed by organisations include co-location, joint physical infrastructure, informal socialisation, job rotation, structured teams and through good leadership (Lawson *et al.* 2009).

Co-locating different members fosters more frequent interaction, breaking down functional barriers between them (Kahn and McDonough III 1997). However, research by Moenaert and Caeldries (1996) provided evidence that locating members closely did not actually increase the quantity of design, but only improved the quality of communication. Instead, the key benefit of co-location actually allows for informal socialisation to take place so that information can be easily shared (Persson and Räisänen 2005). However, informal networks may not work when established information and communication structures are already in place (Leenders and Wierenga 2002). Job rotation increases interaction and improves knowledge transfer. However, members should not be moved frequently as it would prevent building up job knowledge (Moenaert *et al.* 1994a). In terms of leadership, managers should be trained to coordinate with a diverse group of members. They may take on an internal integrator role to resolve differences between individuals or as an external integrator to link members with the management (Brown and Eisenhardt 1995b). Project leaders also help to interpret management concerns and to facilitate discussion among members (Sicotte and Langley 2000).

Other mechanisms proposed by Paashuis (1997) include managing the flow of information, clarifying responsibilities, utilising technological support, employing rewards and incentives, and the involvement of stakeholders. However, Song *et al.* (1998) highlighted that randomly involving all departments during every stage of the design process actually lowers the

performance of new product development; and instead, a more effective involvement may be obtained when function-specific and stage-specific approaches of multi-disciplinary integration are used.

Another integrating mechanism is to use incentives to stimulate performance. However other research showed that when members are unequally rewarded, it may result in undesired behaviours (Thamhain 1990; Griffin and Hauser 1993; Song *et al.* 1997). Other researchers advocated the use of standardisation as an integrating mechanism to establish procedures and outputs, as well as to plan and relay information effectively so that actions may be made known in advance (Nihtila 1999). Nevertheless, Daft and Lengel (1986) argued that although formal rules and information technologies may be important, it is only through rich media such as face-to-face meetings and personal contact that provide first-hand opportunities for members to build understanding and forge relationships. Other factors such as openness, harmony and trust are also conducive elements for integration between multi-disciplinary members (Phelps 1977).

The use of stage-gate aims to synchronise activities and to provide clear steps for each development phase (Cooper 1994). By integrating members early, it minimises downstream issues and reduces rework. The review of each phase verifies the tasks that have been completed which in turn reduces uncertainty. Another integrative method is the concept of a shared information space where members store, manage and retrieve information that would support the needs of joint groups (Sharrock and Anderson 1996; Davis *et al.* 2001). It is similar to the use of collaborative workspaces suggested by Persson (2005b) as a virtual environment that allows learning and building of a joint mindset.

Integration mechanisms should be made and implemented with respect to the company's operations, technologies, people and resources, ensuring that they are applied based on the capacities and capabilities of the company; and ensuring the mechanisms are constantly being reviewed and monitored (Paashuis 1997). Fleischer and Liker (1997) suggested three other factors

that determine the amount of integration required. Firstly, task interdependence establishes the degree to which a member is reliant on another individual for information or material to complete his or her task. Secondly, the degree of task and environmental uncertainty determines the level of clarification or standardisation required for procedures. Thirdly, physical, organisational and cultural distances also influence the amount of coordination required.

Several studies in the literature (Beardsley 1994; Turner 2000; Young *et al.* 2000; Bohemia 2002) have described the industrial designer as an integrator who is able to view problems from a holistic and specialist perspective, capable of visualising the overall product and managing each separate detail to coordinate different aspects of the product. In addition, their multi-disciplinary educational background provides them with an understanding of the various stakeholders and allows them to coordinate and bring members together (Walsh and Roy 1985; Boujut and Laurillard 2002).

Formalisation has also been used as an integrative mechanism and it refers to organisational rules, procedures, and instructions that are written and enforced (Aiken and Hage 1966). When members follow operating procedures and use a similar language, vocabulary differences are reduced. In addition, formal procedures minimise barriers, limit conflicts and reduce differences in thought-worlds (Maltz and Kohli 2000). Formalising and structuring information allows better control towards searching, storing, retrieving, transferring, representing and interpreting information (Lutters *et al.* 2000). Despite the fact that procedures help teams to achieve better work performance (Austin *et al.* 2001a), care must be taken to ensure that high formalisation does not discourage new ideas and innovative behaviour (Darmanpour 1991).

Integration technologies can be grouped into hardware, software and knowledge and skills. Firstly, software technologies include the use of CAD and information management systems to facilitate processes. For hardware technologies, it includes the use of computer and communication links to

support information transfer between people. Human knowledge and skills include familiarity and with experience of technical and social aspects of decision-making and project management (Paashuis 1997). The aspect of information and communication technologies is continued in the next section.

#### **4.5.2 ICT Mechanisms and CSCW Tools**

While mechanisms such as job rotation and co-location require changes to the workspace, the use of Information and Communication Technologies (ICT) does not alter the physical environment but still facilitates socialisation and externalisation among members (Leenders and Wierenga 2002). These mechanisms include e-mail, intranet and tele-conferencing that aim to provide faster and more effective ways of information transfer, management and storage.

Technologies incorporating Computer-Supported Cooperative Work (CSCW) provide tele-presence or tele-data for communication between members (Peng 1994; Schmidt 1998). Examples include a web-based collaborative system proposed by Sprow (1992) allows multimedia-based communication among members, as well as the development of a virtual design studio that enables the sharing of information synchronously or asynchronously while being apart (Kvan 2000).

In education, Bohemia and Harman (2008) proposed the creation of a 'Global Studio' as part of a design course across higher education institutions whereby industrial design students and students of other disciplines are able to collaboratively work together in a global context using online technologies.

Nam and Wright (2001) categorised three classes of CSCW tools that encompass document editing systems, collaborative drawing systems and collaborative 3D visualisation systems. Group document-editing programmes include CSpray (Pang and Wittenbrink 1997), ShrEdit (McGuffin and Olson 1992), SASSE (Baecker *et al.* 1994) and Duplex (Pacull *et al.* 1994).

Collaborative multi-user drawing systems include GroupSketch (Greenberf *et al.* 1995), ROCOCO station (Scrivener *et al.* 1993) and Wscrawl (Wilson 1995). Collaborative 3D CAD tools include Shared 3D Viewer (Hewlett-Packard 2000), OpenSpace (IMData 2000), and Co-CAD (Gisi and Sacchi 1994) that support real-time modelling simultaneously between two users.

Despite the development of these tools, Roller *et al.* (2002) stressed that they do not typically support the entire development process. In addition, most of them are not commercially available or are still under development with technical issues (Huang and Mak 1999; Nam and Wright 2001). The next section brings this research to a new level by discussing the topic of design collaboration and highlighting factors that influence industrial design and engineering design collaboration during new product development.

#### **4.6 Collaboration in Design**

In the traditional design approach, tasks executed in a sequential manner often require numerous iterations. It creates a time consuming and inflexible development effort that results in an inefficient design. Collaborative product development aims for a more organised process by bringing members together to consider constraints and detect conflicts early (Sprow 1992). According to Kleinsmann (2006), collaborative design, also known as co-design, is defined as a process where members of different disciplines share their knowledge about the design process and the design content, so as to create shared understanding, integrate their knowledge and to achieve a common objective of creating a well-designed product

In the context of new product development, British industrial designer James Dyson acknowledged that bridging the gap between engineering design and industrial design would help achieve a balance between aesthetics and functionality in products (Palmer 2006). An example of a successful collaboration is shown in the Trek Y-Bike (Figure 55) where aesthetics, materials, geometry, form, engineering and manufacture have been beautifully combined into a coherent product (Figure 56, 57). In this project, the industrial

designer has ensured that the form complements the structure rather than just a styling exercise (Buxton 2007).

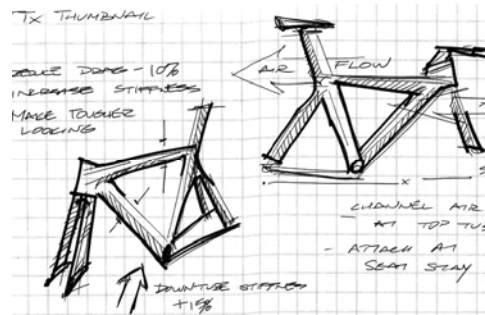


Figure 55: Industrial design sketch of Trek's Y-Bike (Buxton 2007)



Figure 56: Engineering prototype of the Y-Bike (Buxton 2007)



Figure 57: Final design of the Y-Bike (Buxton 2007)

Collaboration on a larger scale can be seen in the successful Nokia 7600 mobile phone project (Figure 58) that encompassed the joint work of several departments from the phone design to packaging, visuals, materials, service applications and retail strategies (Chauhan 2004).



Figure 58: The Nokia 7600 phone

Garner (2004) proposed that products requiring more aesthetic quality involved greater industrial design involvement, whilst mechanical products such as machine tools entailed more engineering design input (Figure 59). As over-engineered products may be unattractive and difficult to use, and over-styled products are unreliable and hard to maintain. It is therefore important for industrial designers and engineering designers to strike a balance between aesthetics and functionality so as to achieve well-designed products.

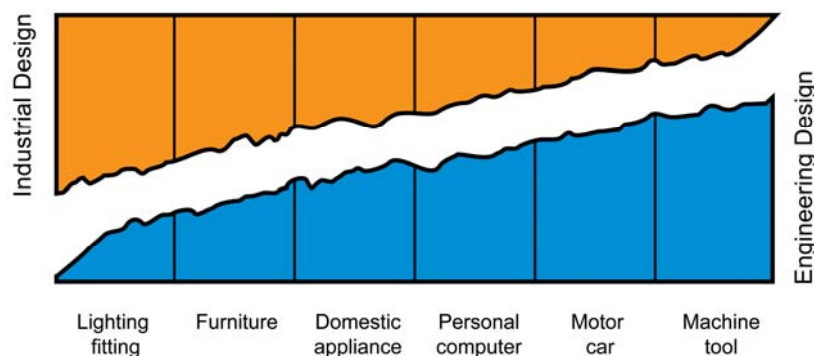


Figure 59: Contributions of engineering design and industrial design in different kinds of products (Garner 2004)

Collaboration simply means to work jointly with others (Merriam-Webster Dictionary 1994). In this research, collaboration is defined as a process whereby members of different disciplines work together with a common vision to achieve joint goals (Kahn 1996b; Tseng and Abdalla 2006). By leveraging on the expertise and experience of multi-disciplinary members, collaboration lowers development expenditure and improves the quality of output (Rothstein 2002). This is summed up by Li et al. (2009) who defined collaborative and multi-disciplinary design as a process that utilises the 'synergy of mutually

interacting disciplinary expertise' which optimises the product development process. Collaboration occurs in nature such as shoals of fish swimming in a synchronised manner. Their common aim allows them to behave like a single entity, making collective decisions based on swarm intelligence to feed, mate or to avoid predators. Other examples of animals and insects working as a team for the benefit of the colony include ants, termites, honey bees and the flocking of birds.

Collaboration can be classified as predetermined and unexpected collaboration (Girard and Robin 2006); or free, encouraged and forced collaboration (Tannenbaum and Schmidt 1973) which are shown in Table 16.

Category	Description
Predetermined collaboration	It is planned and incorporated into the design process, by synchronising activities and resources, thereby building trust (Girard and Robin 2006).
Unexpected collaboration	Occurs during unplanned activities whereby collaboration happens spontaneously among members (Girard and Robin 2006).
Free collaboration	It refers to unrestricted communication that includes unplanned help from other members (Tannenbaum and Schmidt 1973).
Encouraged collaboration	A limited form of collaboration where members may only contribute to certain aspects identified by the manager (Tannenbaum and Schmidt 1973).
Forced collaboration	Members are appointed to specific groups and have collaboration with designated members (Tannenbaum and Schmidt 1973).

Table 16: Categories of collaboration

Multi-disciplinary collaboration is a key aspect towards successful product development (Lawson *et al.* 2009). It requires stakeholders to focus on objectives, have no hidden agendas and accept differences between themselves. It requires cooperation, communication and interaction. In comparison to interaction, collaborative activities signify a stronger connection between members (Persson and Warell 2003c), whereas interaction is limited



to information exchange without socialisation and it alone is insufficient for product success. Collaboration encompasses mutual sharing, understanding, having a common vision, achieving collective goals and a willingness to work together (Kahn and McDonough III 1997)

While Jassawalla and Sashittal (1998) pointed out that higher levels of integration do not translate to greater collaboration, Kahn (1996a) instead argued that interaction and collaboration together achieves interdepartmental integration leading to performance in the development process (Figure 60).

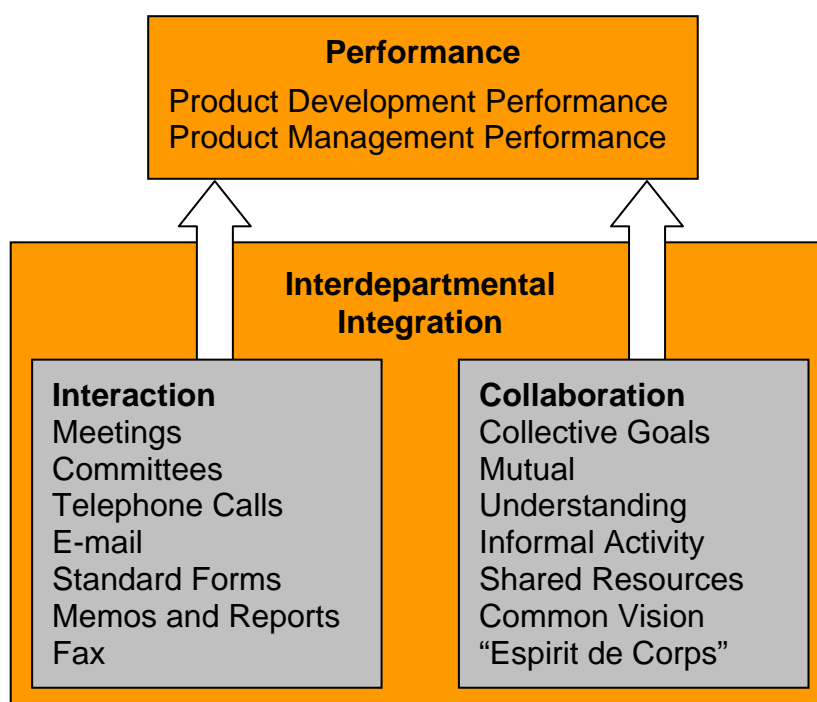


Figure 60: The process of interdepartmental integration

In differentiating key terms, cooperation focuses on working together whereas collaboration is aimed at joint work (Maranzana *et al.* 2007). In the aspect of communication, having more collaboration boosts communication flow, but more communication does not necessarily enhance collaboration since collaboration requires involvement and sharing of goals and resources (Schrage 1990).

Jasawalla and Sashittal (1998) added that for collaboration to take place, members should have a stake in the project ('at-stakeness'), adopt mindfulness, practice transparency and incorporating synergy. In order for members to have a stake in the project, they must share an equal interest when working together. Next, transparency in terms of awareness results from good communication and information exchange. Third, mindfulness means being attentive towards decisions and actions that may impact members. Finally, collaboration incorporates synergy as a positive result whereby the team output is more than the sum of each individual's contribution. According to Dougherty (1992b), knowledge creation and integration are two key goals of a collaborative process. Members must be able to integrate and share knowledge by means of speech or representations. This knowledge integration requires shared understanding among members (Kleinsmann and Valkenburg 2005; Kleinsmann and Dong 2007; Kleinsmann *et al.* 2007) where they have similar views about the design content; and are able to seek the right persons for knowledge within the project (Figure 61).

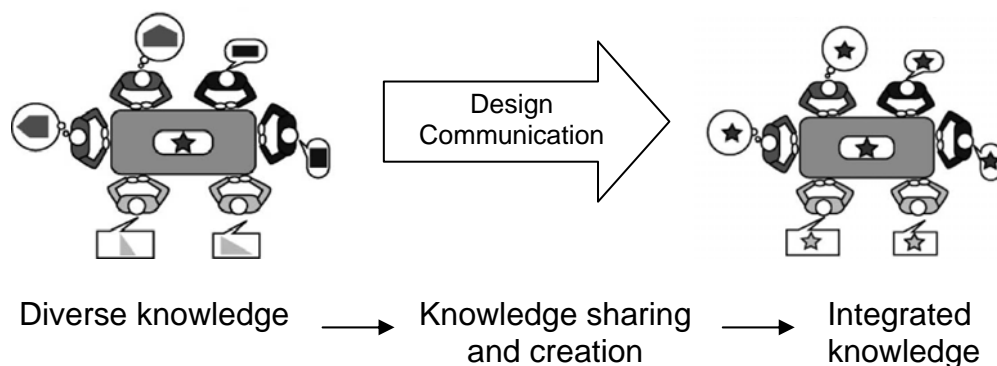


Figure 61: The collaborative design process (Kleinsmann *et al.* 2007)

In terms of organisation, collaborative design can be supported by synchronising tasks between members, through effective planning, and structuring activities so that members build a shared perspective of the project (Chiu 2002; Lang *et al.* 2002). Physical aspects of collaboration include co-locating members and creating strategic alliances that provide opportunities for informal collaborative networks (Leinonen *et al.* 2005; Detienne 2006).

Persson and Warell (2003c) proposed a conceptual model (Table 17) that distinguished four modes of contact between industrial designers and engineering designers. In a one-way communication, information is externalised and conveyed to the receiver but without any feedback. In reciprocal communication, the sender transmits the information and obtains feedback whether the data was correctly and accurately acquired. Interaction at the third level occurs when knowledge gained from communication is applied towards teamwork and involves the exchange of values between two parties (Kahn and Mentzer 1998). In interaction, the actions of members mutually influence others. At the fourth level, collaboration brings communication to a higher plane where members work together to share mutual understanding and achieve collective goals.

Mode	One-way communication	Reciprocal communication	Interaction	Collaboration
Definition	Information externalised and received with no feedback	Sender receives response whether information is obtained correctly and accurately	Involves processes where the actions of individuals influences others	Members share mutual understanding and build a common vision
Objective	Message Transfer	Feedback	Knowledge Applied	New Knowledge Developed
Common Understanding of	Content	Perspectives	Context	Goal

Table 17: Multi-disciplinary relationships (Persson and Warell 2003c)

Another area of discussion involves the use of shared representations and having a common frame of reference within a design team (Visser 2007). Past studies have examined how designers use representations such as sketches to communicate ideas to members. For example, Tang (1991b) investigated the use of sketches, concluding that they were used to store information,

express ideas and to facilitate group work. The discussion on visual design representations will be made in Chapter 6.

Despite the numerous benefits of collaboration, Kalay (2002) highlighted that collaboration may be a restrictive force as it introduces the likelihood for conflict among members. Although members may work together to achieve common goals, they still retain their own long-term goals that may be mismatched with others. The next section examines factors influencing collaboration within new product development.

#### **4.6.1 Factors Influencing Collaboration in New Product Development**

Kleinsmann and Valkenburg (2007) classified barriers that hindered effective collaboration into participant (actor), project and organisational (company) levels. In another study, Kleinsmann (2006) found barriers and enablers existing at the interface between the design team, the outside world and the organisation. Li *et al* (2009) added that because of the product complexity and the varied backgrounds of the stakeholders, collaborative and multi-disciplinary design remains a challenge. In addition, there have been no effective collaborative and multidiscipline development platforms made available or efficient ways for knowledge and information exchange across disciplines (ibid).

Ostergaard and Summers (2003) acknowledged the absence of a common language, shared understanding and organisation issues in collaborative design. In a recent paper, they proposed a taxonomy that classified issues affecting collaborative design based on six major factors: team composition, communication, distribution, design approach, information, and nature of problem (Ostergaard and Summers 2009). Persson (2002a) conducted an observational study with a large industrial company and identified seventeen other factors influencing industrial design and engineering design collaboration (Table 18); while Porras and Robertson (1992) described other factors grouped into four categories to include organising elements, social factors, physical settings and technology.

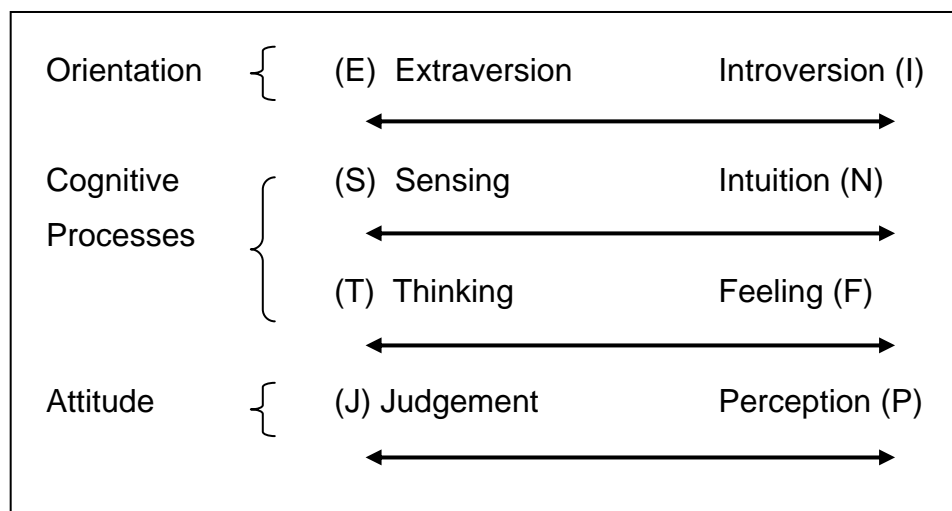
Factors influencing Industrial Design & Engineering Design interaction		
1. Confidentiality and deliberate isolation of industrial designers	7. Differences in skills between novice and senior members	13. Haphazardly accomplished project meetings
2. Industrial designers as a minority	8. Inconsistent concept evaluations	14. Vague design motivations
3. Contradictory roles	9. Diverse languages	15. Attitudes and trust
4. Differences in functions and time plans	10. Differences in internal collaboration	16. Administrative media tools
5. Reward systems and prestige issues	11. Product interpretations	17. Product representations
6. Specification comprehension	12. Differences in education and design problem approach	-

Table 18: Factors influencing industrial design and engineering design interaction (Persson 2002a)

According to Wall and Lepsinger (1994), six major obstacles exist that affect successful multi-disciplinary teamwork that include conflicting organisational goals; competing resources; overlapping responsibilities; conflicting personal goals; lack of priorities; and lack of cooperation. In another recent study, Ernst (2002) conducted a review of the literature and summarised key success factors of new product development based on findings by Cooper and Kleinschmidt (1995) that encompassed new product development, organisation, culture, the role and commitment of senior management, and strategy.

The Myers-Briggs Type Indicator (MBTI) assessment (Myers and McCaulley 1985) has been used as a psychometric questionnaire that measures the psychological judgment and perception in individuals from different professional disciplines. The model is arranged as a set of four dichotomised scales (See Figure 62). Putting these scales together in a matrix further allows 16 psychological types which 'represent the primary view through which an

individual's world is sensed and handled'. By using the MBTI assessment, Durling et al. (1996) highlighted differences in personality traits whereby designers were seen to have a preference to employ personal intuition, as compared to other disciplines who preferred details and facts. Consequently, they stressed that having a deeper understanding of differences between these groups could lead to improved communications between designers and other domains.



### Figure 62: MBTI Scales

In terms of organising arrangements, Persson (2002a) noted that members from industrial design and engineering design are often unclear about the functional roles of others and uncertainty sets in. For instance, when engineering designers are unfamiliar with industrial design, it limits their participation and industrial designers may only contribute to styling. In a separate study by Smith and Whitfield (2005), they highlighted misconceptions and found industrial design to be the least understood among creative disciplines and the public assumed that they worked in factories creating machinery. Persson (2002a) also found that both disciplines held contradicting roles. For example, industrial designers were expected to suggest innovative ideas but were instead criticised for not adhering to project specifications. Also, departmentalisation or specialisation of functions where organisational activities are segregated has been considered a barrier to group cohesion (Levitt 1969; James and Jones 1976; Menon et al. 1997).

Leadership is another critical factor that can be classified as being autocratic, consultative, collective, participative, and leaderless according to the Vroom-Yetton model (Vroom and Jago 1978).

Next, social factors encompass differences in organisation culture, management style, communal relationships, personal thought-worlds and individual attributes (Dougherty 1992b). Digman (1990) suggested five personality traits such as conscientiousness, extraversion, stability, agreeableness, and openness to experience. Other social elements include attitudes, values, interpersonal skills and concerns based on one's expertise, experience and responsibilities (Bucciarelli 1994; Bond et al. 2004), whereby Porras and Robertson (1992) noted issues concerning social factors are the most difficult to change.

Factors involving physical settings include the location of members who may be distributed geographically or within the organisation. This may be classed into three dimensions, namely: geographical proximity, organisational proximity and technological proximity (Knoben and Oerlemans 2006). When teams are distributed, the selection and frequency of communication techniques and language become even more crucial (Austin et al. 2001b). Studies by Janhager et al. (2002) showed that when both disciplines are separated, their contact is minimised. Divided labour and processes result in isolated members and they are unable to interact spontaneously. When they get together, solutions are in conflict and they end up compromising (Persson and Räisänen 2005). Findings by Persson (2002a) also revealed that industrial designers were usually separated from engineering designers and because of confidentiality, engineering designers could not access the design studio. Persson, Räisänen Persson and Warell (Persson and Warell 2003c; Persson et al. 2005) identified that another major barrier surrounding industrial design and engineering design collaboration is their diverging worldview and differing interpretations, as illustrated in Figure 63.



Figure 63: Actors with different viewpoints (Kleinsmann 2006)

In terms of working approach, Lofthouse and Bhamra (2000) noted that industrial designers thought broadly, whereas engineering designers converged problems into a single solution. These dissimilarities may stem from their different level of skills and experience as well as their educational backgrounds. Industrial designers being taught in art-based institutions focused on expression, whereas engineering designers were trained in systematic methods to solve issues. In approaching the design problem, industrial designers worked holistically on the whole product considering social and cultural values such as emotional aspects and market trends, whereas engineering designers focused on solving sub-problems including practical aspects of material, construction and manufacture (Sherman *et al.* 2000; Muller 2001). In addition, other researchers (Walsh *et al.* 1992; Herbruck and Umbach 1997) also reported that design briefs had contained unclear and superfluous information which resulted in misinterpreted information in the cooperation process.

In terms of problem solving, industrial designers preferred novel solutions while engineering designers favoured established solutions. In addition, engineering designers worked systematically through problem-focused strategies, yet industrial designers preferred to keep options open to continually seek better answers (Purcell and Gero 1996). Persson (2002a) also found that industrial designers emphasised on customer requirements and on the product semantics, whereas engineering designers focused towards the functional aspects. Inconsistent evaluation was another issue,



where a visually appealing concept could be chosen even though it was functionally impractical; or a design could be chosen due to ease of manufacture although it did not look attractive. In the case of industrial design, personal perception and gut feeling are often used, whereas engineering designers employed objective and scientific measures to solve problems. Because the information within sketches and models were often intangible, evaluating concepts became problematic. The dissimilar approaches made it difficult for each discipline to understand and evaluate how the design would work in relation to the functional features (Warell 2001).

In summary, several factors may influence the level of collaboration among industrial designers and engineering designers during new product development. However, a major barrier is due to their diverging viewpoints and interpretations when working on a product (Persson and Warell 2003c; Persson *et al.* 2005). In addition, both disciplines adopt different work approaches and when other obstacles such as organisation, social factors, physical settings and technology are not in place, multi-disciplinary teamwork and collaboration become complex and difficult to achieve (Porrás and Robertson 1992). The next section continues the discussion on factors influencing collaboration by stating the differences in language affecting the two disciplines.

#### **4.6.2 Differences in Language affecting Collaboration between Industrial Designers & Engineering Designers**

Understanding differences in language among industrial designers and engineering designers has been one of the cornerstones of research in collaborative work. Initially, inter-departmental language was used to make communication within the domain more efficient. However, this specialised language became difficult for external members to understand (March and Simon 1958; Lawrence and Lorsch 1976). Researchers have acknowledged that multi-disciplinary collaboration has been increasingly complex as each department uses a different language and has their own interpretations of the product (Bucciarelli 1988; Valkenburg and Dorst 1998; Hill *et al.* 2001; Lévy

and Guénand 2003). These differences make information sharing and collaborative work difficult.

In terms of language, English is not necessarily the first choice for all members and each discipline has their own jargon. Engineering designers use technical terminology represented as figures, matrices and lists whereas industrial designers apply visuals, themes and metaphors to the explain design intent. Consequently, it was hard for industrial designers to understand technical documents (Persson 2002a).

In the context of industrial design and engineering design, Sparke (1996) noted that each domain may use different terms that express the same idea. Conversely, the same term may have a different meaning for each discipline. Kleinsmann (2006) cited that the language of each disciplinary member is often jargon laden and difficult for outsiders to understand. Kleinsmann also found that the word 'concept' to a marketer (Figure 64), mechanical engineer (Figure 65), stylist (Figure 66) and a model maker (Figure 67) had different interpretations that could have hampered collaboration. Persson (2002b) also stressed that if a common language is not used, the semantic part of communication is lost. Erhorn and Stark (1994) also stressed that if dissimilar languages remain, communication issues will persist and more errors will be made, affecting overall performance in the long run.



Figure 64: The term 'concept' as used by a marketer

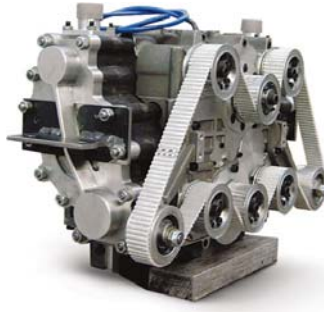


Figure 65: The term 'concept' as used by a mechanical engineer



Figure 66: The term 'concept' as used by a stylist (Olofsson and Sjöln 2005)



Figure 67: The term 'concept' as used by a model maker

Representations such as sketches and drawings are the most common ways to convey information. However, as data on paper is implicit, it relies heavily on one's knowledge and experience to correctly and accurately interpret the intended meaning (Kalay 2002). The tale of the 'Seven Blind Men and the Elephant' (Figure 68) illustrates an example of how each person or department may have their own interpretation and viewpoints despite working on the same project. In the story, each blind man had conflicting descriptions when they touched different parts of the same elephant (Kristensen 1995).

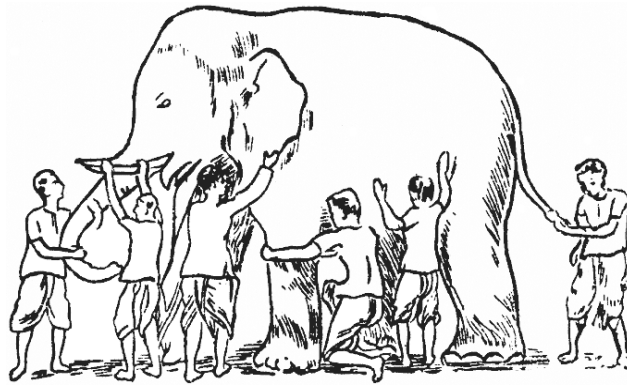


Figure 68: Seven blind men and the elephant

Maltz and Kohli (2000) suggested some approaches to reduce language differences such as multi-disciplinary training, team support, informal socialisation and co-location. However, Persson and Räisänen (2005) stated that these did not effectively bridge the perceptive gap between the multi-disciplinary members and only solved organisational issues. The following section discusses solutions proposed by other scholars in an attempt to improve collaboration within new product development.

#### **4.6.3 Proposed Solutions for Improving Collaboration**

To improve collaboration among members, Persson (2005b) acknowledged that activities, tools and processes should be synchronised by means of social, cultural and technical alignment. This can be achieved by conducting tasks in parallel with organisational activities, establishing dialogues and social interaction, and to have coordinated perspectives, interpretations and actions (Wenger 1998). The key is that members should understand the motives, goals and values of others, as well as externalising one's cognitive biases to establish a common perspective (Persson and Räisänen 2005).

Gutwin and Greenberg (2002) proposed five activities that would enhance a collaborative workspace to include managed coupling, simplified communication, coordinated actions, anticipation, and assistance. Managed coupling refers to the level of work that an individual is able to perform before requiring the involvement of another person, while simplified communication

involves artefacts that make the transfer and understanding of information more efficient. Next, coordinated actions ensure that activities are managed within constraints, whereas anticipation prepares for forthcoming activities with resources in place. Finally, providing assistance takes the form of supporting someone with their tasks, work and goals.

Social dialogues allow members to informally exchange information and to learn from each other (Chung and Wang 2002). Another way to improve collaboration is through collective reflection-in-action that was first proposed by Schön (1983) by means of pausing and then re-framing the problem and the product. In the context of industrial design and engineering design collaboration, Persson and Räisänen (2005) added that this means members need to reflect their contradictions and then re-align their representations, language, mindset, values and processes.

In terms of education, a number of UK institutions and those around the world are now offering courses that have a more rounded approach to design. For example, the Glasgow School of Art and Glasgow University jointly provides a course in Product Design Engineering so that graduates are able to be confident in 'speaking the languages of engineering and design' (Cox 2005). In the United States, the Stanford D-School teaches design to business, engineering and humanities students so as to merge disciplines and encourage collaboration (ibid).

The Cox Review (Cox 2005) further proposed steps that the UK Government, as well as business, broadcasting and education sectors should undertake to ensure that they are able to enhance their productivity by drawing on the creative talents that the UK possesses. The report highlighted that 'creative ideas were often 'impeded by the inability of business people and specialists to speak the same language'. One of the recommendations was that higher education courses should 'better prepare students to work with other specialists', so as to enable those involved to have a broader understanding and to be able to 'speak the same language as their colleagues'.

Recently, Karjalainen et al. (2009) proposed a program that brings students from disciplines of design, business and technology together. By doing so, graduates are able to receive the level of expertise and knowledge expected of their domain, as well as developing the multidisciplinary skills needed for them to interact with other professions.

In another study, Persson (2002a) proposed the concept of a collaborative workspace by suggesting that there should also be a common frame of reference among members to achieve mutual understanding. The key steps involve early participation of industrial designers with the team to build up an integrated work environment. Next, use of product representations would help create a common perspective of the content, structure and visual aspects of the concept. These representations must be well-structured so that the underlying intention can be compared, defined and evaluated with the same level of abstraction. Where possible, technical information should be included with aesthetic features to allow participants to understand the inter-relationship of parts (Schachinger 2002). For all these to work, there must be sufficient physical space and time for members to gather and to provide opportunities for representational objects to be used (Persson 2002c).

The importance of awareness and understanding has been highlighted by Erhorn and Stark (1994) who suggested that at the start of the project, members should share key points and terminologies used in the project. In terms of achieving successful collaborative multi-disciplinary teamwork, Holland *et al.* (2000) suggested six aspects shown in Table 19 that cover group composition, internal processes, task design, external processes, group psychosocial traits and the organisational context.

Karjalainen et al. (2009) also suggested that individuals with multidisciplinary exposure are able to create a 'shared body of knowledge that is more than the sum of individual members' own knowledge and skills'. They commented that forming a multidisciplinary knowledge base may be characterized by the concept of a "T-shaped" skill profile of an individual. These 'T-shaped' persons are experts in their field, who also possess a broader awareness of how their

discipline interacts with others (Iansiti 1993). The vertical of the T showing the depth of knowledge, the horizontal indicating the breadth.

<b>Group composition</b> Right functional mix Team leader selection Clear roles and responsibilities Team tenure	<b>Group psychosocial traits</b> Mutual respect/trust Flexibility and openness to learning/willingness to change Team cohesiveness
<b>Internal processes</b> Overarching team goals Team leader skills and vision Frequent, genuine communication Creative problem-solving Sharing and use of uncertain information Constructive conflict	<b>Organisational context</b> Clear mission from senior management Strategic alignment between functions Senior managers as champions Climate supportive of teams Project leader power Resources/time Training in team process skills Team-based accountability Team-based rewards and recognition Team co-location Mechanisms to co-ordinate activities and share learning between teams
<b>Task design</b> Team empowerment Formal yet flexible integrative processes Customer focus Important, challenging task	
<b>External processes</b> Boundary management	

Table 19: Success factors for multi-disciplinary teamwork (Holland *et al.* 2000)

An article by furniture systems design consultancy, Steelcase, described key physical features for a conducive collaborative workspace (360-DeepDive 2007). Offices should be comfortable to encourage social interaction, such as having adequate seating for visiting members, the provision of clear information, access to information areas and use of configurable surfaces such as mobile furniture. These workspaces should consider users' needs accordingly, for instance bigger desks for engineering designers working with multiple monitors and room for industrial designers working on paper or models. Kelly and Littman (2001) added that offices should provide places for

unplanned meetings with a balance between open and enclosed areas that allow socialisation yet accommodating privacy needs.

In terms of co-location, although it has been acknowledged as a fundamental aspect of collaboration by encouraging communication and cooperation, Sherman *et al.* (2000) revealed that co-location is only effective for full-time members working on a long-term project. For short-term projects, co-location was less effective and could instead be enhanced with more informal interaction.

In terms of technology, interactive and technical product representations may be used as mediating objects to create a common frame of reference to bridge the gap between disciplines (Svengren 1995). The use of technology may be used to support and facilitate collaboration through information sharing, remote meetings and resource distribution (TCT 2004). Information technologies include web-based knowledge systems (Wang *et al.* 2002), communicative tools such as e-mail, messaging, conferencing and application sharing software such as NetMeeting or PCAnywhere. Although the use of CAD is now regarded as a standard application, it is very much limited to single-use and scholars have proposed tools that support distributed, collaborative viewing of CAD data such as ePAD that provides an integrated interface to view virtual product assemblies over the internet (Shyamsundar and Gadh 2002), and Syco3D that allows distributed members to build and edit 3D models collaboratively in real-time (Nam and Wright 2001). While these technologies are available, they should be seen only as a catalyst for collaboration (Rosenthal 1992) and should also be standardised so that members can use them uniformly at ease (Tavcar *et al.* 2005). Other computer-based tools to aid collaboration include Information and Communication Technologies (ICT) and Computer-Supported Cooperative Work (CSCW) tools that were discussed in Section 4.5.2.

While other established tools such Quality Function Deployment and Design for Manufacturing are available, they are more suited for marketing and engineering, presenting very little support for engineering design and



industrial design collaboration (Persson and Räisänen 2005). A more relevant solution would include a product development bank that records decisions for future participants to study, discuss, critique and learn from past concerns and decisions (Chung and Wang 2002). Similarly, Roller *et al.* (2002) proposed another shared database system that allows ideas to be combined, exchanged and shared to foster common understanding and to build shared knowledge. Other attempts to improve the interpretation and transfer of data include standardised notations such as Architectural Graphic Standards for architects, to Initial Graphics Exchange Specification (IGES) standards that allow a consistent level of information transfer for computer systems (Kalay 2002). In summary, although these standards and other approaches have reduced errors in cross-domain translation, there has been very little success in bridging the gap in language between by industrial designers and engineering designers.

#### **4.7 Chapter Summary**

This chapter has provided an introduction to the concept of teamwork in new product development where members bring complementary skills and knowledge to the group to develop the best definition of the product. This involves communication among multi-disciplinary members in the form of audio, visual and text. While communication is only limited to information transfer and exchange; coordination integrates and links stakeholders to accomplish tasks; and cooperation only pools resources and focuses on contributing towards a common work.

At another level, integration unites the disciplines by bringing communication, coordination and cooperation together so as to develop shared values and mutual goals to maximise their contribution. Integration is further supported through use of integrating mechanisms such as locating members in proximity, encouraging informal socialisation, and managing information with use of ICT and CSCW tools.

This chapter ends with the discussion of design collaboration as a high level of integration among members of different backgrounds, interests and expertise. It can be achieved through joint work, sharing of resources and having a common frame of reference in the project. For collaboration to take place, members need to possess high-levels of stake in the project, are mindful, transparent and form synergistic teams. Table 20 clarifies the seven categories of multi-disciplinary contact that constitutes one-way communication, reciprocal communication, coordination, cooperation, interaction, integration and collaboration.

Term	Description
One-way Communication	Information externalised and received with no feedback
Reciprocal Communication	Sender receives response whether information is obtained correctly and accurately
Coordination	Integration and linking of various stakeholders with shared goals to accomplish tasks
Cooperation	Coordinating behaviour among individuals so as to link members together
Interaction	Involves processes where the actions of individuals influences others
Integration	Unites the disciplines by bringing communication, coordination and cooperation together so as to develop shared values and mutual goals to maximise their contribution
Collaboration	Integrated members share mutual understanding and build a common vision, supported with good communication, coordination and cooperation

Table 20: Summary of relational modes of contact between industrial design and engineering design

In summary, while various other factors and solutions that affect collaborative work have been discussed, a key point concerns the differences in language that affect collaboration between industrial design and engineering design. The chapter has highlighted instances where words can have different

meanings, and consequently the same idea may have different terms used. Similarly, as information embedded on physical representations such as sketches and models are implicit, it is dependent on accurate interpretation. The topic on visual design representations is discussed in Chapter 6. To this end, having provided a review of the literature for the research background, the next chapter shall discuss the research investigation, covering the methodological aspects, as well as the quality and validity of the empirical studies.

## **5. INITIAL INVESTIGATIONS**

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### **5.1 Chapter Overview**

As the overall aim of the research is to suggest and develop a design tool that would support collaboration between industrial designers and engineering designers in new product development, the purpose of the empirical study is to identify key problem areas concerning collaboration among the two disciplines and to recommend further research. This chapter describes the use of interviews and participant-observations as a means of data collection and begins by describing the reliability of results and other ethical considerations. The chapter ends with an analysis of the findings with recommendations for the next phase of research.

### **5.2 Reliability of Results and Ethical Considerations**

The purpose of the empirical research was to identify key problem areas concerning collaboration among the two disciplines. Empirical research was achieved by means of semi-structured interviews and participant observations. In order to ensure that the data collection was reliable, the interviews with industrial designers and engineering designers were sampled with a span of large, medium and small industrial design consultancies. In addition, a balanced number of industrial designers and engineering designers themselves were interviewed. To obtain holistic feedback, an additional 16 project managers were also interviewed so as to obtain the management's perspective. As a further complement to the interviews, project documents, reports, specification lists and artefacts were viewed to seek out a better understanding of interview discussion.

To ensure that the questions could be understood, the interview was first pre-tested with the author's supervisors who were academics with industrial design and engineering design work experience. Minor changes in terms of sentence structure for the questions were made. As qualitative research is

hugely associated with words rather than numbers, words may have several meanings and to prevent misinterpretation, the respondents' records were always re-confirmed when they were unclear. According to Stauffer *et al.* (1991), interviews are advantageous because they address specific issues and are relatively easy to implement; yet the disadvantage is that interviews must take into account the subject's memory loss.

The interviews were carried out with 17 industrial design consultancies and took an average of 1½ hours for each respondent. For consistency, the respondents had the same interviewer, were subjected to same interview process with the same interview questions. This consistent approach enhanced the reliability of the study. To ensure that all respondents had an informed knowledge about the interviews, a summary of the research was produced in the form of a booklet (Appendix 13.3) and given to them before the interview took place on the same day. This gave all respondents ample time to understand and to ask questions concerning the research. During the interviews, additional notes such as informal comments or opinions were recorded as supporting data. To minimise memory loss, all interview notes were transcribed on the same day. Reliability was further enhanced by sending a copy of the transcribed notes to the respondents within a day so that the records could be checked and verified. There were two occasions where respondents had emailed changes to their opinions which were updated.

The main limitation for the interviews was the respondent's lack of time to discuss topics in detail as they were busy. Another limitation was that current projects could not be discussed because of confidentiality. It meant that the interviews were based mainly on old projects and had to rely on the memory of the respondents. According to Yin (1994), interviews are subject to problems of bias, poor recall and poor articulation. However, Yin goes on to say that to strengthen the findings, it would be 'worthwhile to corroborate interview data with information from other sources'. This justified the need to

conduct a second round of empirical study by means of observations that will be discussed later.

The issue of ethical conduct for this research was taken into consideration. All respondents were informed very clearly about the research, giving details about either the interview study or the observations. They were told what was expected of them and that they had the right to end participation at any point in time without penalty. They were also told that their participation would be kept anonymous throughout the study with no mention of their organisation. When describing projects as a case-study for discussion, they had the option to either describe the project briefly (e.g. helmet design), or without any association (discussing the project in general). In all instances, their name and company would not be published.

The observations investigated an industrial designer and engineering designer developing a consumer electronics product. The small-sized setting of the industrial design consultancy allowed good access and transparency to the design development process. To minimise interruption, the discussions were made during breaks. During the observations, contemporaneous notes were taken to record issues occurring among the design team. Although note taking did not fully describe the situation, it allowed first-hand accounts to be recorded. When other pertinent information such as documents or sketches looked significant, they were looked at and notes were taken. As the researcher was not allowed to attend confidential meetings, informal interviews were conducted with the team later. By doing so, it allowed the researcher to remain engaged in the day-to-day events.

### **5.3 *Data Collection with Interviews***

According to Miles and Huberman (1985), how structured an interview or observation needs is dependent on the available time, resources and knowledge about the phenomena being studied. For this research, the

empirical studies were conducted in Singapore over ten weeks by taking advantage of the available and ready access to practicing industrial designers and engineering designers. It was facilitated by the researcher's own contacts by having several years of working experience with design consultancies in the country. Industrial design work in Singapore is conducted in an English-speaking environment and international staff are widely employed. For consistency, the industrial design consultancies chosen had to be involved in new product development concerning consumer electronics. In addition, the companies had to employ both industrial designers and engineering designers during the design process.

An initial contact was made with the design manager of each firm with a university cover letter, requesting the company's participation in the study. Out of 20 companies, a total of 17 industrial design consultancies responded positively. The design manager was requested to participate in the interview and was asked to provide the names of available industrial designers and engineering designers working on or who had worked on the same project. Of the 17 firms, there was a good balance of large (more than 10 design staff), medium (between 6-10 design staff) and small industrial design consultancies (less than 5 designers) to allow a wider sampling and to obtain findings from a larger pool of respondents (Figure 69). From these companies, a total of 31 industrial designers and engineering designers were sought. They were qualified practitioners with at least 3 years of work experience. The interviews constituted 45 hours of fieldwork and the statistics are shown in Table 21. Table 22 shows the list of companies and respondents interviewed, categorised according to the respondents' job, name and company. A considerable amount of time was taken to plan and organise each interview so as to achieve a high response rate with no cancelled interviews.

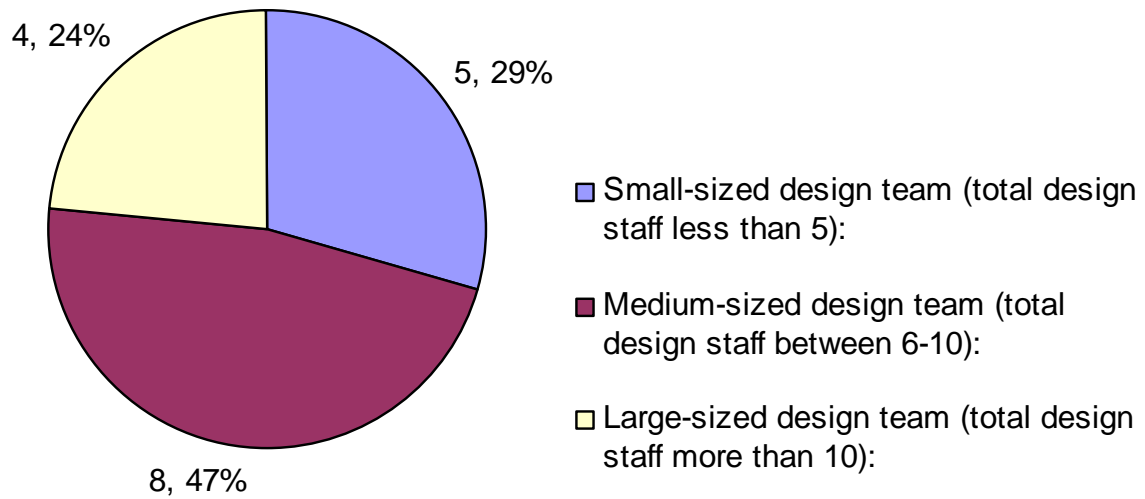


Figure 69: Size of companies employed for empirical research

Details of Interview Study R1	
Total duration of study:	10 weeks
Total duration of interviews	45 hours
Number of Respondents	
Total respondents	31
Industrial designers interviewed	9
Engineering designers interviewed	6
Project Managers interviewed	16

Table 21: Interview Statistics



No.		Respondent Code	Company	Profession
1.	ID	R1-1	Company 1	Project Manager
2.	M	R1-2	Company 1	Project Manager
3.	M	R1-3	Company 2	Project Manager
4.	M	R1-4	Company 3	Project Manager
5.	ID	R1-5	Company 4	Industrial Designer
6.	M	R1-6	Company 4	Project Manager
7.	ED	R1-7	Company 4	Engineering Designer
8.	M	R1-8	Company 5	Project Manager
9.	ID	R1-9	Company 5	Industrial Designer
10.	M	R1-10	Company 6	Project Manager
11.	ED	R1-11	Company 6	Engineering Designer
12.	M	R1-12	Company 6	Project Manager
13.	M	R1-13	Company 7	Project Manager
14.	ED	R1-14	Company 7	Engineering Designer
15.	M	R1-15	Company 7	Project Manager
16.	M	R1-16	Company 8	Project Manager
17.	ID	R1-17	Company 9	Industrial Designer
18.	ID	R1-18	Company 10	Industrial Designer
19.	M	R1-19	Company 11	Project Manager
20.	M	R1-20	Company 11	Project Manager
21.	M	R1-21	Company 12	Project Manager
22.	ID	R1-22	Company 13	Industrial Designer
23.	ID	R1-23	Company 13	Industrial Designer
24.	ID	R1-24	Company 14	Industrial Designer
25.	ID	R1-25	Company 14	Industrial Designer
26.	M	R1-26	Company 14	Project Manager
27.	ED	R1-27	Company 14	Industrial Designer
28.	M	R1-28	Company 15	Project Manager
29.	M	R1-29	Company 15	Project Manager
30.	ED	R1-30	Company 16	Engineering Designer
31.	ED	R1-31	Company 17	Engineering Designer




 Industrial Designer
  Engineering Designer
  Project Manager

Table 22: Description of Company & Respondents Interviewed

### 5.3.1 Interview Method

Interviews provide important insights into situations (Yin 1989). A structured interview has questions that are planned, while unstructured interviews do not have an agenda (ibid). It was decided that a semi-structured interview would be used as it would sufficiently explore issues and provide flexibility within an organised format. It would also allow spontaneity and freedom in describing experiences. The process was structured by using an interview sheet and carried out by note-taking as tape and video recordings were not allowed. Conducting the interview in person as compared to a mail survey allowed the respondent to clearly understand the research. This also enhanced the response rate and to avoid incomplete questions. The respondents were first asked questions to gather demographic data about their educational background, work experience and opinions about completed projects (Table 23). Next, they were asked project-specific questions to identify factors that might have influenced collaborative work (Table 24). It required an example of a project, relating experiences of group interaction, reasons for project successes and failures, as well as tools and methods used for the project. After gathering the information, the interview records were transcribed into Microsoft Word.

<b>A. Background questions</b>
1. Date of interview
2. Name of Interviewee
3. Position of respondent
4. Role & Responsibility
5. Educational background
6. Years of experience
7. Company name and type
8. Number of industrial designers / engineering designers in company
9. Number of industrial designers / engineering designers in the project
10. Describe the company structure and culture

Table 23: Background questions

<b>B. Research-specific questions</b>
1. Describe a recent project undertaken
2. Describe the design approach and strategy adopted
3. What was the project deliverable?
4. What activities were involved?
5. Describe the tools and methods used
6. What design representation methods were used?
7. Did collaboration between industrial designers and engineering designers occur during the project?
8. Describe the quality of group interaction and teamwork
9. What factors might have influenced group work?
10. Were there any leadership or management issues?
11. Name the success or failure factors
12. What is your view of the final product?
13. Did you have any personal concerns working with the other discipline?
14. Suggest some improvements for future collaborative work

Table 24: Research-specific questions

### 5.3.2 Interview Findings

According to Miles and Huberman (1994), data analysis consists of three key activities: data reduction, data display and conclusion drawing / verification (Figure 70). At the first stage of analysis, data reduction selects, sorts, focuses, clusters, codes, simplifies and transforms 'raw' data from the field notes. Next, data display presents the organised information in the form of text, matrices, graphs and charts. The act of designing rows and columns to encode the data is itself a recognised form of analytical data reductive activity. Conclusion drawing and verification is the final stage of analysis to find what things mean, noting regularities, patterns, and explanations (ibid).

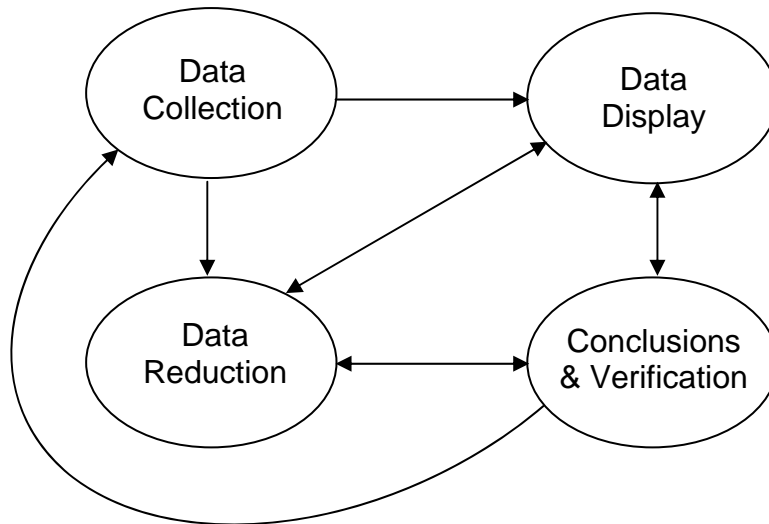


Figure 70: The data-analysis model (Miles and Huberman 1994)

For this research, interviews were employed to investigate problem areas occurring among industrial designers and engineering designers in new product development. The data analysis model by Miles and Huberman (1994) was employed, and in particular the use of coding to reduce data by means of ‘grouping information to allow an emerging pattern to be derived and to seek a more descriptive and thematic approach’.

From the 31 interviews, first level coding was first used to summarise the field notes by putting similar information together. This is known as clustering where the researcher seeks to find similar data based on having similar patterns or characteristics (ibid). This clustering process led to 61 distinct issues that were encoded into Excel sheets in the form of a matrix (Table 25).

1	Not having knowledge of the other field
2	Conflict in Personal Principles
3	Not Understanding each other
4	Poor Direction of Project Manager
5	Not Having a Common Goal
6	No formalised meetings
7	Company Bias on Industrial Design or Engineering Design
8	Not Choosing the right tools and methods
9	Poor Communication Skills
10	Inappropriate Selection of Design Representation Method
11	Untimely Use of Rapid Prototyping
12	Wrong Implementation of Design Representation
13	Poor Translation from 2D Sketch to 3D CAD
14	Fixed Mindsets
15	Individual Differences & Attitudes
16	Inadequate Experience
17	Dissimilar Education Background
18	Western / Asian Approach of working
19	Unfamiliar with Teamwork
20	Conflict in Interest
21	Fixed Working Protocols
22	Members Located Apart
23	Low Level of Trust
24	Not Understanding Technical Requirements
25	Not Having Compatible Solutions
26	Engineering Limitations
27	Company Culture
28	Industrial Designers Wrongly Perceived
29	Poor Team Dynamics
30	Not Having Standardised Computer Files
31	Time Constraints
32	Manufacturing Limitations
33	Engineering Design Not Being Flexible
34	Marketing Controls Budgeting
35	Language as a Communication Barrier
36	Unsure who controls Decision Making
37	Poor Team Leadership
38	Not Being Specific when Requesting for a Design Representation
39	Industrial Designers Getting Carried Away and Fall Behind Time
40	Not Using Standard Codes
41	Issues with Multi-cultural Teams
42	Issues with Other Disciplinary Members
43	Low Morale
44	Complexity of Project
45	Marketing Not Understanding the Project
46	Manufacturing Constraints Not Being Told Early
47	Lengthy Changes to the Design
48	Marketing Not Reacting Fast Enough
49	Late Engineering Issues Affecting Design Aesthetics
50	Client Changes Affecting the Aesthetics
51	Designers Not Understanding Marketing Constraints
52	Cutting Cost Affecting Design Aesthetics
53	Difficulty in Explaining Visual Effects to Others
54	Unequal Rewards
55	Software Incompetence
56	Poor Justification for Decision Making
57	Poor Use of Technology for Communication
58	Safety Requirements Affecting Design Aesthetics
59	Poor Client Involvement
60	Members Trained Differently in the Company
61	Last Minute Considerations to Manufacture

Table 25: 61 issues occurring between industrial designers and engineering designers derived directly from the interview findings

From the 61 issues, the next stage was to identify issues that had high levels of occurrence in the 17 industrial design consultancies. Of these, 19 problem areas were found to occur three or more times among the companies that are highlighted in Table 26 and arranged according to their occurrence.

	Issues	Industrial Design Consultancies Involved																	Occurrences
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
1	Not having knowledge of the other field																		8
2	Conflict in Personal Principles																		6
3	Not Choosing the right tools and methods																		6
4	Poor Communication Skills																		6
5	Inappropriate Selection of Design Representation Method																		6
6	Not Understanding each other																		5
7	Fixed Mindsets																		5
8	Individual Differences & Attitudes																		5
9	Poor Direction of Project Manager																		5
10	Wrong Implementation of Design Representation																		4
11	Fixed Mindsets																		4
12	Not Having a Common Goal																		3
13	Conflict in Interest																		3
14	No formalised meetings																		3
15	Inadequate Experience																		3
16	Poor Translation from 2D Sketch to 3D CAD																		3
17	Company Bias on Industrial Design or Engineering Design																		3
18	Dissimilar Education Background																		3
19	Western / Asian Approach of working																		3

Table 26: Top 19 critical issues among Industrial Designers and Engineering Designers

These 19 issues were further subjected to pattern coding so as to 'simplify these into larger categories and to seek an emergent theme' (Strauss and Corbin 1990). Pattern coding has been used by other researchers (Purcell *et al.* 1996) to summarise findings into condensed categories. It reduces data into themes, causes, relationships, and other theoretical constructs (Miles and Huberman 1985). It 'pulls material with similar attributes together into a meaningful unit and reduces large amounts of information for analysis' (ibid). Pattern coding classifies data by sorting information based on similar attributes (Richards 2005; Bailey 2007). The use of pattern coding has been

commonly employed by researchers in qualitative data analysis (Robson 1993; Singh 2007).

Within pattern coding, Miles and Huberman (1985) cited that a code is 'a symbol applied to words relating to a concept or a theme'. Loftland (1971) suggested that codes may be used to group actions, activities, meanings, relationships and the setting under study; while Bogdan *et al.* (1982) suggested that coding included the context, situation, process, activity and the social structure. Miles and Huberman (1985) suggested a step-by-step procedure to generate pattern codes by:

1. Sorting the data
2. Identifying key variables or factors that occur
3. Bringing the smaller bits of information together
4. Until no further groupings can be made, these become the pattern codes

Pattern coding was used to classify the 19 issues into larger categories. It soon became evident that they concerned three key problem areas that were barriers to collaboration among industrial designers and engineering designers. The three key problem areas were identified as

- A. Conflicts in Values, Principles or Aims
- B. Differences in design representation
- C. Differences in Education

The 'conflicts in values, principles or aims' are in line with Wall and Lepsinger (1994) who found conflicting personal goals as a barrier to multi-disciplinary collaboration, as well as attitudes and values as social elements influencing collaboration (Bucciarelli 1994; Bond *et al.* 2004). From the literature review, it was found that the 'differences in design representations' and 'differences in education' had been acknowledge by Persson (2002c) who had conducted an observational study and identified fifteen other factors influencing industrial

design and engineering design collaboration (Table 18, Section 4.6.1). The three problem areas are now discussed in detail.

#### **A. Conflicts in Values, Principles or Aims**

The first issue concerns conflicts in values, principles or aims. From the interviews, it was found that industrial designers saw engineering designers having different ways of working and they did not understand each other (1), nor having a sound knowledge of the other field (2). The engineering designers worked logically with measurable solutions based on efficiency or cost. Industrial designers preferred a more creative approach and presented solutions informally. This was a conflict in their personal principles and way of working (3). In some of the industrial design consultancies interviewed, the management recognised this to be a problem and implemented protocols to standardise working procedures. However, it was found that both disciplines felt it was hard to follow working procedures as each project was unique. In addition, the industrial designers were not able to draw sketches to scale for the engineering designers. The project manager was busy with other projects and did not acknowledge the conflicting values among the two disciplines. There was also poor direction from the project manager who gave conflicting instructions (4), leading to members not having a common goal (5). In some of the industrial design consultancies, it was found that there were no formalised meetings (6) and it made having a common goal difficult to achieve. Lastly, in some of the consultancies interviewed, there was more emphasis placed on industrial design aesthetics for the project and less importance on the engineering aspects. This was recognised as a company having a bias towards one discipline (7). In summary, conflicts in values and in principles and aims were found to be barriers to collaboration because of:

1. Not understanding each other
2. Not having knowledge of the other field
3. Conflict in personal principles
4. Poor direction of project manager
5. Not having a common goal



6. No formalised meetings
7. Company bias on industrial design or engineering design

## **B. Differences in design representation**

From the interviews, it was found that there were different methods of design representations used by industrial designers and engineering designers. At meetings, engineers used technical jargon and facts with calculations, technical information and specifications. In contrast, industrial designers used sketches and images that were difficult to justify. Both disciplines criticised that they had problems understanding the other parties' representation. In addition, engineering designers commented that industrial designers had overdone their presentations with unnecessary graphic effects (e.g. shadows) leading to misinterpretation (1, 3, 5). In addition, technical specifications from the engineering designers were difficult to understand (2). Poor sketches and inadequate verbal communication did not help improve the situation (2). The engineering designers had issues in translating a paper sketch into 3D CAD model (4). There were no common design representations available to both disciplines. In addition, rapid prototyping was used too early in the design process where the design or engineering components were not yet finalised (6). In summary, differences in design representation were found to be barriers to collaboration because of:

1. Not choosing the right tools and methods
2. Poor communication Skills
3. Inappropriate selection of design representation
4. Poor translation from 2D sketch to 3D CAD
5. Wrong implementation of design representation
6. Untimely use of rapid prototyping

## **C. Differences in Education**

Due to differences in background and education, both disciplines had different specialities, approaches and expectations. Both disciplines had fixed mindsets

whereby the engineering designers were adapted to systematic problem solving with facts; while industrial designers solved problems intuitively without quantified data (1, 2). In addition, some members had different education qualifications or had unequal working experience (3, 4). This influenced each individual's perspective towards the project. Some members were educated in an Asian institution having more emphasis on technology, while others were taught by a Western institution that was more focused on the areas of creativity. This led to difference in their approach to work (5). From the interviews, it was found that industrial designers had infrequently worked in groups, while engineering designers found group work to be more common in their education. In summary, differences in education were found to be barriers to collaboration because of:

1. Fixed mindsets
2. Individual differences & attitude
3. Inadequate experience
4. Dissimilar educational background
5. Western / Asian approach to working

The three key problem areas as (A) Conflicts in Values, Principles or Aims, (B) Differences in design representation, (C) Differences in Education are now illustrated in Figure 71 below.

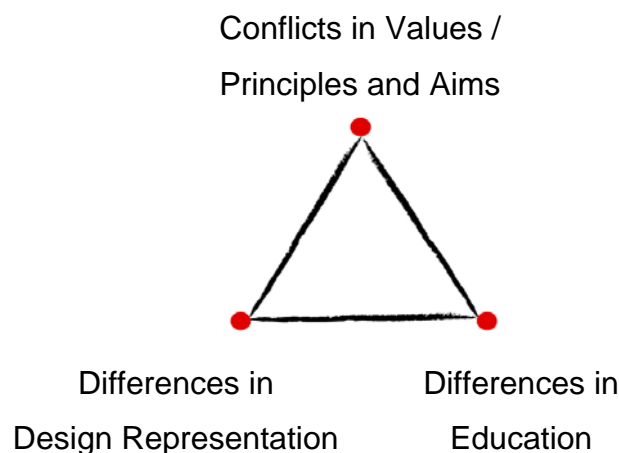


Figure 71: The three key problem areas occurring between industrial designers and engineering designers

## **5.4 Data Collection with Observations**

The aim of the observations was to confirm the interview results and to obtain new findings. According to Yin (1994), observations employ seeing and listening as key sources to gather information. The advantage is that the researcher is able to see collaboration taking place between engineering designers and industrial designers in their working environment. In addition, data from observations are presented in their pure form, with little distorted interpretations of events and processes (Paashuis 1988). Observations also provide a means of understanding the project background and context of working (Persson 2002c), all of which are relevant to the aim of this empirical research.

In an observation, the researcher watches and records events and activities in a real-life context. While it may be unobtrusive and relatively easy to administer, observations may be time consuming to conduct (Stauffer *et al.* 1991). In addition, it is important to bear in mind that the observer should not be biased during the process of observation. During observations, it is also common for physical artefacts to be collected or observed as part of the investigation to allow the researcher to develop a broader perspective (Yin 1994). Stauffer *et al.* (1991) classified observations as unstructured, structured or participant observations.

Unstructured observations are conducted without an agenda and allows the researcher to discover more about the nature of the domain, while structured observations contain an agenda with the observer looking for specific behaviours and records their occurrence. In participant observation, the observer is a member of the team being studied.

The participant observation approach (Stauffer *et al.* 1991; Robson 1993) was chosen whereby the researcher would undertake a supporting role within the group in assisting the industrial designer. It was chosen as it allowed a flexible and informal approach with considerable freedom to gather and record

information. More importantly, this approach would provide an entry into the team's working and social world by investigating their social conventions and habits. Although the participant observation approach might lead to hesitancy from others to provide information (Robson, 1993), it provided an entry into the group with first-hand accounts of situations. The small-scale setting also allowed the researcher to capture his observations effectively while being close to the subjects. For this study, the participant observation approach did not require the observer to take on demanding tasks and the researcher was limited to relatively simple supporting jobs. This allowed the researcher to gain access to the design activities. Although participant-observations are known to pose potential biases (Tellis 1997) and the investigator may have less ability to work, this approach still provided the best opportunity for an in-depth study (Yin 1994). Research by Bucciarelli (1984) also adopted the participant-observation method, where the researcher acted as an observer while being involved as an engineer. It allowed Bucciarelli to gain a better understanding of the social process when group members were at work. Bucciarelli was able to understand the scope of the project, gaining an intimate access to the design process and obtained data by reflecting his experiences. In light of the trade-offs between opportunities and problems, it was decided that using a participant-observation method would be the most effective way to see collaboration taking place between engineering designers and industrial designers in their natural working environment.

#### **5.4.1 Observation Method**

The observations occurred over 2 weeks within a Singapore-based industrial design consultancy employing 12 staff. The project involved the design of an electronic consumer product. As it was an on-going live project, details could not be published and video and voice recordings were not allowed. The study involved the project manager, an industrial designer and an engineering designer observed by the researcher from the start of the design brief to the completion of the 3D CAD model (Tables 27, 28). In total, 80 working hours over 2 weeks were dedicated to the observations. Records were made by

note-taking when the industrial designers and engineering designers were interacting, communicating or while employing design representations.

To gain a holistic understanding, data was analysed at the end of each day. Information from each respondent was analysed to identify the existence of barriers occurring among the two disciplines. The case study provided an enriching experience in understanding work processes and observed collaboration activities. The findings of the observations are now discussed.

Details of Observation Study R2	
Total number of respondents	3
Industrial designers observed	1
Engineering designers observed	1
Project Managers observed	1

Table 27: Observation statistics

No.		Respondent Code	Company	Profession
1.	ID	R2-1	Company 4	Industrial Designer
2.	ED	R2-2	Company 4	Engineering Designer
3.	M	R2-3	Company 4	Project Manager


 Industrial Designer
  Engineering Designer
  Project Manager

Table 28: Description of company & respondents observed

### 5.4.2 Observation Findings

The observations began with a project briefing by the project manager. Having both industrial designers and engineering designers at the meeting ensured that initial issues could be resolved openly at the first meeting. All members were clear about the time frame and project deliverables. To allow for

creativity, technical specifications were minimised at the early stages. During concept selection, the members regrouped to determine the concepts for development. Healthy conflict was noted where each concept was discussed openly and justified. There were few misunderstandings as explanations and limitations were discussed in detail.

It was observed that conflict between the industrial designer and the engineering designer arose during concept development. A chosen concept in the form of a paper-based sketch was required to be translated into a 3D CAD model. For this to happen, the engineering designer wanted the industrial designer to include dimensions in his concept sketches that were in a perspective view. This meant that the industrial designer had to translate the drawings into an orthographic view. When the CAD model did not match the intended design, the industrial designer had to spend time with the engineering designer to guide the 3D modelling of the product. As the modelling progressed, engineering limitations became known. The engineering designer had to highlight these constraints and the industrial designer had to redesign with a limited amount of time. In another instance, the engineering designer wanted simple sketches for the buttons but instead the industrial designer created time-consuming marker renderings that were unnecessary. The request for a 'sketch' was unclear and their dissimilar interpretation of a design representation made collaborative work strenuous. When the CAD model was nearing completion, the project manager stepped in and made changes to the design. He claimed that the client wanted the product to take on a narrower profile as stated in the design brief, but this message was conveyed only at the very last minute and affected the design aesthetics. Despite these issues, the project was delivered on time.

From the observations, It was found that formal and informal meetings were valuable in enhancing collaboration by providing opportunities for discussion, exchange of information and sharing knowledge. Co-location was a positive factor since the members being closely located had greater interaction as

compared to other departments located at a different level. The observations also found that different working principles were adopted. The engineering designer focused on technical problems while the industrial designer emphasised on design aesthetics. It was also observed that while visual design representations such as sketches, drawings and CAD were the focal point of discussion among the two disciplines, each discipline had different views and interpreted them at a different level. From this observation study, the success factors for collaboration comprise of:

1. Members being clear about deliverables
2. Issues were openly discussed
3. Having formal and informal meetings
4. Co-located members

The issues in collaborative work were:

1. Dissimilar principles
2. Unclear communication by project manager
3. Inappropriate selection of design representation
4. Wrong implementation of design representation
5. Inaccurate 2D to 3D CAD translation
6. Not being specific in requesting for a design representation
7. Last minute changes by client

## **5.5 Analysis of Findings**

From the observations, it was found that three issues were found to fall into the category of 'design representations' from Table 29, namely:

1. Use of Different Representations – (no. 5)

2. Use of Inappropriate Representations – (no. 12)
3. Not being specific in requesting for a Design Representation – (no. 38)

1	Not having Knowledge of the other Discipline
2	Conflict in Work Principles
3	Using Different Tools and Methods
4	Poor Communication Skills
5	Use of Different Representations
6	Not being able to Understanding Each Other
7	Fixed Mindsets
8	Individual Differences & Attitudes
9	Poor Direction of Project Manager
10	Use of Inappropriate Representations
11	Differences in Personal Values
12	Not Having a Common Goal
13	Absent updates / Not updated Milestones
14	Lack of Sufficient Meetings
15	Job / Task Inexperience
16	Translation from 2D Sketch to 3D CAD
17	Company Emphasis on Design or Engineering
18	Differences in Educational Background
19	Western vs Asian Approach of Working
20	Conflict in Interest
21	Rigid Working Protocols
22	Location of Support Members
23	Lack of Trust as a high-level understanding
24	Not Knowing the Technical Requirements
25	Not Working Towards Joint-Solutions
26	Production & Manufacturing Limitations
27	Company Culture Conflicts with Individual
28	Engineers do not Understand Role of Designers
29	Issues with Team Members
30	Not having Standard / Compatible Software / Files
31	Limitations in Time leading to Poor Engineering
32	Limitations to Size of Electronic Components
33	Creativity and Flexibility of Engineer
34	Marketing Controlling Budget affecting Design Quality
35	Language as a Probable Barrier
36	Knowing who is In-charge / Roles & Responsibilities
37	Unbalanced Team Dynamics
38	Not being Specific when requesting for a Design Representation
39	Not Meeting Schedules / Deadlines
40	Not Using Standard Codes
41	Issues with Multi-cultural Teams
42	Lack of Experience with Multi-Discipline Teams
43	Lack of Team-spirit
44	Over-complexity of Project
45	Marketing Not Understanding Designers
46	Designers Not Understanding Manufacturing Constrains
47	Problems in Testing, Reviewing, Changing, Refining
48	Marketing Slow to Progress
49	Engineering Issues affecting Design Aesthetics
50	Client Changes affecting Design Process
51	Designers not understanding Marketing Viewpoint
52	Sudden budget cuts
53	Difficulty in Explaining Visual Effects to Engineers
54	Company Values not shared among Employees
55	Software Incompetence
56	Not accepting changes
57	Not utilizing Technology for Enhanced Communication
58	Changes in Design due to Safety Requirements
59	Poor Client Involvement
60	Different Education leading to different ways of working
61	Difference between a Designer and an Artist

Table 29: The observations found 3 out of the 61 issues to fall into the category of 'design representations'



It was found that the problem area of design representations emerged in both interviews and the observation study more prominently compared to other issues. In addition, the author's previous work experience also sparked a personal interest to find how and why representations were employed differently among the two disciplines. A decision was therefore made to further investigate the use of design representations by industrial designers and engineering designers.

## **5.6 Chapter Summary**

The empirical research results were found to be in-line with work from Persson and Warell (2003a), Persson (2005a), Kim and Kang (2008) and Kleinsmann and Valkenburg *et al.* (2003; 2007; 2008) who noted differences between industrial designers and engineering designers in terms of their different work approaches and the social factors that might have influenced collaborative design.

This chapter has revealed that there are three problem areas influencing collaborative work among industrial designers and engineering designers during new product development. They are conflict in values and principles, differences in design representation, and differences in education. Of these, the problem area of design representations has been found to be highly significant in both interviews and the observation study and a decision was made to conduct a further investigation.

Having identified a gap in the knowledge where little material and no design tools exist, it is the aim of the next chapter to recommend a suitable tool that would support design collaboration by means of standardised visual design representations among industrial designers and engineering designers during the new product development process. With this remit, the topic of design representations must now be discussed and shall be the theme for the next chapter.



## 6. VISUAL DESIGN REPRESENTATIONS

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### 6.1 Chapter Overview

The purpose of this chapter is to gain an understanding of visual design representations and related issues before recommendations for a design tool can be developed. The previous chapter had linked theory and evidence through empirical research, highlighting three problem areas among industrial designers and engineering designers in new product development. It revealed conflicts in values and principles, dissimilar education backgrounds and differences in the use of representations. A decision was made to focus the study on visual design representations, starting with a detailed review of previous research in the area.

While previous research has been conducted on visual design representations, most have not fully investigated how the use of design representations could support collaboration in new product development. For instance, Romer *et al.* (2001) identified methods that were effective for solution development, testing or documentation, but was limited to only sketches, models and CAD, while Söderman (2002) substantiated that visual design representations were advantageous, but did not provide evidence to show what features should be emphasised in a representation.

The chapter begins by discussing what visual design representations are and their purpose. The chapter then discusses that because of ambiguity, members of a multi-disciplinary group can interpret representations according to their own culture and worldviews and stresses the importance of having a common frame of reference when using representations. Later sections discuss the types of representations used during the phases of new product development, acknowledging a trend that low-fidelity representations are used earlier; while drawings and prototypes tend to be used as high-fidelity representations later. To identify the types of visual design representations, it

is also necessary to identify the materials and tools employed during new product development, which are divided into manual (non-digital) and digital media for a 2D or 3D outcome.

## **6.2 What are Representations?**

Chapter Two discussed the act of design where mental images are first visualised and then processed. They are externalised through words, gestures, references and representations that allow concepts and solutions to be formulated (Bly 1988a; Tang 1989; Eckert and Stacey 2000). Representations are objects or things that stand for something else (Kaplan and Kaplan 1982; Palmer 1987). According to Saddler (2001), design representations are a 'perceptible expression of a design idea, proposal or fact'. For this research, in line with Johnson (1998), 'visual design representations' are defined as artefacts that reproduce properties of a product by means of a physical or digital format. The most common form of visual design representations take the form of marks on paper with colour, shading and text such as those shown in Figure 72 (Arnheim 1969; Brown 2003).

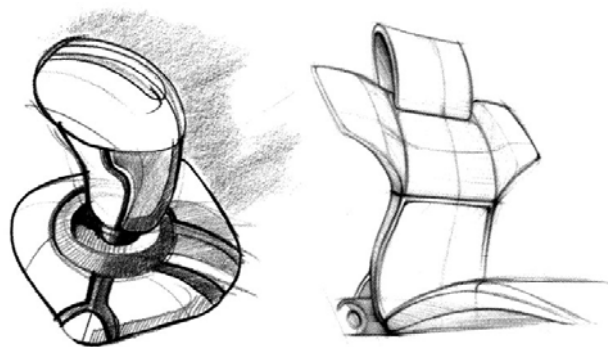


Figure 72: Pencil sketches with shading and varying line thickness (Olofsson and Sjöln 2005)

Traditionally, these paper-based representations are used before computers, thus the term 'pencils before pixels' (Baskinger 2008). Other modes of representations include models, scenario storyboards, working prototypes, 3D CAD models and virtual reality (Van Welie and Van der Veer 2000; Suri 2003).

A pattern can be observed whereby a greater realism is achieved when moving from 2D to 3D representations (Leonard-Barton 1991). Despite the fact that 3D objects are tangible and more realistic, 2D visual design representations offer minimal commitment, are intuitive and easy to create (Lipson and Shpitalni 2000; Holmquist 2005; Cardella *et al.* 2006). In terms of choice, studies by Johansson *et al.* (2001), found that large and small companies used a wide range of visual design representations but advanced technologies such as virtual reality were unpopular as they are expensive and not intuitive.

Several researchers have proposed classifications to group these visual design representations. Chiu (2002) proposed that sketches, orthographic drawings, tables and photographs could be grouped as being asynchronous, while visual presentations with oral explanations were synchronous. Goldschmidt and Porter (2004) proposed four classifications of representations: internal/external, transient/durable, self-generated/ready-made and abstract/concrete (material). Internal representations reside in the mind while external forms include written lists and drawings. Transient representations such as dialogues and gestures are seldom recorded, while durable representations such as physical models can be stored. Self-generated representations like dialogues are created during the design activity, while ready-made representations consist of materials such as cardboard, wood and wire to create objects. Abstract representations leave details undefined, whereas concrete representations such as technical drawings are specific. Saddler (2001) proposed a broad form of classification that encompassed conversations, proposals and plans, spaces and clusters, sketches, symbolic and schematic illustrations, scenarios and storyboards and prototypes as shown in Figure 73. Cain (2005) grouped visual design representations according to their fidelity. Low fidelity representations are limited and only represent certain product features. They allow general matters to be discussed and changes to be made. High fidelity models are complete and closely resemble the final design, allowing detailed discussions

but minor changes to be made. In general, detailed representations are used to obtain finer and more focused issues (Wong 1992; Brandt 2005).

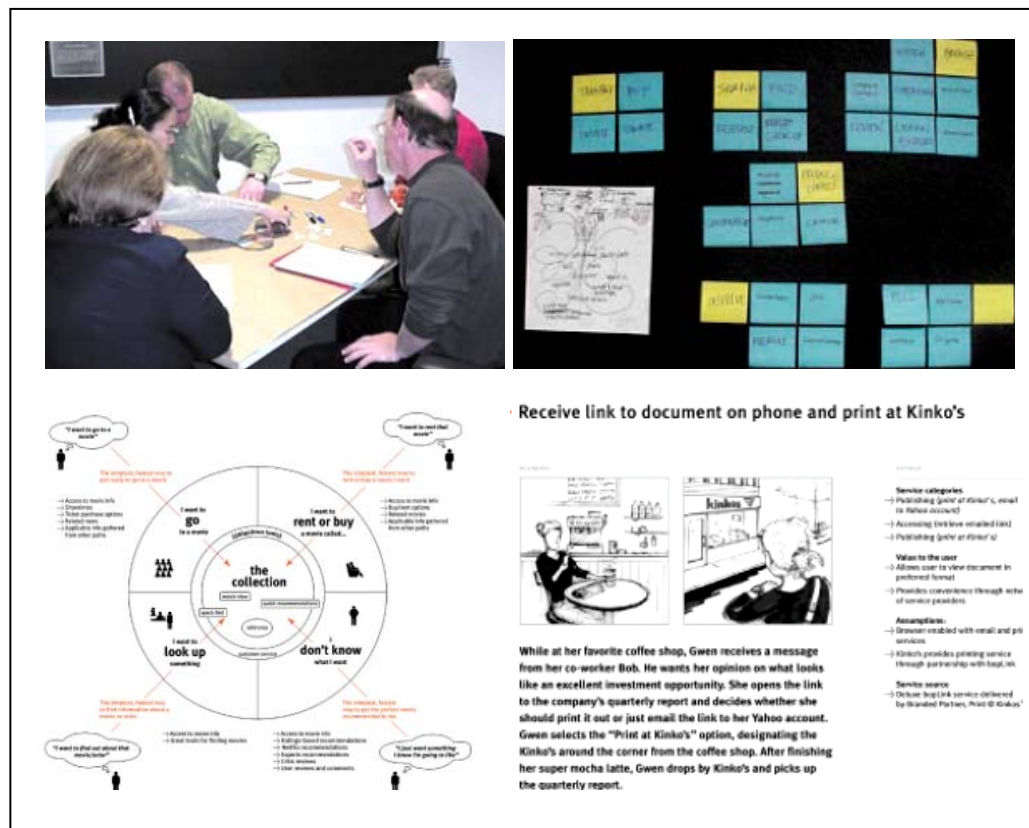


Figure 73: Classification of representations as conversations, information maps, symbolic illustrations and storyboards (Saddler 2001)

Among the quickest form of representations are freehand sketches for personal use or for discussion (Verstijnen *et al.* 1998). Other schematic illustrations are made up of symbols, lines, boxes and arrows to denote hierarchical information; while scenarios and storyboards represent the interaction activities between the user and product. The next section shall describe the purpose of these representations in detail.

### 6.3 The Purpose of Visual Design Representations

When an idea has been crystallised in the mind, it is usually reproduced as a sketch or physical model through hand-eye co-ordination. At this point, the image becomes new information (Purcell and Gero 1998; Tovey *et al.* 2003).

The designer is able to further perceive and identify patterns and to construct new knowledge to develop the next idea (Figure 74) (Schön and Wiggins 1992). This process of interactive conversation occurring between the designer and the material is termed as 'interactive imagery' by Goldschmidt (1991a). It stops when specifications are met, when creativity has been exhausted or when time and cost become a limiting factor.

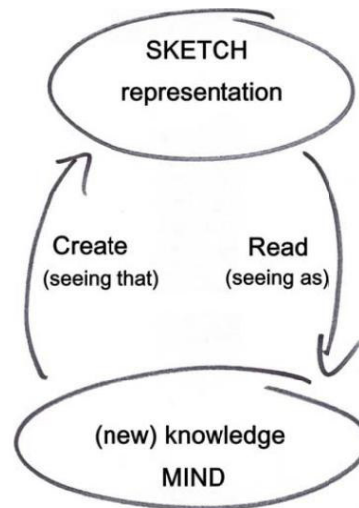


Figure 74: The cycle of sketching and creating new knowledge

Visual design representations relieve the cognitive load from memory to enable further mental processing (Koutamanis 1993; Suwa and Tversky 1997; Schweikardt and Gross 2000; Romer *et al.* 2001). They also serve as an aid that helps ideas to be recalled or for checking (Goldschmidt 1989, 1991b, 1994; Andreasen 1994; Goldschmidt 1995b; Fish 1996; Ulrich and Eppinger 2003; Hendry 2004). It allows designers to assess whether the current idea satisfies the project goals as a whole or at a component level (Purcell and Gero 1998; Seitamaa-Hakkarainen and Hakkarainen 2000). This allows testing, modifications and mistakes to be made before investing on manufacture (Garner 2004). More importantly, representations are open to extension, modification, and interpretation (Schmidt and Wagner 2004). Representations are a 'designer's principle means of thinking' to allow the developer to discover new ideas and to stimulate dialogue for questions, insights, revisions and answers (Suwa and Tversky 1996; Tohidi *et al.* 2006). This has been supported by Gerner (1994) who interviewed 74 experienced

designers and found that 69.3% of the respondents indicated sketching had helped towards developing a solution. Similarly, Engelbrektsson and Soderman (2004) performed studies to investigate types of representations used for design work in general and for communication with customers (Figure 75). Of these, hand sketches, prototypes and construction design drawings were most common and virtual reality rarely used. The results also showed that to communicate with customers, prototypes were most used and 3D CAD was more popular than construction design drawings that were difficult for non-technical viewers.

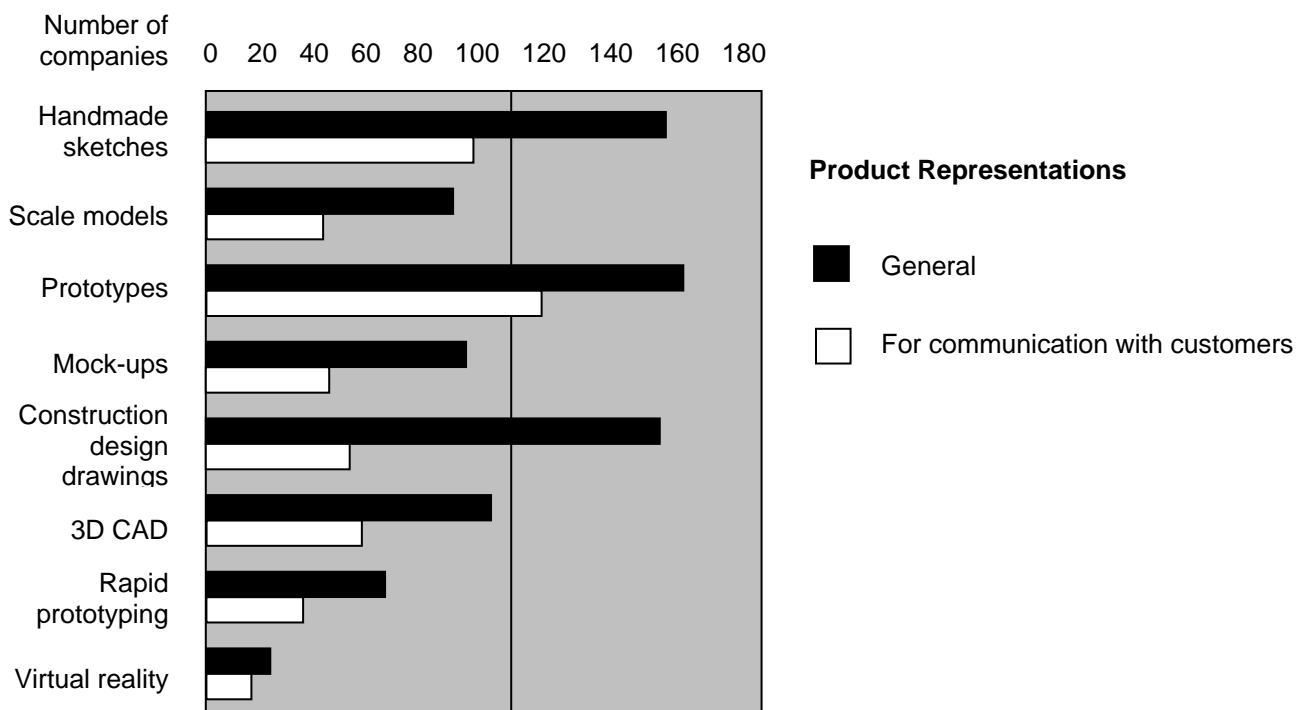


Figure 75: Product representations used by companies in the early phases of product development (Engelbrektsson and Soderman 2004)

Romer *et al.* (2001) found that sketches were most used for developing solutions and for communication, while CAD was used for documentation. Simple models were primarily used for supporting communication; and complex models were popular for testing solutions as shown in Figure 76.



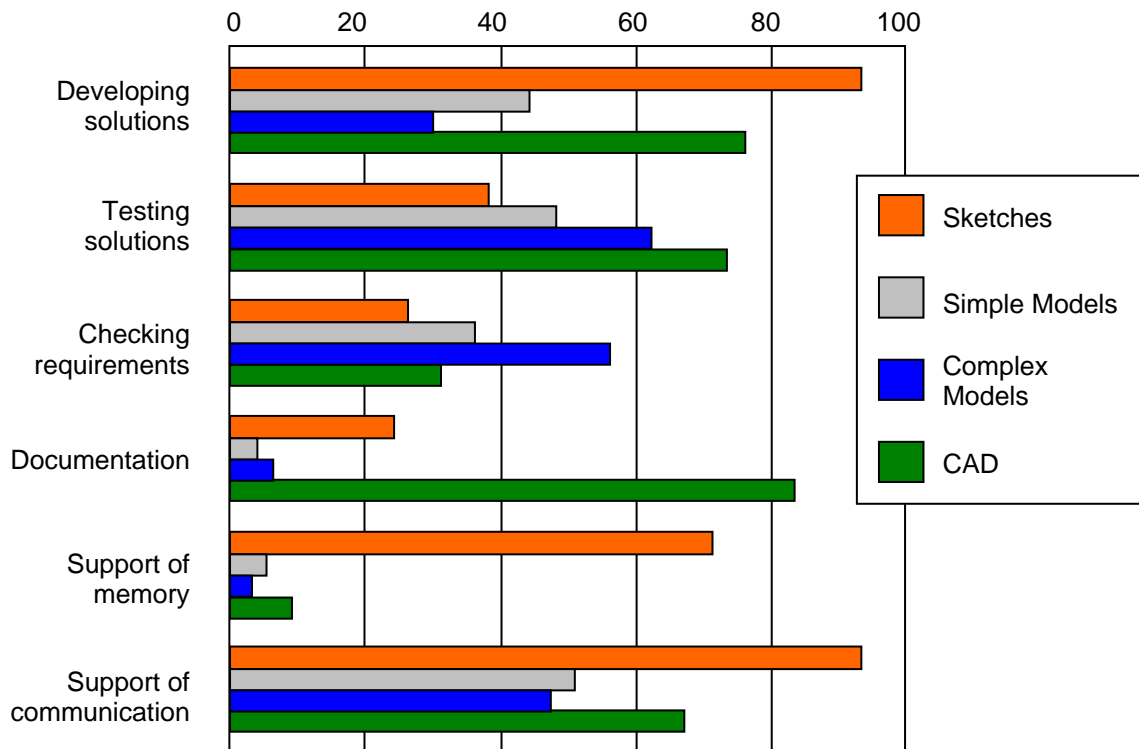


Figure 76: Purpose of external representations (in %) (Romer *et al.* 2001)

In the social context, physical representations enable the developer to convey information to others that might be difficult to express in words (Eckert and Boujut 2003). In another study, McKoy, Vargas-Hernández *et al.* (2001) provided evidence that a graphical representation such as sketching is a preferred medium for expressing and is a better-suited language for producing good design as compared to words in terms of creativity and quality. It enables others to know what one is thinking, allowing them to understand, participate and contribute towards the project. Through integrating the perspectives of different members, and if correctly implemented, shared representations create a common frame of reference among stakeholders, allowing them to consistently compare options and to rationalise the design in terms of form and function (Ferguson 1992; Johansson *et al.* 2001; Do 2002; Buxton 2007). This has been supported by Logan and Radcliffe (2000) who showed that artefacts when used individually and collectively, enabled common reference in terms of visual reference points. Importantly, Goldschmidt (2007) highlighted that sketches allow the mental models of

individual designers to converge for them to see issues eye-to-eye. By acting as a medium for pointing, talking and sketching, they function as mediators; and through manipulation, provide feedback to the person and to the observer (Heath and Luff 1991; Perry and Sanderson 1998; Gutwin and Greenberg 2002). To sum up, they are the foci of interaction that supports collaborative work (Lakin 1990; Robertson 1996; Perry and Sanderson 1998; Eckert and Boujut 2003).

As a key element of the design activity, representations promote communication and the discussion of ideas (Lawson 1994; Scrivener and Clark 1994; Bilda *et al.* 2006). They encourage creative group activities to enable multi-disciplinary members to share the same attitude towards the project (Leonard-Barton 1991; Schrage 1993; Ulrich and Eppinger 2003; Olofsson and Sjöln 2005; Alisantoso *et al.* 2006). They help bridge barriers between different perspectives and to build a platform for sharing ideas, to persuade and to point out issues (Hack and Canto 1984). In the larger picture, visual design representations also support more effective communication with external stakeholders such as model-makers, contractors and the client. Examples of visual design representations such as freehand sketches can be seen in Figures 77 and 78 showing the development of form in the design.



Figure 77: Notebook sketches by Khodi Feiz (Eissen and Steur 2008)

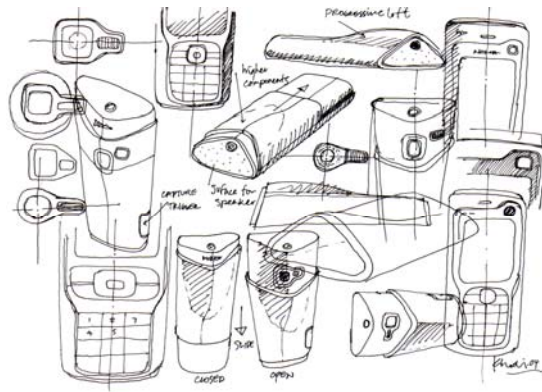


Figure 78: Initial sketches of the Nokia N70 and N80 by Feiz Design Studio (Eissen and Steur 2008)

While manual sketches are frequently used by industrial designers and engineering designers in design practice, the use of Computer Aided Design (CAD) offers different advantages by allowing storage, transmission and rework of designs relatively quick. Despite these benefits, manual sketching on paper still presents a much faster and freer approach without the need to type commands or to specify determined shapes or sizes (Do 2002). Computer images are better suited for working in detail as they can be rotated, moved and visualised realistically on the computer (Utterback *et al.* 2006). In terms of digital 3D modelling, CAD surface modelling is more commonly used to model aesthetics, while solid modelling provides technical precision (Johansson *et al.* 2001; Cross 2007).

Regarding technical aspects, Ullman *et al.* (1990) has acknowledged the importance of representations in engineering. These include technical drawings or construction plans that provide instructions for fabrication (Lawson 1997). Other representations such as scaled drawings allow greater control when managing the magnitude of parts (Jones 1974). Exploded views (Figure 79) show overlapping components positioned in a uniform direction and describe component relationships in terms of assembly and manufacture, while structured diagrams illustrate connections, analysis and graphical data (Ulusoy 1999). Towards the later stages, representations are used to check and detect last minute errors (Boote 2006).

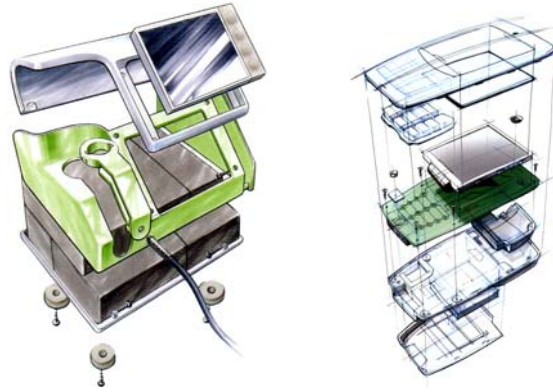


Figure 79: Exploded view drawings (Olofsson and Sjöln 2005; Garner 2006)

Technical details are not limited to engineering designers. Industrial designers may also incorporate these details to sketches to allow engineers to better understand the design. Examples include Sir Alec Issigonis' sketch for the Austin Mini (Pipes 2007) (Figure 80) and a sketch showing the folding mechanism for an artist's easel (Garner 2006) (Figure 81).

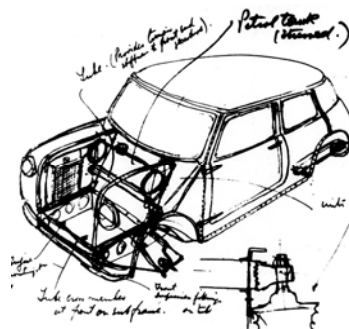


Figure 80: Technical sketches for the Austin Mini (Pipes 2007)

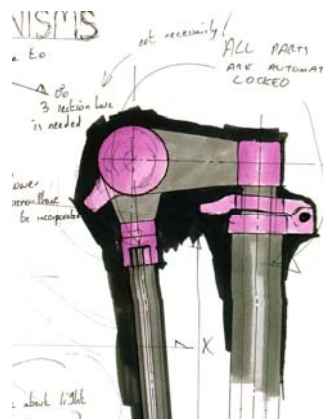


Figure 81: Sketches showing the folding mechanism of an easel (Garner 2006)

In terms of industrial design, Olofsson and Sjöln (2005) summarised that sketches have four main uses: for investigation, exploration, explanation and persuasion. They emphasise aspects of form, size, proportion and colour. 2D representations may be drawn in different perspectives to explain shapes and connections that would otherwise be limited if seen from only one view. Other benefits in terms of visual understanding include step-by-step illustrations (Figure 82) that explain actions, such as how an object would work; or using cross-section lines to describe the shape and form. Visual design representations may also be used as a persuasive tool to sell the design concept to the management and marketing team (Tovey 1989; Löwgren 2004).

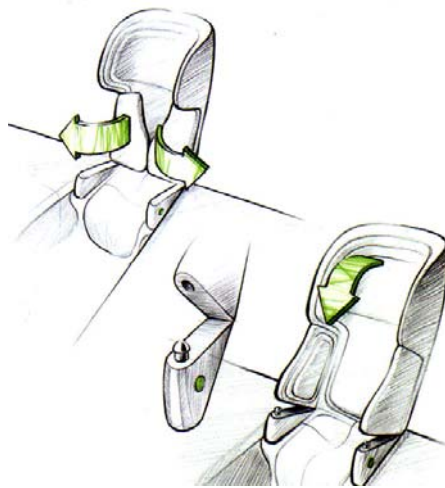


Figure 82: Step-by-step illustrations (Olofsson and Sjöln 2005)

By adopting the classification of Visser (2007), the purpose of visual design representations can be grouped into four key areas including personal, social, aesthetic and technical aspects (Table 30). In a personal setting, visual design representations assist in achieving a clearer mental processes, for cognitive off-loading, recording, organising, reasoning and discovery. In terms of social aspects, they aid towards communication and support group activities. They integrate the perspectives of multi-disciplinary members and to forge a common frame of reference. Aesthetic aspects are concerned with how a design can be communicated or visualised, while technical aspects are about the technical or functional details behind the design. Some design representations such as a vague sketch may have multiple purposes and this phenomenon is regarded as 'ambiguity' which is now discussed.

Personal Aspects	
1.	Makes it easier to convey information difficult to express in words
2.	Acts as cognitive artefacts that suggest new meanings
3.	To envision the design before manufacture
4.	As a persuasive tool to sell the idea to management or marketing
5.	To record thoughts
6.	Serves to generate further ideas
7.	To obtain information from a potential end-user or the client
8.	Serves as a communication medium for ideas to be expressed
9.	Relieves the cognitive load from memory
10.	Structures information and represent data graphically
11.	Allows the developer to focus on details or to look at the product as a whole
12.	Does not require huge commitments in terms of time and cost
Social Aspects	
1.	Stimulate dialogues among the group to achieve better design
2.	Allows members to compare options easily
3.	Shows stakeholders what one is thinking, enabling participation
4.	Supports creative group activities
5.	Helps to coordinate work within the group
6.	Serves as a communication medium for ideas to be expressed
7.	Integrates the perspectives of different functions
8.	Allows stakeholders to obtain important design knowledge
Aesthetic Aspects	
1.	Makes it easier for a complex design to be visualised
2.	Allows greater control in the relationships of parts
3.	To visually assess whether current idea meets the project objectives
4.	Explains a series of actions e.g., step-by-step illustrations
5.	Enhances awareness of visual details such as shape, texture and colour
6.	Allows the developer to test aspects such as size, proportion and colour
7.	Shows various viewpoints for a better understanding of shape and connections
Technical Aspects	
1.	Allows the checking of final changes and detect last minute errors
2.	Incorporate technical details made available for engineering designers
3.	Shows the relationship of parts in terms of assembly and manufacture
4.	Highlights technical or functional aspects behind the idea

Table 30: Use of visual design representations in 4 key areas

## 6.4 Ambiguity in Visual Design Representations

The term ‘ambiguous’ means that a subject is capable of being understood in more than one way (Longman Dictionary 2005). Being ambiguous could also mean that an object is vague and imprecise (ibid). Visual design representations used early in product development may be incomplete but allows flexibility in terms of design attributes. They enable seeing things in a different way that in turn produces new designs (Fish and Scrivener 1990;

Goldschmidt 1991a; Schön and Wiggins 1992; Park 1996; Suwa *et al.* 2000). The more incomplete or vague a representation is, the greater and wider the perceptual interpretation space becomes. An example of an ambiguous representation can be seen from the shapes in Figure 83 that may look like rectangles, trapezoids or simply irregular shapes. In contrast, a 3D CAD wire-frame model is precise so its perceptual interpretation space is limited (Stacey and Eckert 2003).

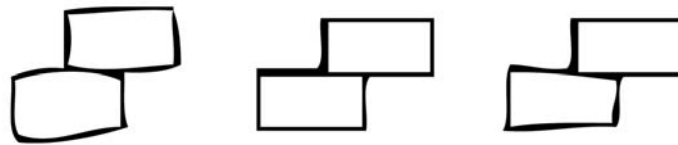


Figure 83: Ambiguous shapes (Stacey and Eckert 2003)

While ambiguity may be useful for creativity, Eckert and Stacey Eckert (2000) cautioned that it may have adverse effects in hand-over situations. Their studies showed that when incomplete, inaccurate and inconsistent representations are submitted, recipients interpret according to their own experience and end up with designs that do not reflect the original intent. In light of this, researchers (Eckert and Stacey 2000; Eckert and Boujut 2003) proposed that ambiguity may be removed by improving the accuracy of the representation such as having cross-section lines to describe the profile (Figure 84).

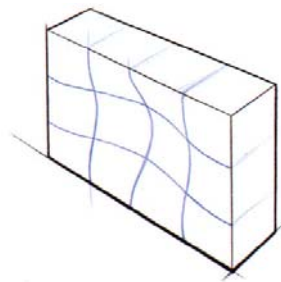


Figure 84: Cross-section lines (Olofsson and Sjöln 2005)

According to Stacey and Eckert (2003), unintentional ambiguity may arise because of misread codes, contradicting values and missing information; and also occurs when notational conventions are in conflict. For example, the lines



on the garment sketch in Figure 85 were intended to describe the structure pattern, but they could also be interpreted as coloured stripes. Ambiguity also happens when symbolic elements become unclear. For example, the sleeves of the garment sketch are meant to be equal but have been drawn in a distorted manner.



Figure 85: Ambiguous sketch of a garment (Stacey and Eckert 2003)

In a separate study to identify the perceived level of technical content or form, Engelbrektsson and Soderman (2004) revealed that hand-made sketches received the lowest score because of the high level of uncertainty and vagueness as shown in Figure 86. In contrast, virtual reality and rapid prototyping provided high levels of technical content and form.

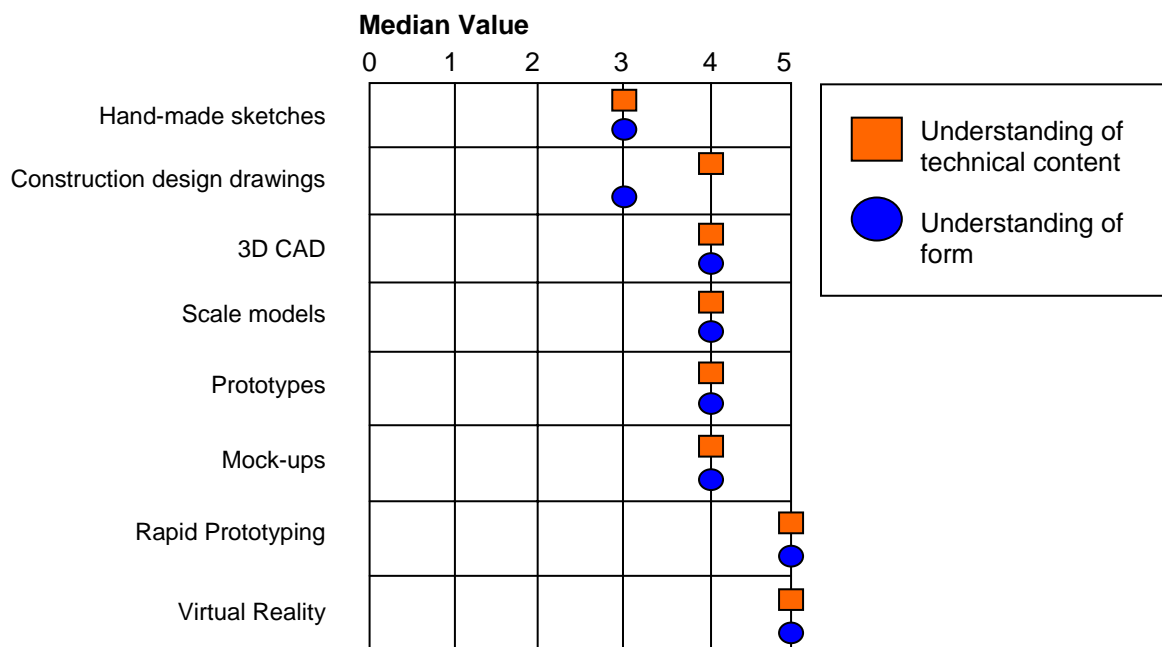


Figure 86: The perception of representations in terms of technical content and form (Engelbrektsson and Soderman 2004)



Buur and Andreasen (1989a) purposed a matrix in Figure 87 showing the level of detail in a visual design representation. The sketch at the top left-hand corner is vague and representations down the matrix increase in their level of detail. From left to right, the representations take on a 2D to 3D form. In conclusion, a purposeful representation should provide a level of fidelity that matches the intended requirements. Too little fidelity makes the representation unclear, yet high-fidelity makes the representation completely over-done with no room for creativity, improvement or refinement (Buxton 2007).

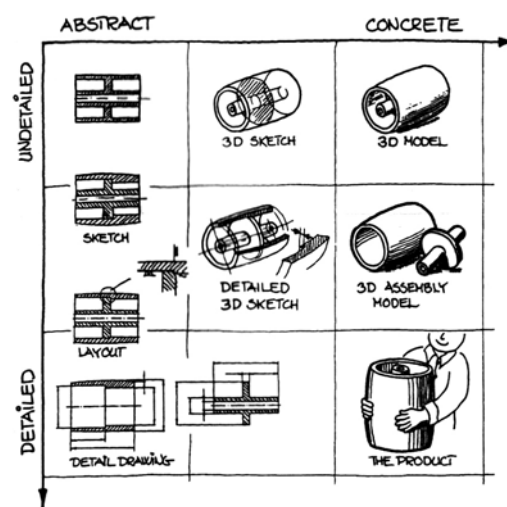


Figure 87: Degree of abstraction and level of detail in a visual design representation (Buur and Andreasen 1989a)

## 6.5 A Common Ground in Visual Design Representations

Section 6.3 discussed that a shared visual design representation would help create a common ground among multi-disciplinary members. To achieve a common frame of reference or having a shared context, members must undertake a collective effort to establish a mutual understanding. There should be a firm agreement toward motives, intentions and interpretations (Dummett 1993). The representations must have a consistent meaning across disciplines and a suggestion is to use prototypes and documents together whereby the prototype clarifies the design intent while documents provide the right context to interpret the artefact (Ostwald 1995). However, producing prototypes involve major commitment in terms of cost and time and is

impractical for some projects. Other scholars have proposed the use of 'cognitive synchronisation' (Falzon 1994) with the aim of achieving compatible representations. However, Bucolo (2007) suggested that rather than focusing on a common ground for better collaboration, it could be possible to retain the strengths of each discipline while bridging them with a common language. But because words such as 'concept', 'context' or 'prototype' may have different meanings, the project leader must be able to translate between the disciplines' interpretations. The project leader should also be able to keep members focused on the overall outcome (a common ground), yet ensuring that each member has the freedom to explore discipline-specific concerns. A recent study by Kim and Kang (2008) identified eleven critical success factors of cross-functional teamwork where 'a unified culture with partners' was viewed as the most important. They also noted that a culture with common language and common geographic conditions would forge good relationships between stakeholders.

When visual design representations are used among the developer and the object; or between several stakeholders, it is termed as 'intermediary object', (Vinck and Jeantet 1995), 'coordinative artefact' (Schmidt and Wagner 2002), or 'boundary object' (Star 1989; Maier *et al.* 2007). They retain their primary purpose across the organisation, yet still allowing use within each discipline. They take the form of artefacts, language and representations. (Wenger 1998; Boujut and Laurillard 2002). Therefore, members need to be clear about the intent and nature of the representation. In addition, as different viewpoints exist among stakeholders, members interpret an object differently or select different aspects from the same representation (Visser 2007). This again justifies the need for a design tool that would allow an understanding regarding the use of visual design representations as boundary objects - that is an interface between multi-disciplinary members.

## 6.6 Visual Design Representations Used in Stages

As visual design representations have different purposes, they are employed during different stages of product development (Dorta 2008). The four stages as discussed in Section 2.5, comprise concept design, concept development, embodiment design and detail design. Yamamoto *et al.* (2000) described two distinct spectrums of representations linked to the stages of design. At one end, visual design representations in the early stages are used for problem solving. On the other end towards the later stages, they are solution-based and embody aspects of the design into a final product. Romer, *et al.* (2001) also investigated the application of representations during the stages of task clarification, conceptual design and embodiment design (Figure 88). They found that 95% of the respondents used rough sketches during conceptual design, 67% used 2D and 3D CAD and 58% used prototypes. Over half of them (52%) used simple scaled models and just over a third (37%) employed models with ready-made materials. Technical representations such as simulations (13%) and virtual reality (5%) were rarely used. However, their study did not cover representations such as drawings, CAD models and prototypes.

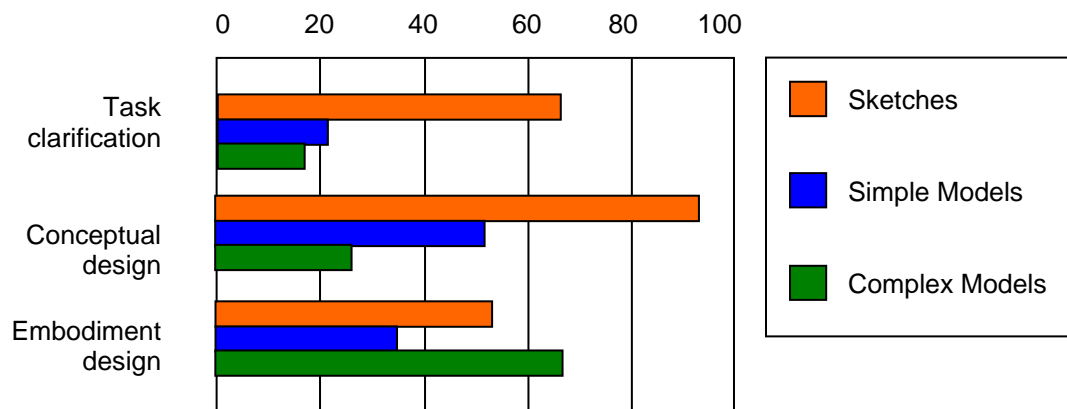


Figure 88: Frequency of use of external representations in the stages of the design process (Romer *et al.* 2001)

Buxton (2007) provided a clear summary by proposing a table consisting of four key groups of representations used according to their respective design stages shown in Table 31. Each stage is now discussed in detail.

Detail	Stage	Representation	Purpose
Low	Concept Design	Freehand sketches, rough physical models, etc.	For externalising and visualising the design intent and for communication
Medium	Concept Development	Digital 3D CAD models, drawings, etc.	To better communicate concepts to external members and clients
High	Embodiment Design	Technical drawings, plans or sections and rapid prototyped models, etc.	To communicate exact and definitive information to build the artefact
Very High	Detail Design	Detailed technical drawings, prototypes etc.	To accurately document the design ready for manufacture

Table 31: Summary of visual design representations used at each design stage

At the concept design stage, unstructured forms such as sketches, abstract diagrams and sketch plans are commonly used (Figure 89) (Purcell and Gero 1998). Most of them are based on pen and paper to allow rapid externalisation, although rough physical models may also be used (Chen *et al.* 2003). They enable the developer to take full control without requiring unnecessary time commitment and to externalise the design intent spontaneously (Temple 1994). The aim is to translate ideas quickly and uncover ideas with only the key elements that are necessary (Judson 1980; Yamamoto *et al.* 2000). In addition, when externalising mental images, the representations should be ‘fluid, abstract, ambiguous and imprecise’ (Goel 1995).

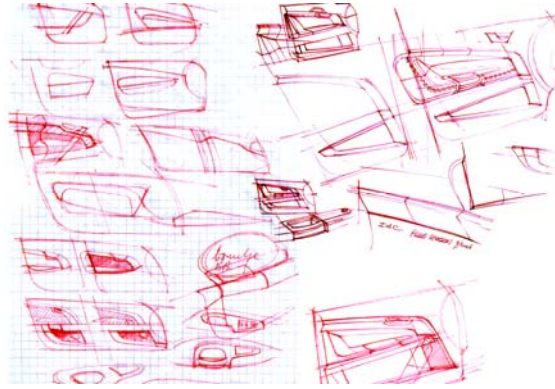


Figure 89: Concept design sketches for a vehicle door panel exploring shapes between components (Eissen and Steur 2008)

At the concept development stage, the aim is to formulate a more concrete design and to combine visual and factual description for ideas to be selected, retrieved and evaluated (McGown *et al.* 1998). The representations are less abstract and feature more practical aspects as compared to concept design sketches. As they would be presented to external members for feedback, they tend to be more realistic. Some examples of visual design representations used at this stage include perspective, isometric and axonometric drawings in 2D.

At the embodiment design stage, the aim is to communicate the selected design to the stakeholders. Common visual design representations include 3D CAD models and line drawings (Figure 90). Physical models may also be employed to confirm that the specifications are met. At this stage, exploded views are also sometimes used to clarify technical and manufacturing aspects and to respond to production issues (Pipes 2007).

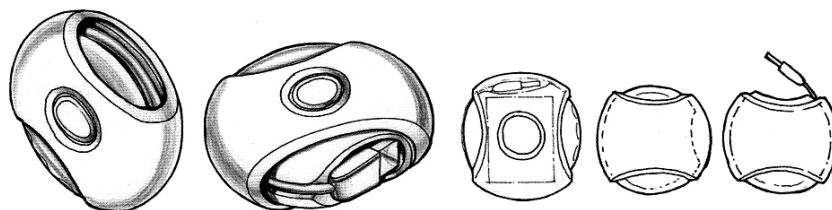


Figure 90: Sketches showing technical details with 2D CAD drawings of a portable hard drive (Pipes 2007)

The detail design stage requires representations that are highly structured so as to accurately document the design for manufacture (Purcell and Gero 1998). They are precise, complete and accurate by having standards such as projection drawings with plan, elevation and auxiliary views to communicate the form and geometry (Figure 91) (Pipes 2007).

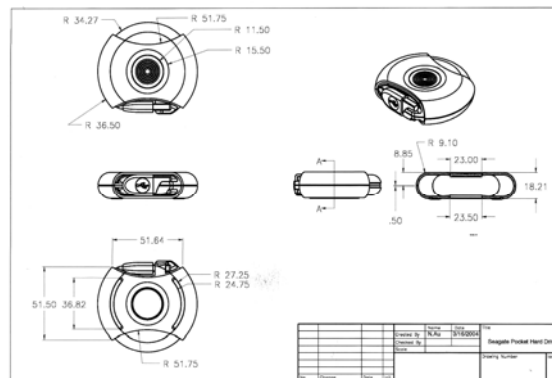


Figure 91: Final technical drawings for manufacture (Pipes 2007)

In summary, it has been shown that different visual design representations are used because of the different requirements at each stage. A pattern can be observed whereby there is an increase in the level of detail of representations used as the development progresses. Having acknowledged the significance of visual design representations and their application during different stages of the design process, the tools and materials used to create these representations shall now be discussed.

## 6.7 Visual Design Representation Media

According to Tjalve *et al.* (1979b) and Buur and Andreassen (1989a), there are six key aspects forming a morphology that should be considered before creating a visual design representation. First, the modelled properties such as the structure, form, material, dimension and surface must be determined. Second, the receiver must be identified who in turn sets the criteria. Third, choose the codes i.e. graphic symbols used to convey information for communication such as electrical symbols and drafting conventions (sectioning, lines, projections and dimensions). Next, the technique, or the method used to create the representation in turn reflects the quality of the

representation. Fifth, tools such as pencils or pens must be chosen. Lastly, the right representation medium such as paper or a digital format needs to be selected. This is summed up in figure 92.

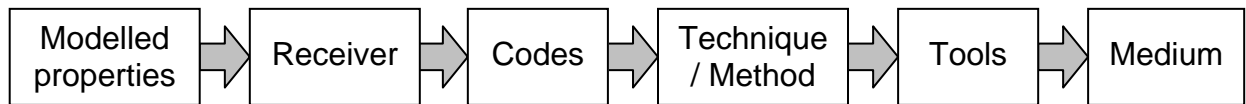


Figure 92: Morphology of design modelling (Andreasen and Olesen 1993)

The term ‘medium’ (plural: media) refers to tools and materials where something can be expressed, communicated or achieved (AskOxford 2008). Pavel (2005) commented that the choice of medium should enable the designer to express ideas quickly without losing the design intent. Gantz (2005) commented that today’s media have also evolved to support faster development work, providing more accessibility and being more economical. For this research, representation media have been grouped into four classifications as shown in Table 32: 2D manual media, 2D digital media; 3D manual media or 3D digital media.

World / Type	Manual Media	Digital Media
<b>2D representations</b>	2D manual media: Paper, pencils, erasers, pens, markers, charcoal, airbrush, conte crayons, gouache, water colour, geometry set consisting of compasses, dividers, rulers, protractors, set squares, stencil templates, French curves and bendy splines, etc	2D digital media: Keyboards, mouse, digital pens, 2D image scanners, digital tablets, computer tablet, vector graphic editors and raster graphic editors, etc
<b>3D representations</b>	3D manual media: Paper, cardboard, plastic sheets, baking clay, balsa wood and rigid cellular foam, wires, epoxy resin, crafting knives, hot glue guns, files, sandpapers and spray paints, etc	3D digital media: Keyboards, mouse, 3D mouse, digital pens, 3D image scanners, cybergloves, haptic force feedback devices, Solid CAD modelling, surface CAD modelling, additive fabrication, subtractive fabrication and formative processes, etc

Table 32: Examples of design representation media

The term 'manual' refers to the act of making or working on something with one's hands as opposed to digital methods (AskOxford 2008). It is an 'analogue' approach where the qualities or properties of an object are changed by physical methods (Longman Dictionary 2005). For this research, '2D manual media' is used to describe the use of materials such as pens, pencils and markers with other hand equipment to produce a 2D visual design representation (Figure 93) through hand-eye coordination and articulation without computers.

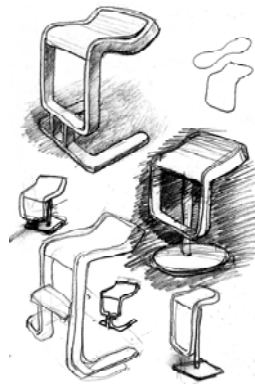


Figure 93: Pencil sketches by Shin Azumi for a stool (Pipes 2007)

The term digital refers to the use of a system in which information is created, recorded or sent electronically by computers (Longman Dictionary 2005). For this research, '2D digital media' is used to describe electronic forms of media created, viewed and manipulated by computer to produce 2D visual design representations. Digital input devices allow the developer to enter data into the computer. They include keyboards, digital pens, 2D image scanners and digital tablets with the use of a graphic editor (Figure 94).



Figure 94: Wacom Cintiq digital tablet



In contrast, working on '3D manual media' may take the form of simple pieces of paper and cardboard, to large clay models (Figure 95). The more popular materials are paper, cardboard, plastic sheets, baking clay, balsa wood and rigid cellular foam. Other tools include solvent glue, wires, epoxy resin; and tools include crafting knives, hot glue guns, files, sandpapers and spray paints. The use of 3D manual media is advantageous as it allows a hands-on approach to explore and evaluate the design that may be too complex to visualise on computer.



Figure 95: The use of full-scale clay models (Corbet 2009b)

Lastly, '3D digital media' is associated with using Computer Aided Design (CAD) to produce 3D digital visual design representations either on screen or as a 3D physical model. The advantages of using CAD include faster speed, greater precision, more efficient modifications and ease of information transfer (Schweikardt and Gross 2000). Other advantages include reproducing the design as a photo realistic image or viewing it from various angles with a choice of colour or texture (Figure 96).



Figure 96: Various textures and materials can be mapped to make a 3D CAD model more realistic (Pipes 2007)

The output from a 3D Digital media can be used to produce physical parts by means of additive fabrication, subtractive fabrication and formative processes (Kai and Fai 1997). Additive fabrication is the manufacture of parts by building a layer at a time and includes the use of rapid-prototyping technologies that produce the physical model based on 3D CAD data (Romer et al. 2001). Rapid prototyping may be categorised as liquid-based e.g. Stereolithography (SLA); solid-based e.g. fused depositional modelling (FDM); or powder-based e.g. selective laser sintering (SLS) (Kai and Fai 1997). While additive fabrication builds a successive layer of material at a time, subtractive fabrication trims a solid block of matter by means of drilling, turning, milling, etc. (Figure 97). Lastly, formative processes involve using mechanical or restrictive forces to shape parts by means of forging, injection moulding, etc. (Kai and Fai 1997). Other compressive methods include smithing, rolling, bending and pressing. They may be worked with hand tools or with machines such as a press tool that reforms a piece into a 3D object.



Figure 97: CNC milling on a medium-density fibreboard

For navigation in a virtual 3D space, devices such as the SpaceNavigator (Figure 98) enable users to push, pull, twist or tilt the controller cap to achieve panning, zooming and rotating functions. Other systems include the use of a SensAble FreeForm system (Figure 99), Omega's haptic force feedback device (Figure 100) or with 'Cybergloves' to provide sensory input to the viewer based on physical attributes such as solidity, elasticity and surface texture (Bishop 2001).



Figure 98: Panning left / right and zoom, panning up / down and rotate, and tilting functions with the SpaceNavigator controller cap



Figure 99: The SenseAble Phantom haptic input device (Pipes 2007)



Figure 100: The Omega haptic force feedback device (Pipes 2007)

## 6.8 Chapter Summary

The chapter has described that visual design representations have several key purposes. For example, the use of representations allow the developer to externalise the mental image of the design, as a language of communication with other stakeholders, and to allow the team to better visualise and foresee the design before committing to manufacture. The earlier sections highlighted that although low-fidelity representations such as sketches and models were useful for creativity, their vagueness is prone to incomplete, inaccurate and inconsistent interpretation among members from different disciplines (Figure

101). The chapter also stressed the need for a common ground when employing visual design representations so that members are clear about the design intent and to recognise what it signifies to the receiver. The section on visual representation media has provided a review of the tools and materials used in terms of manual and digital media. The next chapter shall discuss the types of visual design representations and key design and technical information from the literature review.

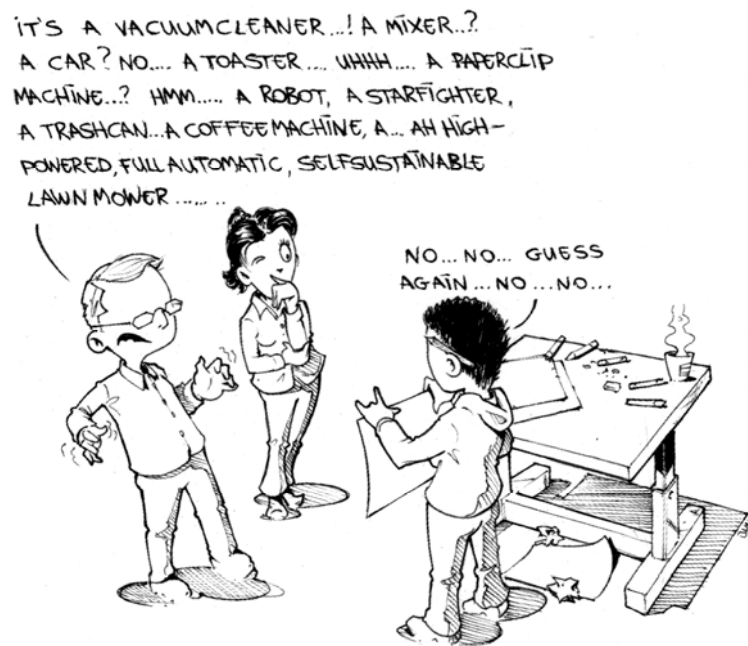


Figure 101: Ambiguous representations cause confusion and misinterpretation (Eissen and Steur 2008)

## **7. TYPES OF VISUAL DESIGN REPRESENTATIONS AND KEY DESIGN & TECHNICAL INFORMATION**

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### **7.1 Chapter Overview**

This purpose of this chapter is to provide an overview of visual design representations employed by industrial designers and engineering designers during new product development by means of a literature review. With the exception of several papers and books, little work has been done to provide an inclusive source of reference for visual design representations used by industrial designers and engineering designers during new product development. The Design Secrets series of books (IDSA 2003; Haller and Cullen 2006) provided case-studies but only briefly described the representations that were employed. Other books focused on sketches or drawings (Tjalve *et al.* 1979b; Olofsson and Sjöln 2005; Pavel 2005; Pipes 2007; Eissen and Steur 2008), while research by Evans (2002) covered only models and prototypes; and Cain (2005) only provided an overview of conventional and digital representations.

The list of visual design representations was then classified into four taxons consisting of sketches, drawings, models and prototypes being established as the top-level categories which were further expanded downwards into sub-categories as discussed in the next section. Finally, the chapter reviews the design and technical information relevant to new product development from the literature. Design information is concerned with visualisation, aesthetics and usability of the product, while technical information is concerned with issues such as assembly, mechanism and materials.

### **7.2 Taxonomy of Visual Design Representations**

From the literature, various design representations that have been employed by industrial designers and engineering designers were mapped out. They are shown as graphic representations (comprising sketching and drawing); and



modelling (comprising models and prototypes) (Figure 102). A more defined classification was then made to distinguish each of the sketches, models, drawings and prototypes (Figures 103, 104).

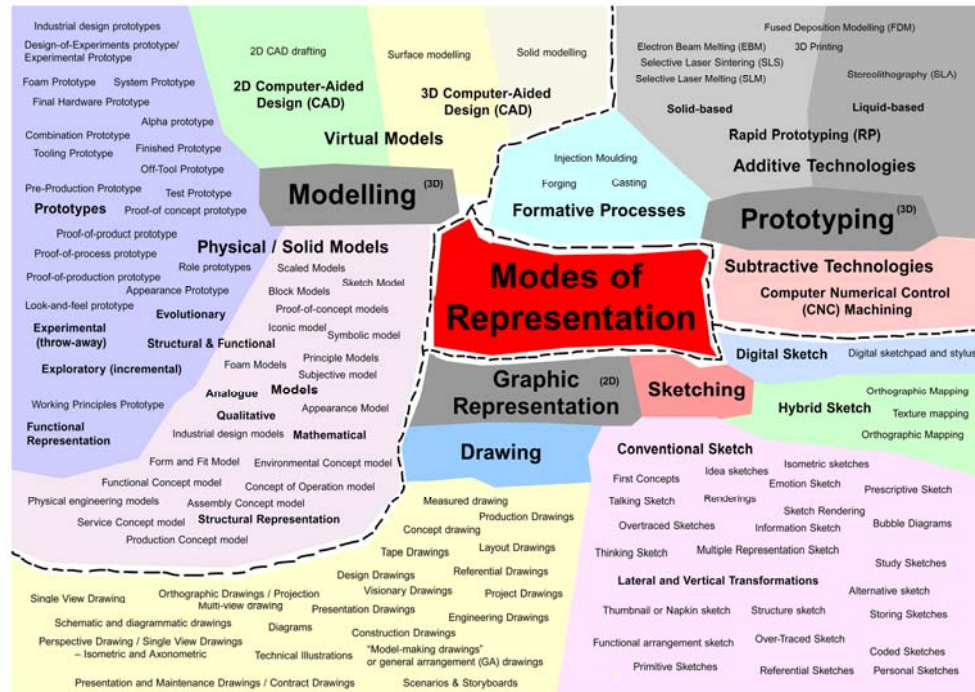


Figure 102: Modes of representation (initial overview of various design representations)

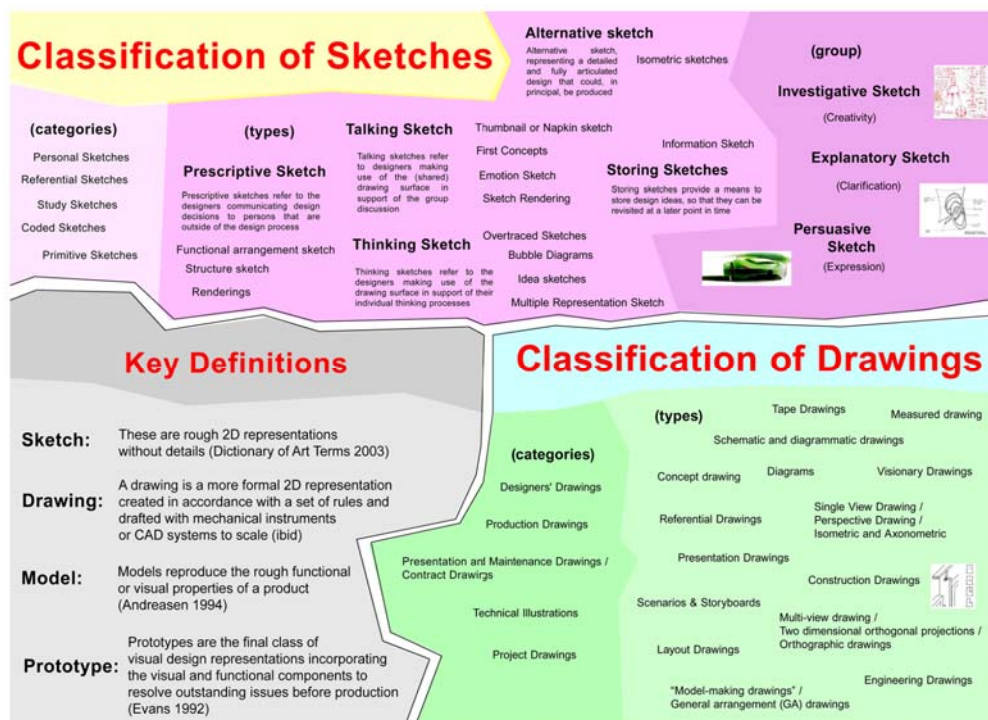


Figure 103: Classification of sketches and drawings

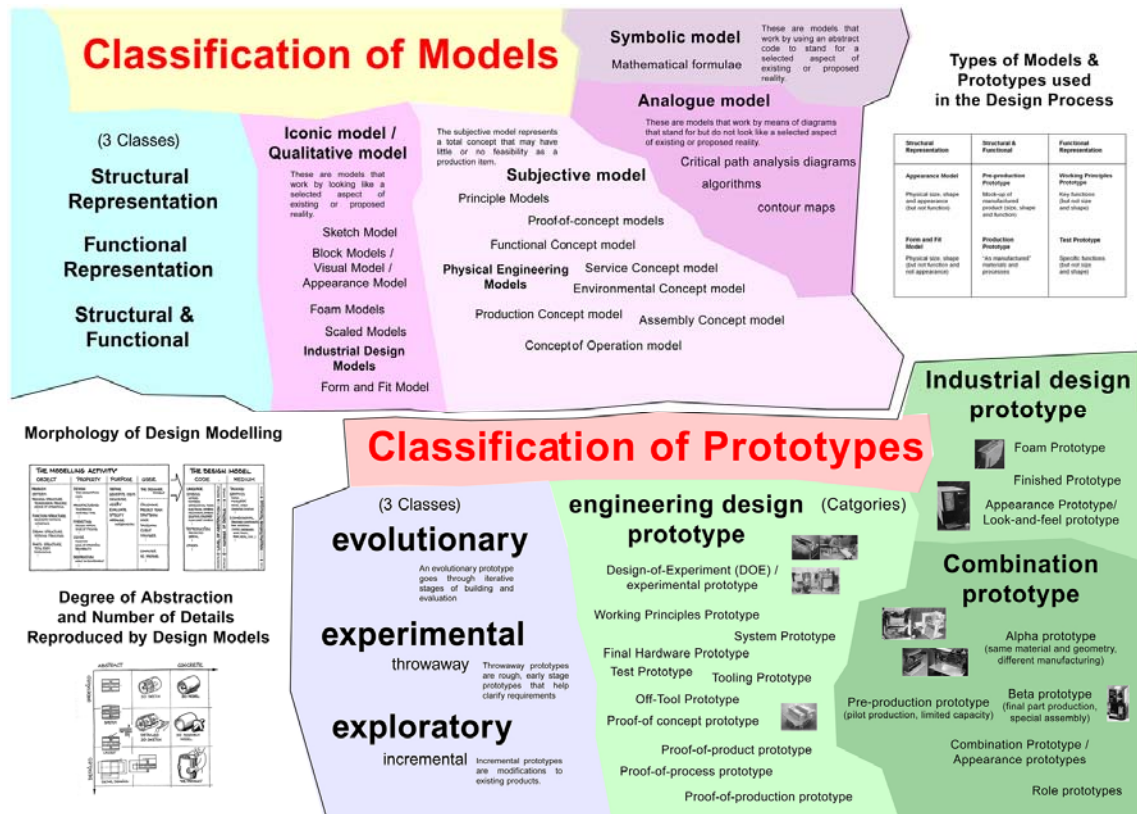


Figure 104: Classification of models and prototypes

As several of the terms overlapped, a more organised framework was developed as shown in Table 33 to represent the four groups of visual design representations, sub-groups and representations. To further distinguish the visual design representations, sketches and drawings are classified as 2D visual design representations as the final output is paper or screen-based, while the final output of models and prototypes are usually physical and have a more tangible presence. They are hence classified as 3D visual design representations. From the framework of visual design representation groups (Table 33), a decision was made to develop this information into a taxonomy in which Ostergaard and Summers (2009) referred to it as 'a study of arrangements'.

Group		Sub-group	Visual Design Representation
2D Visual Design Representations	Sketches	Personal Sketches	Idea Sketch Study Sketch Referential Sketch Memory Sketch
		Shared Sketches	Coded Sketch Information Sketch
		Persuasive Sketches	Renderings Inspiration Sketch
		Handover Sketches	Prescriptive Sketch
	Drawings	Industrial Design Drawings	Concept Drawings Presentation Drawing Scenario & Storyboard
		Engineering Design Drawings	Diagram Single-View Drawing Multi-View Drawing General Arrangement Drawing Technical Drawing Technical Illustration
3D Visual Design Representations	Models	Industrial Design Models	3D Sketch Model Design Development Model Appearance Model
		Engineering Design Models	Functional Concept Model Concept of Operation Model Production Concept Model Assembly Concept Model Service Concept Model
	Prototypes	Industrial Design Prototypes	Appearance Prototype Alpha Prototype Beta Prototype Pre-Production Prototype
		Engineering Design Prototypes	Experimental Prototype System Prototype Final Hardware Prototype Tooling Prototype Off-Tool Prototype

Table 33: Framework of visual design representation groups

This taxonomy in the form of a hierarchical format (Figure 105) clearly shows the four major groups of sketches, drawings, models and prototypes. Each of these groups are further sub-divided. Visual images of each representation were also obtained from the literature (Figure 106) which consequently created the final taxonomy shown in Figure 107. This image was used in a postgraduate researcher's poster competition (Figure 108) held in 2006 that obtained a finalist prize. Each of the visual design representations and its categories shall now be discussed.



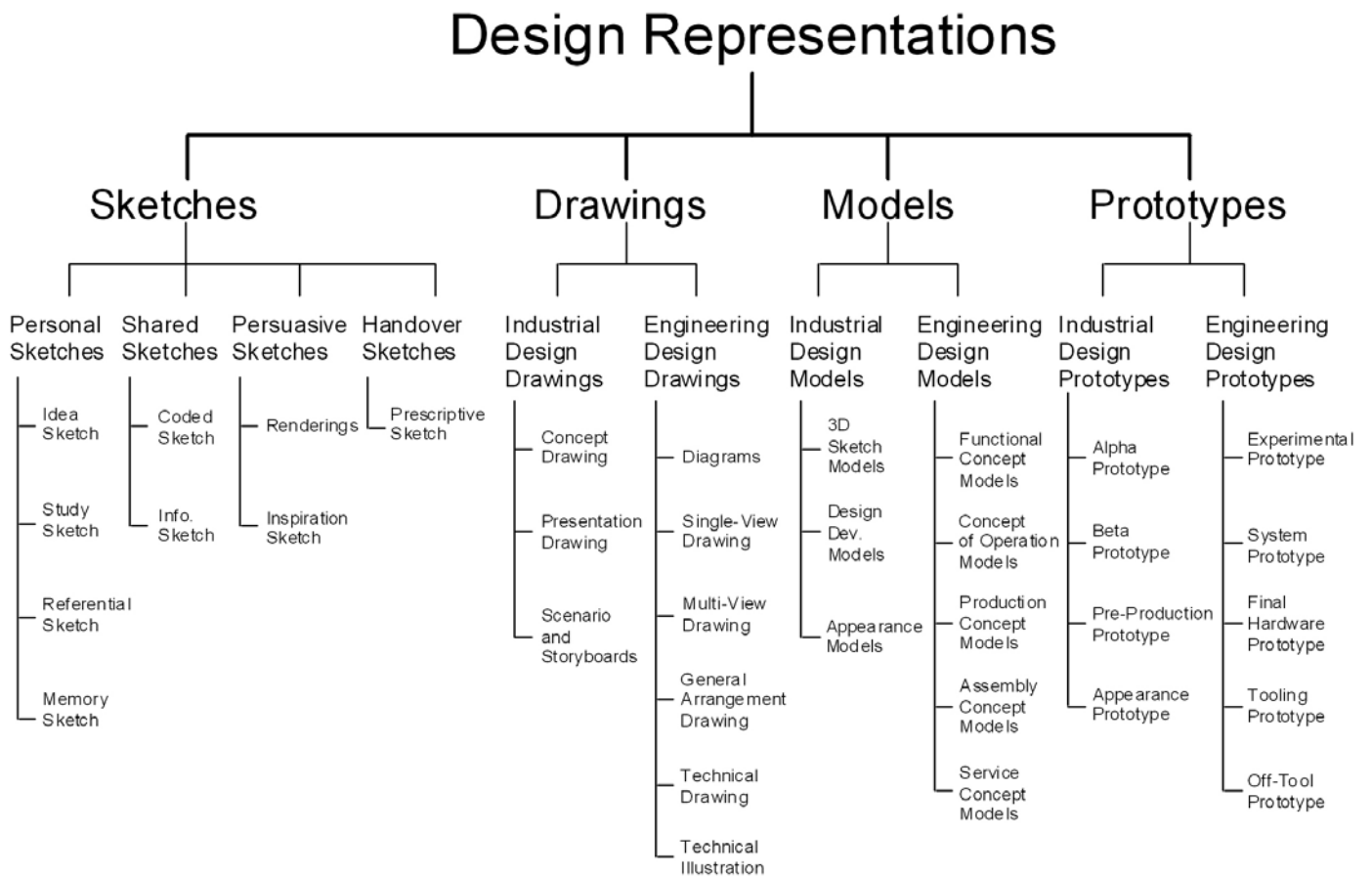


Figure 105: Taxonomy of Design Representations

# sketches

# drawings

# models

# prototypes



Figure 106: Visual images of each design representation

# Taxonomy of Visual Design Representations

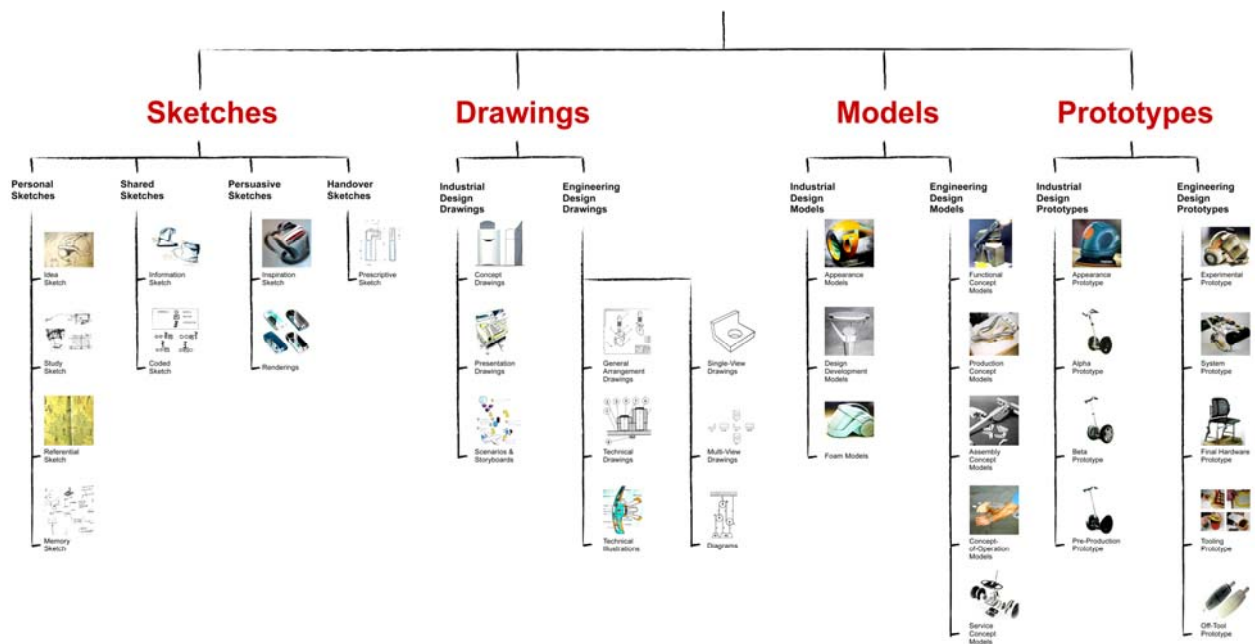


Figure 107: The Taxonomy of Visual Design Representations

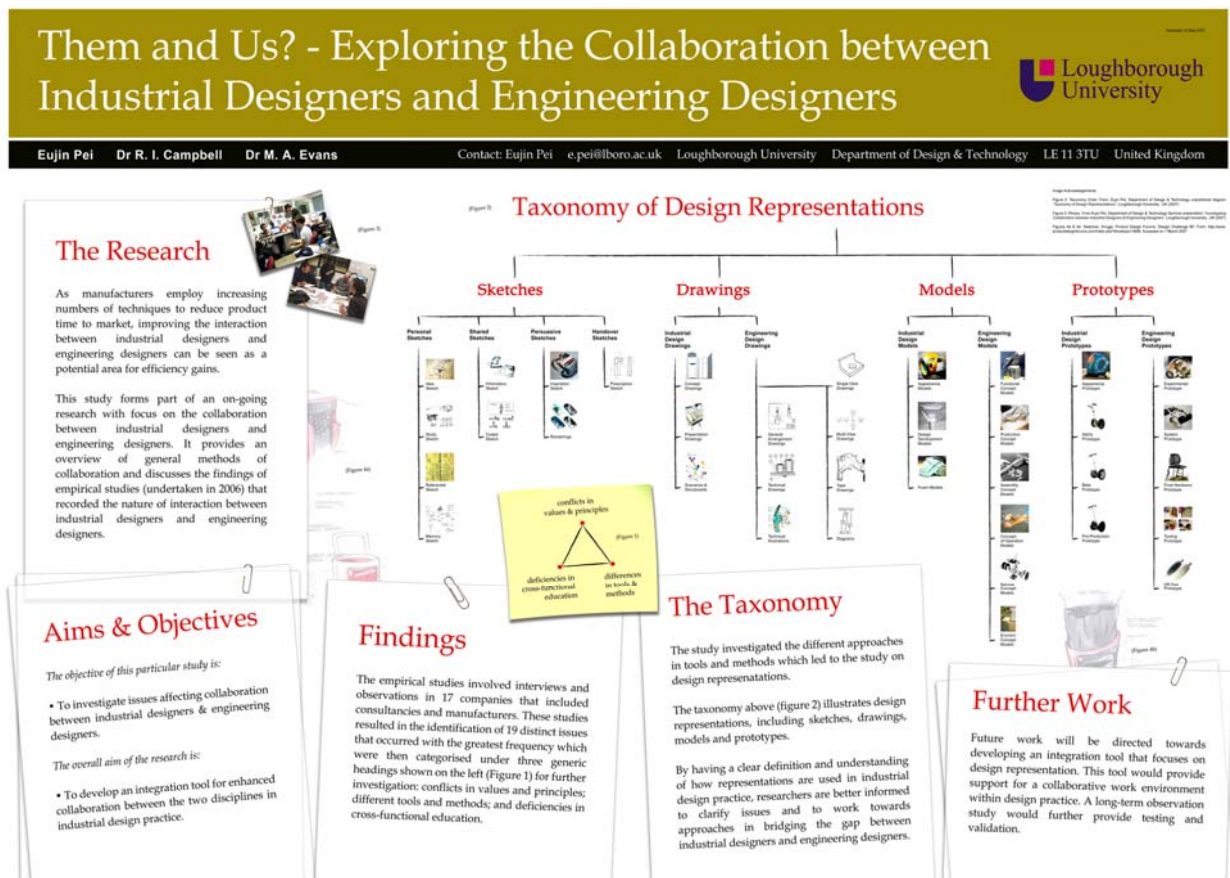


Figure 108: Research poster

### 7.3 Sketches

A 'sketch' is a preliminary, rough visual design representation of something without detail for the basis for a more finished product (Dictionary of Art Terms 2003). More importantly, it is usually rapidly executed to present only the key elements of the design. According to Pipes (2007), a sketch is a collection of visual cues that forms a stylised 'skin' over a product's components. They comprise of informal freehand marks without use of instruments (Tjalve *et al.* 1979b) and consist of draft lines, text, dimensions, and calculations that help explain the meaning, context and scale of the design (Ullman *et al.* 1990; McGown *et al.* 1998; Stacey and Eckert 2003) (Figure 109).

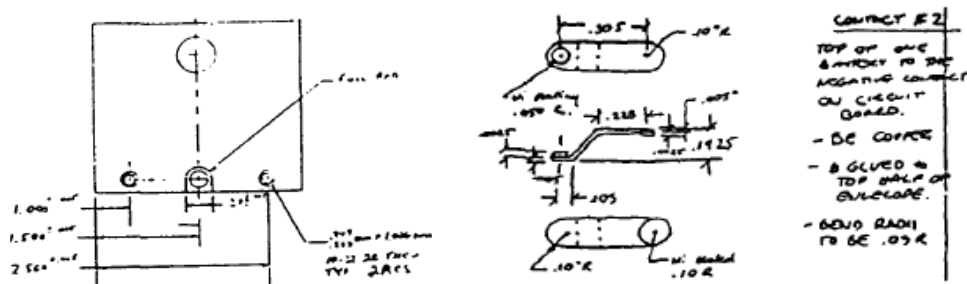


Figure 109: Example of marks made on paper showing sketch, draft, text, dimensions and calculation marks (Do 2005)

In addition, sketches are also accompanied with varying line weight to suggest depth (Figure 110), or over-tracing, redrawing and hatching to define a selection and to draw attention to an area (Do 2005; Ling 2006b) (Figure 111).

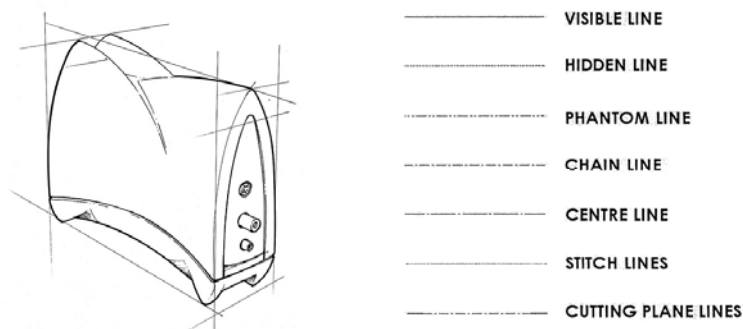


Figure 110: Varying line thicknesses (Ling 2006b)

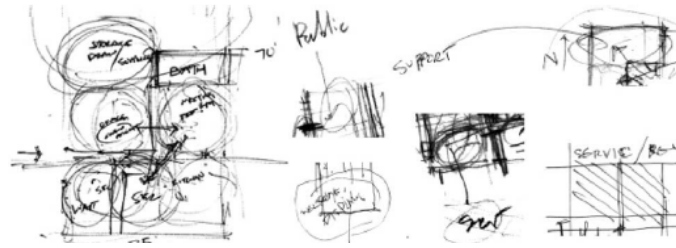


Figure 111: Hatching, redrawing and over-tracing marks (Do 2005)

In terms of visual detail, Tovey *et al.* (2003) classified five levels of sketches, similar to that proposed by Chen, *et al.* (2003). The first level consists of uniform monochrome lines with no shading. At the second level, varied thickness of monochrome lines are used with text annotations. At the third level, the sketches incorporate shading. The next level uses shading in colour; while the last level of sketches encompass colour, shading, shadows, text and dimensions. Buxton (2007) identified key characteristics of sketches in that they are quick, timely, inexpensive, disposable, plentiful and ambiguous. Engineering designers do not use sketches to express an idea with realism, but as a means to solve mechanical and production engineering details and to generate solutions (Tovey 1989; Yang and Cham 2007). In contrast, industrial designers use sketches to represent visual thoughts for communication and assessment of ideas (Rodriguez 1992; Ehrlenspiel and Dylla 1993; Fish 1996) (Figure 112).

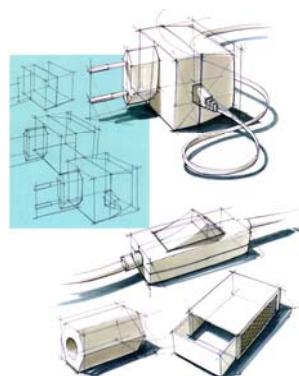


Figure 112: Sketch rendering for a plug (Eissen and Steur 2008)

In categorising sketches, Pipes (2007) broadly grouped them as theme sketches that emphasised aesthetic qualities; or package-constrained sketches that are bound with fixed dimensions (Figure 113).

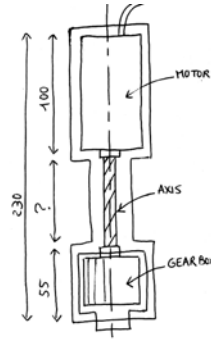


Figure 113: A package-constrained sketch of a hand mixer (Pipes 2007)

Other researchers (Ullman *et al.* 1990; Ferguson 1992; Van der Lugt 2005) classified them as thinking sketches for problem solving; prescriptive sketches for providing instructions; talking sketches for discussion; and storing sketches that retain ideas. Similarly, Olofsson and Sjöln (2005) grouped them as investigative sketches for problem definition; explorative sketches for generating and evaluating solutions; explanatory sketches to describe and communicate the design; and persuasive sketches for selling an idea. For clarity and consistency, this research shall classify sketches as personal, shared, persuasive and handover as shown in Table 34. The first group consisting of personal sketches are now discussed.

Purpose	Sketch Classification		
Source	Ullman, <i>et al.</i> 1990; Ferguson 1992; Van der Lugt 2005	Olofsson and Sjöln 2005	Proposed Classification
For problem solving	thinking sketches	investigative sketches	Personal
For retaining ideas	storing sketches	-	
For generating and evaluating solutions	-	explorative sketches	
For providing instructions	prescriptive sketches	-	Handover
For discussion	talking sketches	explanatory sketches	Shared
For selling an idea	-	persuasive sketches	Persuasive

Table 34: Proposed classification of sketches



### 7.3.1 Personal Sketches

Personal sketches are 2D visual design representations that employ freehand marks on paper for private use. They are often ambiguous and are created spontaneously in large volumes. They are usually monochrome and show only key elements of the design on paper. The group of personal sketches comprises idea sketches, study sketches, referential sketches and memory sketches.

#### 7.3.1.1 Idea Sketch

These are often used in the early design stages for the externalisation, visualisation, exploration and self-development of ideas (Kojima *et al.* 1991; Raudebaugh and Newcomer 1999). Idea sketches consist of basic shapes with simple labels and arrows to show relationships between objects (Moyer 2007) (Figures 114 - 116). The purpose is to record the idea quickly and to allow the developer to explore other possibilities.

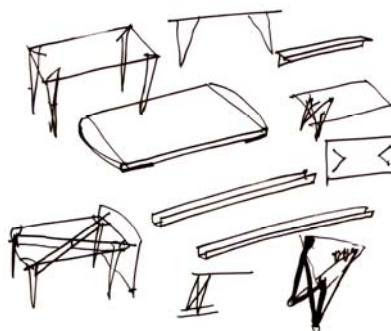


Figure 114: Idea sketches for a table (Haller and Cullen 2006)

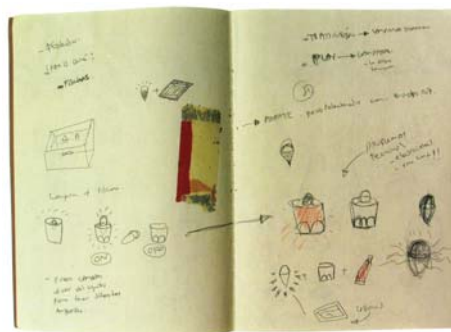


Figure 115: Spontaneous idea sketches on paper (Pipes 2007)

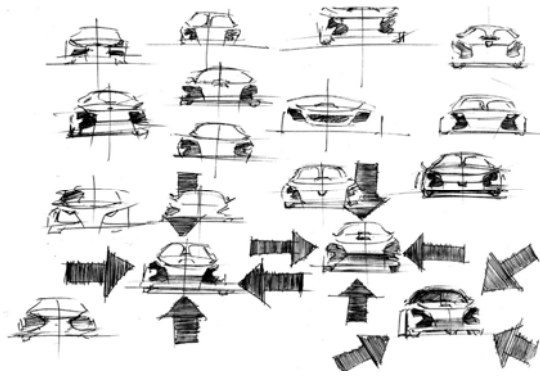


Figure 116: Idea sketches with arrows emphasising potential development (Olofsson and Sjöln 2005)

Idea sketches are small, ambiguous and require few materials to start with. They are also known as thumbnail sketches (Olofsson and Sjöln 2005), memo sketches (Pavel 2005) or napkin sketches (Ling 2006a; Baskinger 2008). For this research, idea sketches are 2D visual design representations used at a personal level for externalising thoughts quickly and to show how the design looks as a physical object.

### 7.3.1.2 Study Sketch

Study sketches are also known as thinking sketches (Ullman *et al.* 1990; Ferguson 1992; Van der Lugt 2005) or investigative sketches (Olofsson and Sjöln 2005). They are used to assist the developer to focus and guide thoughts about the design (Ferguson 1992) (Figure 117, 118).

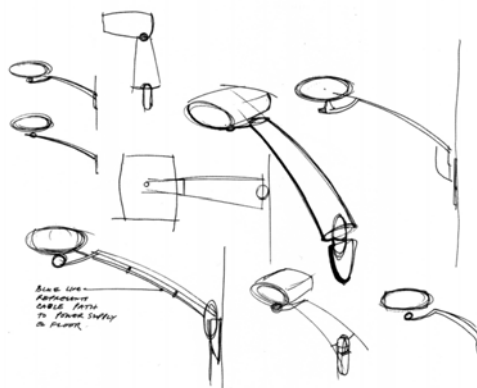


Figure 117: Study sketch for an optical receiver (Haller and Cullen 2006)





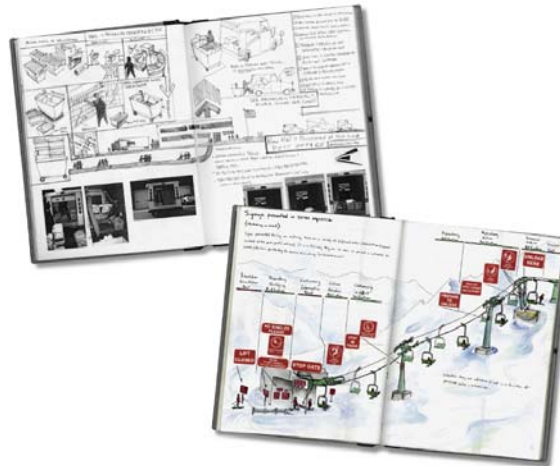


Figure 120: Notebook references to observations (Baskinger 2008)

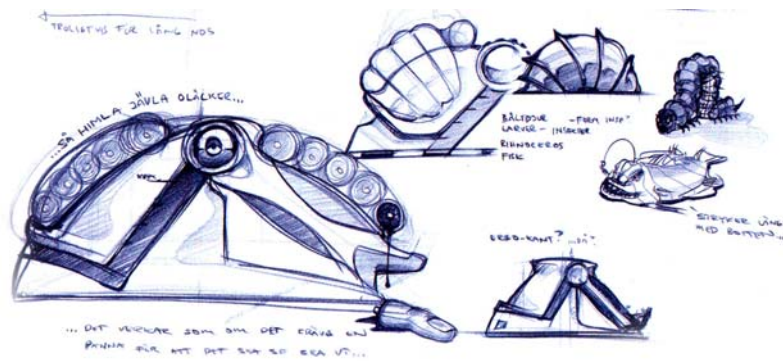
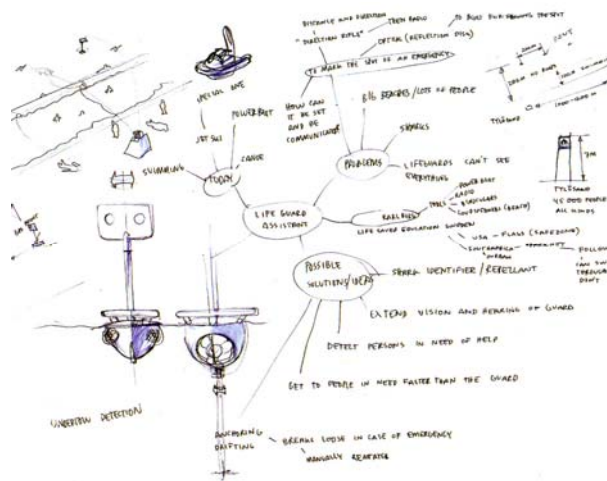


Figure 121: Design of a domestic iron (Olofsson and Sjöln 2005)

#### 7.3.1.4 Memory Sketch

These private sketches keep a record of the thoughts and steps taken, serving as an extension to memory (Do *et al.* 2000). While other sketches are used to develop concepts, memory sketches capture thoughts to retain information and to make such information easily accessible for further development (Van der Lugt 2005) (Figure 122, 123). For this research, memory sketches are 2D visual design representations that help users recall thoughts and elements from previous work with notes and text annotations.



For this research, coded sketches are 2D visual design representations that categorise information to show an underlying principle or a scheme.

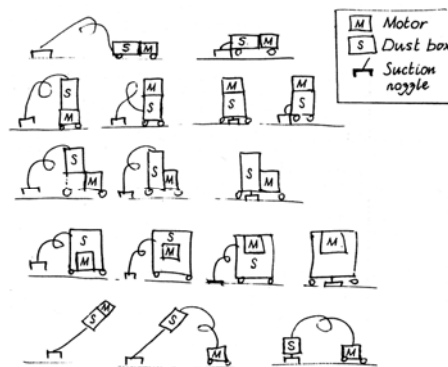


Figure 124: Coded sketch for a vacuum cleaner (Tjalve *et al.* 1979b)

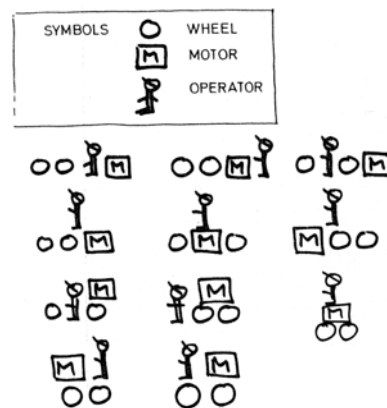


Figure 125: Coded sketch for a motorised wheel (Tjalve *et al.* 1979b)

### 7.3.2.2 Information Sketch

These sketches are widely used by industrial designers to explain the form, function and structure of a concept to stakeholders and clients for evaluation (Van der Lugt 2005). They encourage discussion and a common understanding of the design idea among the team (Ferguson 1992). Colour and text annotations allow details to be explained clearly, as well as adding realism to convey the design intent across the group (Figures 126, 127). They are also known as explanatory sketches (Eissen and Steur 2008), communication sketches (Raudebaugh and Newcomer 1999), pitching sketches (Pavel 2005) or talking sketches (Ferguson 1992). For this research, information sketches are 2D visual design representations that allow

stakeholders to understand the designer's intentions by explaining information clearly and to provide a common graphical setting.

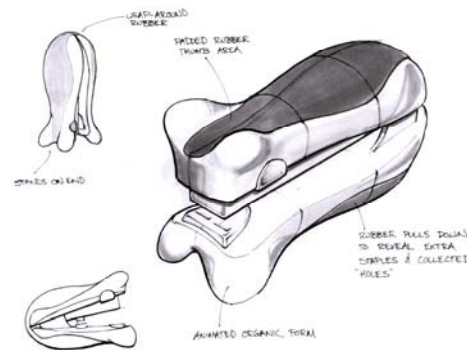


Figure 126: Orca Mini Stapler (IDSA 2003)

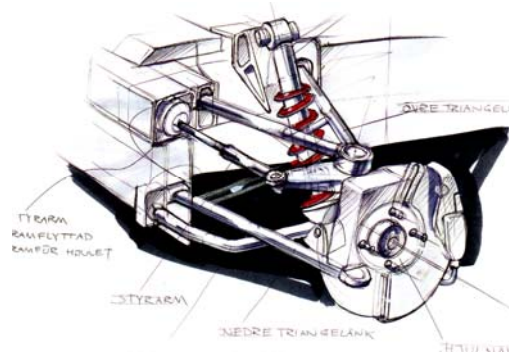


Figure 127: Sketch showing a suspension mechanism (Olofsson and Sjöln 2005)

### 7.3.3 Persuasive Sketches

This group of sketches are realistic 2D visual design representations in full colour, illustrating how the final product would look. They are used as a selling tool to allow stakeholders and clients to visualise and evaluate the design proposal. Persuasive sketches comprise renderings and inspiration sketches.

#### 7.3.3.1 Renderings

Rendering involves the application of colour and tone to express the design as realistically as possible. The high level of realism reduces ambiguity and enables the viewer to better understand key features of the design (Evans 2002). They are usually produced in perspective views and created either with

manual media such as markers, or digitally (Goldschmidt 1992; Garner 2006) (Figures 128, 129). They are also known as sketch renderings (Evans 2002) or first concepts (Monahan and Powell 1987). For this research, renderings are 2D visual design representations showing formal proposals of design concepts that involve the application of colour, tone and detail for realism.



Figure 128: Rendering of a bicycle helmet (IDSA 2003)

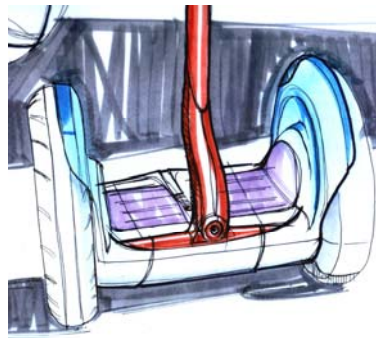


Figure 129: Rendering of a Segway Human Transporter (Haller and Cullen 2006)

### 7.3.3.2 Inspiration Sketch

These are highly form-orientated visuals that illustrate a design concept in detail (Figures 130, 131). The purpose is to influence an audience and to sell the idea by using artistic qualities to convey emotion or a theme. Although they may be time consuming to produce, they express qualities that are hard to achieve with 3D CAD modelling (Olofsson and Sjöln 2005). As the main aim is to convey the feel of a product, these sketches may not be accurate. Inspiration sketches are also known as visionary drawings (Lawson 1997) or emotional sketches (Ling 2006a). For this research, inspiration sketches are form-orientated 2D visual design representations used to communicate the

look or feel of a product by setting the tone of a design, brand or a product range.



Figure 130: Inspiration sketch of a ski visor (Olofsson and Sjöln 2005)



Figure 131: Inspiration sketch of a saw handle (Olofsson and Sjöln 2005)

### **7.3.4 Handover Sketches**

Visual design representations of this group include prescriptive sketches that serve as a preliminary technical drawing to provide information for creating a product. As the name implies, the aim is to provide sufficient information to convey to another member of the design group. These sketches often include orthographic views showing important visual aspects of the product to reduce ambiguity.

#### **7.3.4.1 Prescriptive Sketch**

According to Pipes (2007), prescriptive sketches are created during the development stages of the design process prior to a more detailed general arrangement drawing. They show key dimensions in a freehand orthographic projection with three views drawn to scale (Bertoline 2002) (Figure 132). They



are used for checking details in preparation for the physical or CAD model and are also known as specification sketches (Pavel 2005). For this research, prescriptive sketches are informal 2D visual design representations that communicate design decisions and general technical information such as dimensions, material and finish.

Figure 132: Prescriptive sketch of an electronic device (Pavel 2005)

## 7.4 Drawings



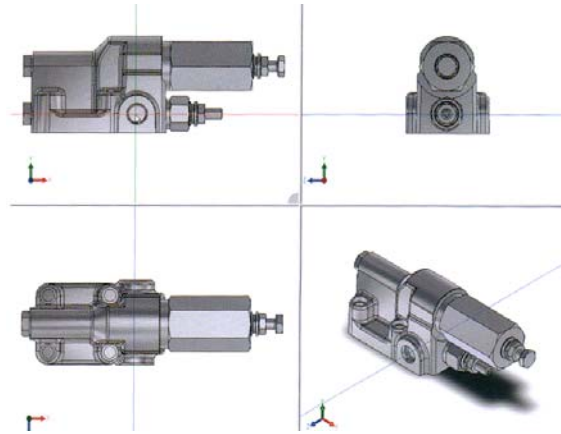


Figure 133: Example of an orthographic and isometric representation from SolidWorks (Pipes 2007)

A formal definition was proposed by Tjalve, *et al.* (1979a) who defined drawings as the modelled properties of a design (e.g. structure, form, material, dimension, surface, etc.) and coded in terms of symbols (e.g. coordinates, graphical symbols, types of projection). They serve as a record to analyse and check details, as well as a communication medium between the designer and the manufacturer (Ullman and Dietterich 1987; Ullman *et al.* 1990; Bucciarelli 1994). Besides the type of projection, drawings include the use of colour and dimensions to provide more information (Yang 2003; Song and Agogino 2004). In addition, there are conventions such as the British Standards Institution BS8888:2008 for technical product specification and the American ASME Y14.5M as guidelines for size, lines, lettering, dimensions and symbols (Pipes 2007).

In classifying drawings, Fraser and Henmi (1994) analysed architectural drawings in a study and grouped them as referential drawings, diagrams, design drawings, presentation drawings and visionary drawings. For this research, drawings that are created for the key purpose of visual aesthetics are classed as industrial design drawings (Figure 134); while drawings created for technical use are classed as engineering drawings although a sketch may sometimes overlap over both groups.

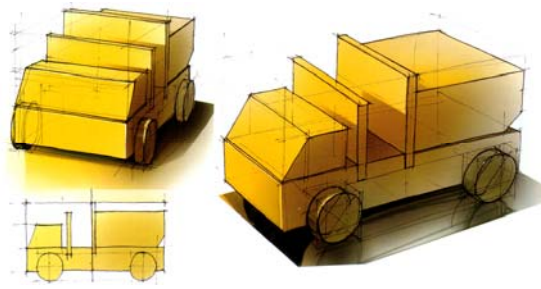


Figure 134: Industrial design drawings (Eissen and Steur 2008)

### 7.4.1 Industrial Design Drawings

Industrial design drawings are 2D visual design representations that employ formal lines to determine a particular form and they are often drawn to scale. They are created with the purpose of representing visual aesthetics and often include the use of colour and text annotations. The group of industrial design drawings comprises concept drawings, presentation drawings and scenarios and storyboards.

#### 7.4.1.1 Concept Drawing

Also known as layout drawings (DTI 1992), concept drawings are used by industrial designers to define the form and to show how the finished product would appear in an orthographic view (Figures 135, 136). Usually several of these drawings are used in internal discussions to evaluate possible proposals (Tovey 1989). For this research, concept drawings are 2D visual design representations that show the design proposal in colour with orthographic views and precise lines.



Figure 135: Concept drawing of a hair dryer, created as a hand-drawn sketch and finished in Adobe Photoshop (Pipes 2007)



Figure 136: C-Shell Compact Disc Holder (IDSA 2003)

#### 7.4.1.2 Presentation Drawing

According to Powell (1990) and Buxton (2007), presentation drawings are used to sell the idea and to inspire confidence to the client and external stakeholders about concepts. The outcome is usually a single workable design to be carried forward to the next phase to work out the fine details. Presentation drawings offer a higher level of realism as compared to concept drawings. They are usually drawn in perspective as opposed to orthographic views and may be created using manual media or on computer (Figures 137, 138). Unlike inspiration sketches that have a more artistic outlook, presentation drawings are more formal. For this research, presentation drawings are 2D visual design representations drawn in perspective that act as final drawings for clients and other stakeholders.



Figure 137: Optical transceiver (Haller and Cullen 2006)

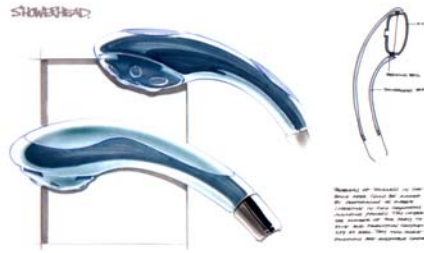


Figure 138: Presentation drawing of a showerhead (Pavel 2005)

### 7.4.1.3 Scenario & Storyboard

These 2D visual design representations aim to explain a concept by showing possible settings of a product, user or an environment. They are used with text to explain and make the storyboard more understandable (Olofsson and Sjöln 2005). They may take the form of a time line to describe stages of a product's use (Pavel 2005) (Figures 139 - 141). For this research, scenarios and storyboards are 2D visual design representations to suggest user and product interaction, and to portray its use in the context of artefacts, people and relationships.

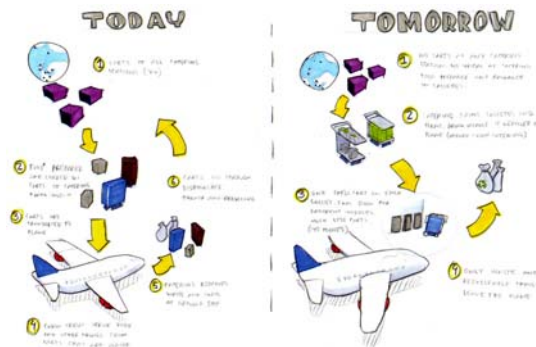


Figure 139: Scenario of a food supply system (Olofsson and Sjöln 2005)

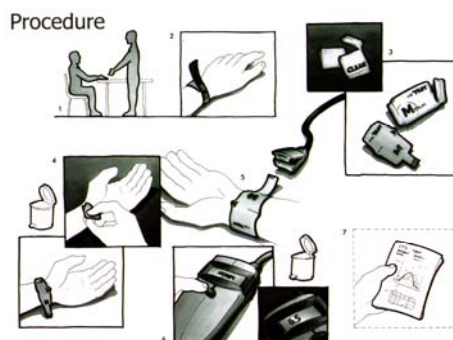


Figure 140: Procedure to using Neurometrix NC-Stat (IDSA 2003)



Figure 141: Timeline of a product's use (Pavel 2005)

## 7.4.2 Engineering Design Drawings

Engineering design drawings are concerned with representing technical information through the use of formal lines and being drawn to scale. The use of text, dimensions and other technical data provide additional information for the viewer. Engineering design drawings are 2D visual design representations comprising of diagrams, single-view drawings, multi-view drawings, general arrangement drawings, technical drawings and technical illustrations.

### 7.4.2.1 Diagram

The purpose of a diagram is to group data visually so that the information can be clearly understood (Blackwell 1997). They are also used to show the structure and relationships of components in a system. Most diagrams are represented with simple geometric elements such as arrows, lines and hatching to illustrate the principle or operation of the system (Do *et al.* 2000) (Figures 142 - 145). For clarity, the aesthetic form is omitted (Lawson 1997). Diagrams are also known as diagrammatic or schematic drawings (Tovey 1989) and the more common diagrams include mechanical, hydraulic, pneumatic, electronic and electrical diagrams to record functional structures of the product (Tjalve *et al.* 1979b). Larkin and Simon (1987) noted that because the information within diagrams is indexed, they may be only useful to those

who understand the codes. For this research, diagrams are 2D visual design representations that show the underlying principle of an idea or to represent relationships between objects, represented with simple geometric elements.

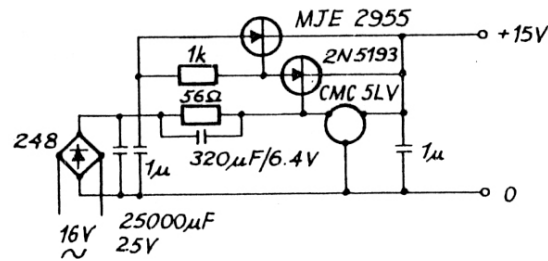


Figure 142: Diagram for a DC power supply (Tjalve *et al.* 1979b)

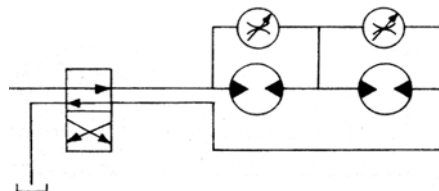


Figure 143: Diagram for a hydraulic system for two motors (Tjalve *et al.* 1979b)

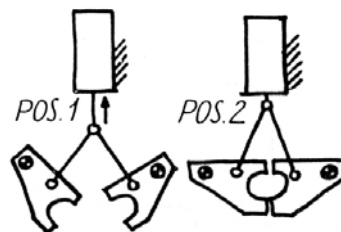


Figure 144: Symbolic diagram for a mechanical system (Tjalve *et al.* 1979b)

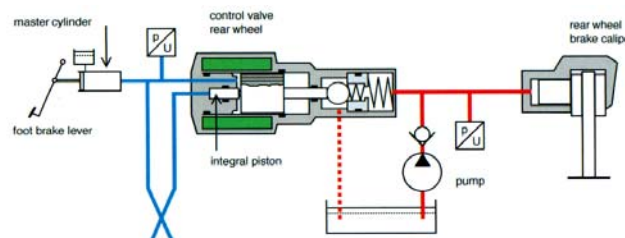


Figure 145: A diagram showing a vehicle braking system (Pipes 2007)

#### 7.4.2.2 Single-View Drawing

For this research, single view drawings are 2D visual design representations drawn in an axonometric projection made up of either isometric, trimetric, diametric, oblique or perspective views (Lueptow 2000; Bertoline 2002) (Figure 146). They have minimal aesthetic details and are illustrated as an outline with little colour to describe different aspects of the design, to examine the geometry and show alternative arrangements (Do *et al.* 2000) (Figures 147, 148). A more thorough definition of isometric, trimetric, diametric, oblique and perspective views are described under Section 7.7.6.

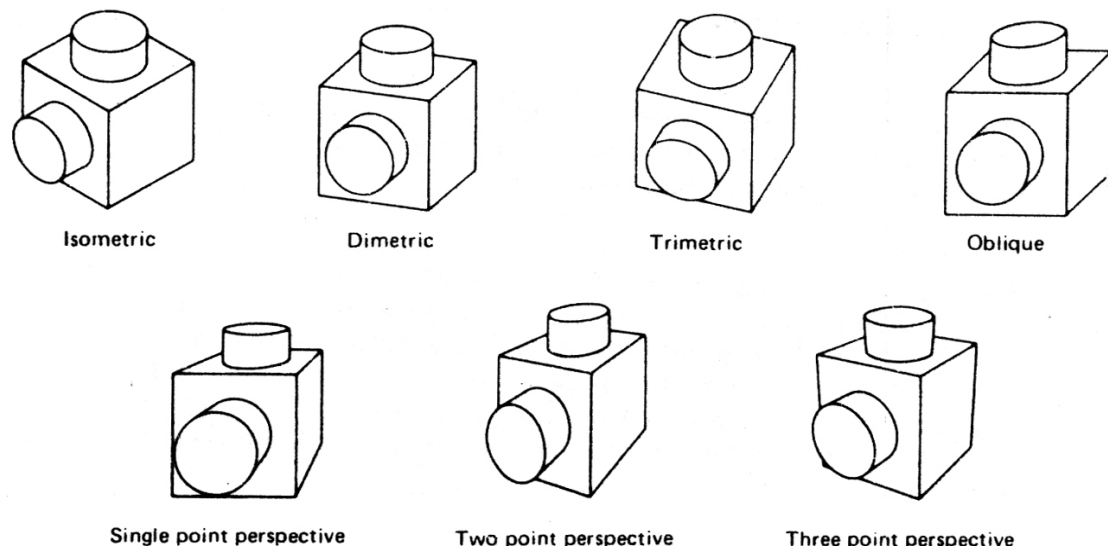


Figure 1: Single-views of various projections (Tjalve *et al.* 1979b)



Figure 2: Watercone (IDSA 2003)



Figure 3: Handy Paint Pail (Haller and Cullen 2006)



### 7.4.2.3 Multi-View Drawing

Multi-view drawings comprise of projections to describe a product in 2D (Pavel 2005). Also known as an orthographic projection, they are a formal system used to describe the features and geometry of a product through three coordinated orthogonal planes made up of plan view, front elevation and end elevation (Raudebaugh and Newcomer 1999; Bertoline 2002) (Figure 149).

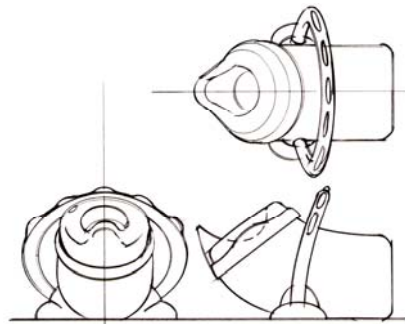


Figure 149: Perfect Portions baby bottle (Haller and Cullen 2006)

There are two types of projections for multi-view drawings. A first-angle projection (Figure 150) consists of a plan view and the front face drawn immediately above it and the end elevation to the right. In a third-angle projection (Figure 151), one elevation is placed below the plan, with the end elevation to the left of the first elevation. For this research, multi view drawings are 2D visual design representations employed through first or third angle projections. More information 'multi-views' is described in Section 7.7.7.

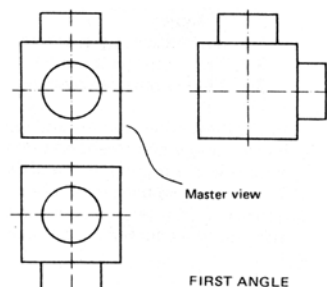


Figure 150: First angle projection drawing (Lee 2008)

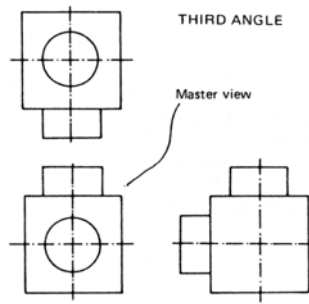


Figure 151: Third angle projection drawing (Lee 2008)

#### 7.4.2.4 General Arrangement Drawing

Once a concept has been approved, the next step is to produce a general arrangement drawing (GA drawing), also known as model making drawings (DTI 1992). At the concept development stage, the design has a refined layout with fixed dimensions. They are created prior to a technical drawing and represent an overview of the design and how the parts are put together (Powell 1990) (Figure 152).

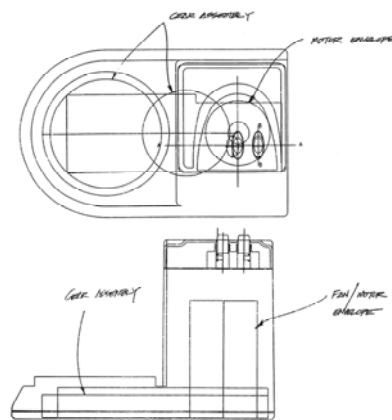


Figure 152: GA Drawing of a Quick 'N' Easy Food Processor (IDSA 2003)

As compared with prescriptive sketches, GA drawings are more formal by incorporating a multi-view drawing, dimensions, parts list, sub-assemblies, drawing angles and break lines (Martin 1989; DTI 1992) (Figure 53. When colour and shading is applied, they become a powerful communication tool that can be used for discussions with non-technical members (Powell 1990). GA drawings are often used by model makers for creating appearance models. For this research, general arrangement drawings are 2D visual design

representations that embody the refined design but omit the internal details. They are used for the production of appearance models with limited detail.

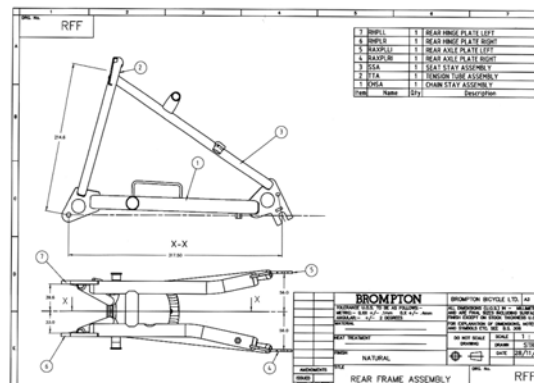


Figure 153: A general arrangement drawing for the rear frame of a folding bicycle (Pipes 2007)

#### 7.4.2.5 Technical Drawing

Technical drawings represent the last stage of the design development process where the design is ready for manufacture. They may be created by manual drafting or with a computer. Also known as documentation drawings (Raudebaugh and Newcomer 1999) or production / working drawings (Bertoline 2002), they are formalised, complete and standardised, showing the material specification, parts list, manufacture, finish and assembly details (Figures 154, 155). These representations are also used for organising and calculating the production costs involved (Tjalve *et al.* 1979b).

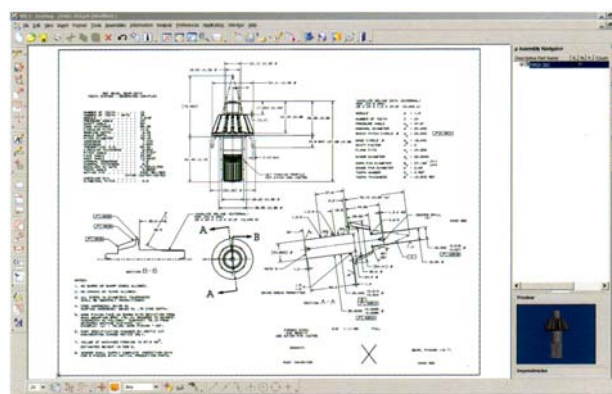


Figure 154: Technical drawing of a gear pinion (Pipes 2007)

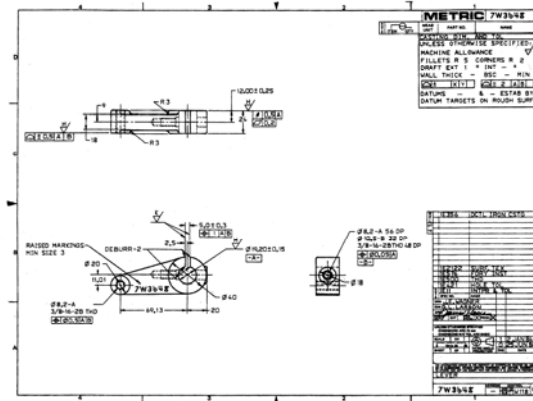


Figure 155: A technical drawing showing orthographic views, dimensions, tolerances, finishing, part number and material type (Bertoline 2002)

To ensure clarity and consistency, most technical drawings conform to industry standards such as the BSI (British Standards Institution) BS8888 standard with guidelines to define, specify and graphically represent products. At the time of writing, the latest update is British Standards BS8888:2008. In the United States, the American equivalent is the ASME Y14.5M standard for dimensioning and tolerancing (Pipes 2007). For this research, technical drawings are formal 2D visual design representations used to define, specify and graphically represent the built object and to cover every detail for manufacture.

#### 7.4.2.6 Technical Illustration

These are representations created at the very end of the development process. Because orthographic projections or technical drawings may be too complex for a layman to understand, technical illustrations simplify the engineering details and highlight key features without omitting important information (Pipes 2007). For explanation, technical illustrations are accompanied with sections, cut-aways (Figures 156, 157), ghosting (Figure 158) and exploded views (Figures 159). Cut-aways show the inside of a product that is hidden by the casing (Eissen and Steur 2008). Ghosting is another technique that makes an area transparent to show the internal components, and keeping the overall form recognisable.



Figure 156: Technical illustration showing the cutaway section of a pump



Figure 157: Manual ink drawing of a technical illustration with thick lines for important areas and the use of shading and break lines (Pipes 2007)



Figure 158: Ghosting sketches (Eissen and Steur 2008)



Figure 159: An exploded illustration of a two-cavity mould (Pipes 2007)

Although similar to presentation drawings, technical illustrations are used to explain the engineering aspects rather than to communicate the aesthetics (Bertoline 2002). They may be created with airbrush or on a computer and are used for instruction manuals, installation guides, maintenance manuals, catalogues, advertisements and in training books. For this research, technical illustrations are 2D visual design representations that simplify the engineering details and highlight key features without omitting important information from the product.

The definition for each drawing is summarised in Appendix 13.4.2. The next section discusses the various types of industrial design and engineering design models.

## **7.5            *Models***

According to Holmquist (2005), models are non-functional objects used to describe the visual appearance of an intended product. However, Buur and Andreasen (1989b) cited that they can also be used to reproduce the rough functional properties. Consequently, 'modelling' is the creation and use of physical artefacts to 'elaborate, synthesise, evaluate and communicate' a design proposal (Andreasen 1994).

Models are used because 2D sketches and drawings are inadequate to explain three-dimensional attributes of an object (Tovey 1997). They allow both industrial designers and engineering designers to explain the function, performance and aesthetic aspects of a design, enabling them to 'describe, visualise and sculpture thoughts' (Buur and Andreasen 1989a), and to 'develop, reflect, and communicate design ideas with others' (Peng 1994). However, Garner (2004) pointed out that some models are more suitable for communicating information, while others were better suited for testing ideas. Lucci *et al* (1989) acknowledged that the translation from a 2D to 3D object is a significant phase of the design process. A full size or scaled physical model allows feedback from stakeholders and to iron out issues before committing to

tooling or manufacture and to minimise downstream mistakes (Powell 1990). They are useful to show how components are integrated so that clients may visualise the design (Woodtke 2000). More importantly, Brandt (2005) highlighted that models function as boundary objects where each member has a common understanding, yet being in control of their interests. Models vary according to the scale, accuracy and material, and serve as an abstract representation to the final design (Kvan and Thilakaratne 2003). They allow the developer to gain tactile clues (Ferguson 1992), described by Smyth (1998) as 'designers thinking with their hands', or a 'design-by-doing' activity described by Ehn and Kyng (1991). The act of modelling is comparable to Schön's (1983) description of a designer 'conversing with an image on paper'. Dorta and Pérez (2006) added that this sense of touch is important for perception and allows the developer to fully understand the geometry of the design.

In terms of classification, Emori (1977) grouped models as either qualitative or subjective. A qualitative model emphasises the aesthetics and is traditionally fabricated from solid materials since internal parts are unnecessary. In contrast, a subjective model is more concerned with functional aspects in terms of performance and use. Another classification was proposed by Garner (2004) with three groups, i.e. iconic models being the physical representations or full-size renderings of a product; symbolic models as coded representations such as mathematical formulas; and manual models as diagrams that communicate a principle. Baxter (1995) provided another classification by grouping physical models into structural, functional, and structural and functional representations as shown in Table 35.

Structural Representation	Structural & Functional	Functional Representation
Appearance Models	Pre-production Prototypes	Working Principles Prototypes
Physical size, shape and appearance (but not function)	Mock-up of manufactured product (size, shape and function)	Key functions (but not size and shape)
Form and Fit Models	Production Prototypes	Test Prototypes
Physical size, shape (but not function and not appearance)	“As manufactured” materials and processes	Specific functions (but not size and shape)

Table 35: Types of Models used in the Design Process (Baxter 1995)

Although rough models are fast to produce and suitable for creative work, they tend to contain very limited information. Conversely, models providing detailed information are usually labour-intensive to produce. Therefore, simple models are used during early stages of design where ideas and development take place; whereas detailed models are used when a concept has been confirmed. Veveris (1994) acknowledged this trend whereby the complexity, cost and functional capabilities of models increase with the progress of product development. This is in-line with Garner’s (2004) chart that shows models in the early stages of design tend to be cheap and easy to produce, whereas models created in the later stages are usually costly and lengthy to produce (Figure 160).

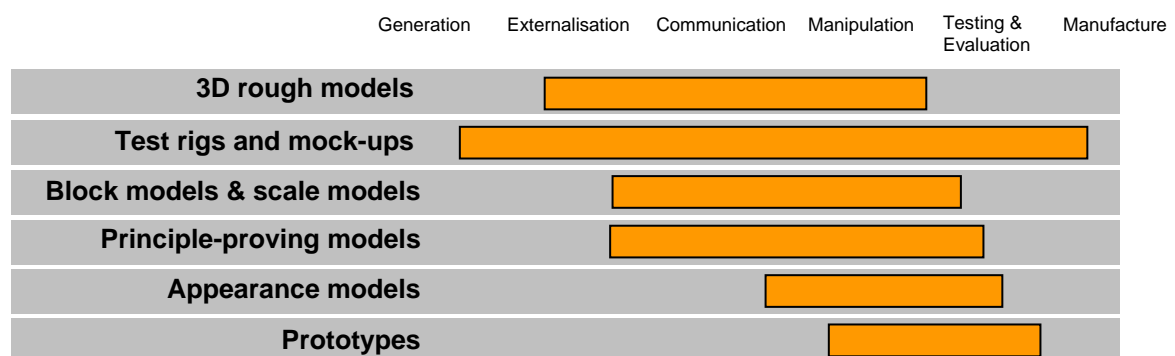


Figure 160: Classification of models according to phases of design activity (Garner 2004)



British industrial designer James Dyson has used cardboard and foam models very early in his development work to test the technical aspects of his vacuum cleaner concept and allowing him to gain a good understanding of the functional limitations (Figure 161). This hands-on approach has remained an essential step in the company's working methods (Te Duits 2003). For this research, models created for the purpose of aesthetics, ergonomics and other design related aspects are classed as industrial design models; while those for functional and technical development are classed as engineering models although a particular model may overlap over both categories.

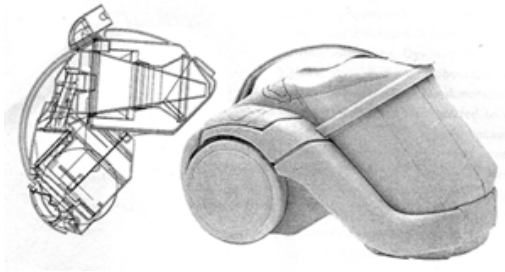


Figure 161: Working drawing of the Dyson DC02 and form study in plastic foam (Te Duits 2003)

### **7.5.1 Industrial Design Models**

Industrial design models are 3D visual design representations used to reproduce the three-dimensional attributes of an intended product in a tangible form. They are non-working models that emphasise visual aesthetics such as form and structural aspects. The group of industrial design models comprises 3D sketch models, design development models and appearance models.

#### **7.5.1.1 3D Sketch Model**

Also known as sketch models or 3D rough models (Garner 2006), a 3D sketch model is used similar to 2D sketching (Lucci and Oirlandini 1989). It is an affordable and quick way of physical representation that allows the exploration

of potential ideas, obtaining visual feedback, and to translate 2D representations into a tangible medium (Evans 2002). Soft materials such as foam and balsa wood are used for achieving the general shape, and forming details with files, drills and sandpaper (Figures 162, 163). For this research, 3D sketch models are 3D visual design representations that represent an idea.



Figure 162: A rough 3D sketch model of a shoe



Figure 163: 3D sketch models for an armrest (IDSA 2003)

#### **7.5.1.2 Design Development Model**

Upon confirmation of a design concept, these models are used to create a batch of accurate representations. They are used to refine shapes, to investigate how components are fixed or for testing. They are created quickly with materials such as balsa wood and foam (Figures 164, 165). To enhance realism, parting lines, slots and buttons may be drawn on the material, as well as the use of paint and ready-made working parts. Evans (1992) described these models as 'foam models'. However, as a wide range of materials may be applied, the term 'design development model' is used as it is more inclusive. For this research, design development models are 3D visual design

representations used to understand the relationships between components, cavities, interfaces, structure and form.



Figure 164: Rigid cellular foam models of products where markers have been used to show details (Garner 2006)

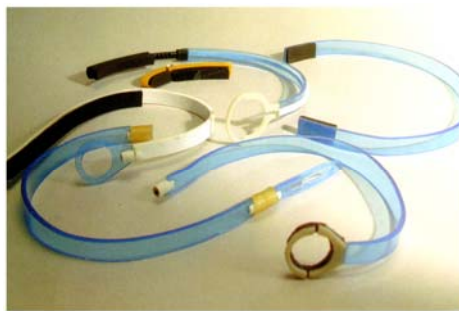


Figure 165: Development model for a headgear (IDSA 2003)

### 7.5.1.3 Appearance Model

The purpose of an appearance model is to enable stakeholders and clients to accurately evaluate the aesthetics of a design as compared to sketches or drawings (DTI 1992). Appearance models are also known as maquettes (Baxter 1995) or block models (Evans 1992). Powell (1990) described that these models allow the design to materialise into a realistic physical form where for the first time stakeholders and clients are able to properly evaluate the design. However, it is important to note that appearance models are only concerned with the external outlook without any functional features (Baxter 1995). In terms of fabrication, a wide variety of materials may be used, including wood, plastics, metal, fibreglass, etc. The appearance model is

usually finished to a high level of surface treatment and complete with decals to closely resemble the final product (Figures 166, 167). Increasingly, rapid prototyping technologies have enabled detailed parts to be fabricated, shortening the model making time. For this research, appearance models are 3D visual design representations that realistically define the visual aspects of a product, but do not contain any working mechanisms.



Figure 166: A non-working appearance model made of wood and plastics (Garner 2006)



Figure 167: Appearance model of a toaster (IDSA 2003)

### 7.5.2 Engineering Design Models

Engineering design models are 3D visual design representations used to represent the technical aspects of a product. They show functional moving parts that represent performance and use. The group of engineering design models comprises functional concept models, concept of operation models, production concept models, assembly concept models and service concept models.

### 7.5.2.1 Functional Concept Model

Functional concept models are used to investigate the working parts of a product concerning aspects such as yield and performance (Buur and Andreasen 1989b). They are also known as principle models (Evans 1992) or principle-proving models (Garner 2006) to prove that a technology or a functional part works. They are mechanical-looking and do not have the appearance of the final product (Figures 168, 169). For this research, functional concept models are 3D visual design representations that show functionality and highlight important functional parameters including yield and performance factors.



Figure 168: Principle-proving model of a drive system produced during the industrial design of a lawnmower (Garner 2006)



Figure 169: Functional concept model of a juicer (IDSA 2003)

### 7.5.2.2 Concept of Operation Model

According to Buur and Andreasen (1989b), these models show how the product would be operated, controlled or managed. It allows developers to demonstrate how a product would be operated in terms of operation, control

or handling (Figure 170). For this research, concept of operation models are 3D visual design representations that help communicate the understanding of operational strategies and usage procedures relating to the product.

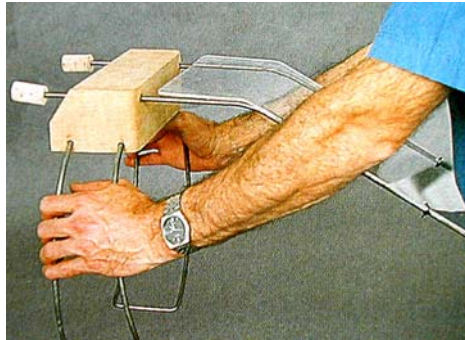


Figure 170: Operation model for a propulsion unit (Bairstow *et al.* 1999)

#### 7.5.2.3 Production Concept Model

The term production refers to the process of how things are made, produced or manufactured (Longman Dictionary 2005). The term production concept model therefore refers to physical representations that allow the product developer and other stakeholders to understand, evaluate and prepare the design for production (Buur and Andreasen 1989b) (Figure 171). They allow the assessment of processes, costs and requirements before committing to manufacture. For this research, production concept models are 3D visual design representations used to help assist the evaluation of production processes or manufacturing technologies for final production.



Figure 171: Production concept model for a lacrosse stick (IDSA 2003)

#### 7.5.2.4 Assembly Concept Model

Assembly refers to the fitting or putting of parts together (Merriam-Webster Dictionary 1994). These physical models allow developers to establish and ascertain aspects concerning the assembly of a product. They allow issues relating to costs and investments in equipment to be evaluated early in the development stages (Buur and Andreasen 1989b) (Figure 172). For this research, assembly concept models are 3D visual design representations that provide confidence regarding the component relationships in terms of assembly, cost and investment.

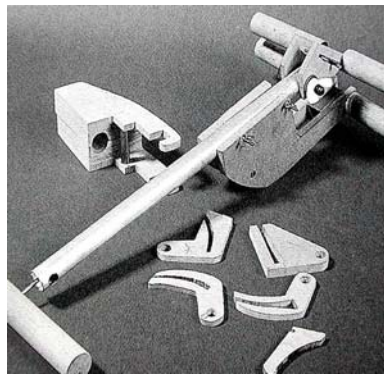


Figure 172: An assembly concept model (Bairstow *et al.* 1999)

#### 7.5.2.5 Service Concept Model

According to Buur and Andreasen (1989b), service concept models show how a product may be serviced and maintained. During the development process, it is important to consider how the product could be cleaned and serviced throughout its lifecycle. These models help developers to establish solutions such as how a user would install a new set of batteries, or how a service technician would be able to disassemble a product for repairs (Figure 173). For this research, service concept models are 3D visual design representations that illustrate how the product may be serviced or maintained.





Figure 173: Service concept model of a heater (Haller and Cullen 2006)

The definition for each model is summarised in Appendix 13.4.3. The next section discusses the various types of industrial design and engineering design prototypes.

## 7.6 *Prototypes*

The aim of prototyping is to produce information for design processes and design decisions, as well as to explore and communicate the final design (Kurvinen *et al.* 2008). In the context of design, there are several definitions for the term ‘prototype’. According to Holmquist (2005), prototypes only consists of functional parts and do not resemble a final product. Other researchers clarified them as being full-scale physical representations (Luzadder 1975; Evans 1992); while Best (2006) considered prototypes as being in either a physical or virtual form. Other related terms such as ‘rapid prototyping’ refers to the additive layered-manufacturing process; while ‘virtual prototyping’ refers to digital representations created with computer simulation (Kiefer *et al.* 2004). For this research, the term ‘prototype’ refers to full-scale 3D visual design representations that incorporate working components.

Kelly and Littman (2001) described prototypes as being ‘worth a thousand pictures’. They serve as a tangible artefact providing confidence to stakeholders about the final design (Kelley 2001). With a physical representation, stakeholders can interact and finalise aspects of the design



(Bødker and Buur 2002; Preece *et al.* 2002). It brings multi-disciplinary perspectives together and acts as a medium where joint decisions can be made and for refinements to be conducted safely and cheaply (Kolodner and Wills 1996). According to Subrahmanian *et al.* (2003), prototypes are not static and they dynamically develop as the design progresses. Otto and Wood (2001) clarified that multi-disciplinary members used prototypes differently according to their needs (Table 36). Industrial designers used prototypes to investigate the look and feel of a design, while mechanical engineers used them to analyse functional properties. Although it does not show its use by engineering designers, the table has described the contrasting uses in terms of discipline.

Industrial design	Electrical design	Mechanical design
For testing the aesthetics and artistic impression of a design	Layout and physical models of printed circuit boards	Product component layout and connections
Arrangement of internal components and its effect on shape	Test fixtures for electronic function and control	Machine design
New product concepts	Electronic function	Fabrication and testing of package
Ergonomic studies	Assessment of electrical ratings	Material selection
-	Standard component studies and integration	Tool, manufacture and assembly design and drafting

Table 36: Uses of prototypes according to discipline (Otto and Wood 2001)

As a physical working representation of a design proposal, prototypes are used to test the feasibility of the finalised concept, for customer assessment and to clarify production and technical issues (Holbrook and Moore 1981; Finn 1985). Yang and Daniel (2005) added that the process of constructing

prototypes itself allows developers to understand issues first-hand that cannot be gained from 2D drawings or computer models. An example is the plywood chair built by Morrison (1990) where a hands-on approach in the construction enabled the designer to have good understanding when explaining to manufacturers. This means that prototypes require greater commitment in terms of skills, time and cost as compared to other representations. They may be created in a specialist in-house workshop or outsourced to an external contractor (Avrahami and Hudson 2002). It is also important for the prototype to closely resemble the actual product so as to avoid false expectations (Rosenberg 2006).

Models are better suited during the early stages of development for problem solving and idea generation, whereas prototypes are employed towards the later stages to confirm and evaluate the aesthetics, ergonomics and performance of the design (Ullman 2003; Frishberg 2006). As an integration medium, prototypes show how the components fit together and to detect discrepancies. In terms of milestones, they act as a physical goal that demonstrates a level of progress has been met. Prototypes are also used by manufacturers to confirm the tooling, for cost analysis and as a promotional material. In addition, Ulrich and Eppinger (2003) identified a pattern whereby products with high technical or market risks tend to require more prototypes to be built and tested.

Evans (1992) pointed out that it is important to understand the underlying reason for producing a prototype so that the right intention may be interpreted. For example, a functional prototype may look unattractive, but its purpose is to illustrate the mechanical aspects and not its outlook. However, a prototype may contain several uses. For instance, a proof-of concept prototype showing functional aspects may also be useful for developers to examine its mechanism, size and dimensions such as the prototype BeoSound 5 system (Figure 174) that has a mix of Lego, cardboard and computer components.

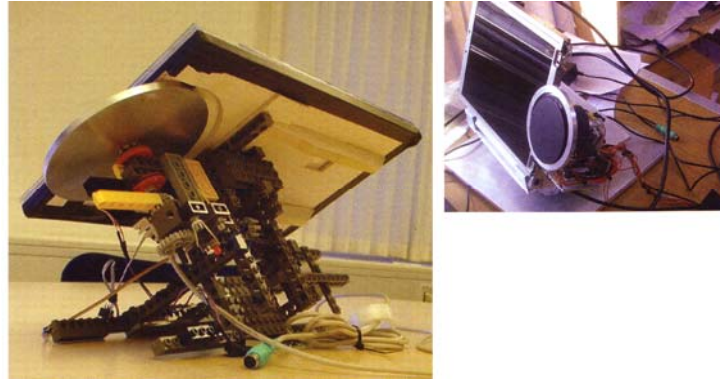


Figure 174: A prototype of the Bang & Olufsen's BeoSound 5 (Corbet 2009a)

In classifying prototypes, Sommerville (1995) grouped prototypes as throwaway, evolutionary, or incremental. A throwaway prototype is used early in the development stage for clarifying ideas. Evolutionary prototypes are continually developed and evaluated; while incremental prototypes bring small changes to the design. This classification is also similar to that of Budde *et al.* (1992) who classified prototypes as evolutionary, experimental, and exploratory. In another classification, Ulrich and Eppinger (2003) grouped prototypes according to their degree of comprehensiveness. A comprehensive prototype is a full-scale working version of the product shown to clients and potential customers to evaluate the overall design. Focused prototypes on the other hand, contain some characteristics such as having only electronic parts. Barge (2008) classified prototypes into four groups. They were visual prototypes such as sketches or drawings, models that are physical representations of a product, screen-based prototypes and fully working or functional prototypes. Lastly, Preece *et al.* (2002) classed prototypes as being low-fidelity or high-fidelity. Low-fidelity prototypes are made of simple and cheap materials such as cardboard and do not resemble the final design. They are fast and cheap to fabricate and are only concerned with producing or exploring specific attributes (Hanington 2006). In contrast, high-fidelity prototypes are expensive and time consuming representations that aim to replicate the final design using same materials as the final product. Despite these differences, low fidelity prototypes can still provide the necessary feedback and are just as successful as high-fidelity prototypes for development (Virzi *et al.* 1996).

For this research, prototypes are classed as industrial design prototypes and engineering design prototypes. In the former, they are created to finalise the aesthetics, ergonomics and other design related aspects; while the later are used to test, evaluate and validate the functional and technical aspects of the final design. Similar to other visual design representations, a prototype may overlap over both groups.

### **7.6.1 Industrial Design Prototypes**

Industrial design prototypes are 3D visual design representations that reproduce the final form, ergonomics and design related aspects of the product. They emphasise the look and feel of the final design and may contain working parts using the actual materials for the product. Industrial design prototypes comprise of appearance prototypes, alpha prototypes, beta prototypes and pre-production prototypes.

#### **7.6.1.1 Appearance Prototype**

According to Evans (2002), appearance prototypes define the physical outlook as well as integrating the functional components, and are also called integration prototypes (Yang and Daniel 2005). Knoblaugh (1958) emphasised that they resemble the production item and are a check before tooling. Findings by Evans and Campbell (2003) provided evidence showing appearance prototypes have been useful in helping developers to evaluate the final design and the user interface prior to manufacture (Figures 175, 176).



Figure 175: Assembly of an appearance prototype for a lawnmower (Garner 2006)



Figure 176: Mouse Sander appearance prototype (IDSA 2003)

In distinguishing an appearance model and an appearance prototype, the latter is more complicated as it integrates function and aesthetics; whereas an appearance model only defines the exterior surface with no internal components. Due to the high level of detail and cost, appearance prototypes are usually made during the final stages of development. Rapid prototyping has been increasingly used to fabricate components for appearance prototypes as it allows complex and delicate parts to be made that are not possible to be created by hand. For this research, in line with Evans (1992), appearance prototypes are highly detailed, full-scale 3D visual design representations that combine function and aesthetics.

#### 7.6.1.2 Alpha Prototype

Also known as first prototypes (Veveris 1994), the alpha prototype incorporates the material and layout that would be used for the actual product. It brings together parts that have been proven and 177, 178).



Figure 177: Alpha prototype of a Segway Human Transporter (Haller and Cullen 2006)

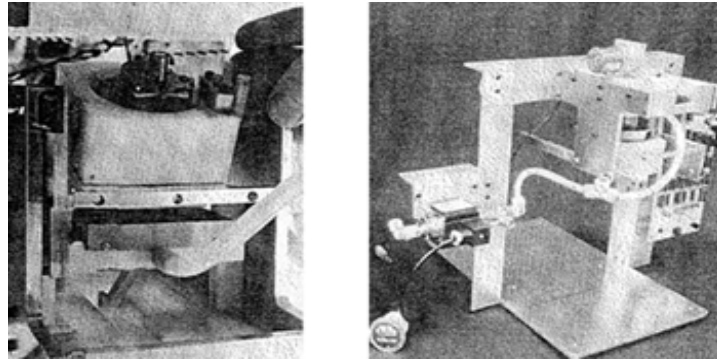


Figure 178: Alpha prototype of a coffee brewer (Otto and Wood 2001)

However, the parts are produced in low-volume using techniques such as rubber moulding instead of injection moulding. According to Ulrich and Eppinger (2003), they are mainly used by industrial designers to verify the outlook; or sometimes by engineering designers for strength and impact tests. For this research, alpha prototypes are 3D visual design representations used to verify the outlook and construction of sub-systems that have been individually proven and accepted with the actual materials, aesthetics and layout for the actual product.

#### **7.6.1.3 Beta Prototype**

Beta prototypes, or second prototypes (Veveris 1994), are constructed in the same way as alpha prototypes but are full-scale and contain more details. They review the resolved features of the alpha prototype and are used for assembly trials, production evaluation and performance tests. They are classified under industrial design prototypes because they are mainly used by industrial designers to examine how the product would be used in its intended environment. However, they are also sometimes used by engineering designers to calculate the final costs and to work out regulatory issues (ibid). In terms of parts, beta prototypes contain the same materials as the final product but may be fabricated by CNC machining and are assembled by hand (Otto and Wood 2001) (Figures 179, 180). For this research, beta prototypes are full-scale and fully-functional 3D visual design representations constructed

from the actual materials and used to examine how the product would be used in its intended environment and to work out regulatory issues.



Figure 179: Beta prototype of a Segway Human Transporter (Haller and Cullen 2006)



Figure 180: Beta prototype of a coffee brewer (Otto and Wood 2001)

#### **7.6.1.4 Pre-Production Prototype**

Pre-production prototypes, pilot-production prototypes (Ulrich and Eppinger 2003) or third and final prototypes (Veveris 1994) are the final class of 3D visual design representations where all issues have been worked out and the design is ready for tooling and production (Otto and Wood 2001). At this stage, the production line is ready for a pilot-run and a short production run is undertaken to verify the quality in terms of assembly and finish (Evans 1992) (Figure 181).



Figure 181: Pre-production prototype of a Segway Human Transporter (Haller and Cullen 2006)

They are classed as industrial design prototypes as most of the engineering details are in place and they are therefore used to check the product and its finishing as a whole. The pre-production prototypes are also used to gauge the manufacturing capability and the parts are sent to the clients for feedback. For this research, pre-production prototypes are final 3D visual design representations used to check the product and its finishing as a whole and to perform production and assembly assessment in small batches.

## **7.6.2 Engineering Design Prototypes**

Engineering design prototypes are 3D visual design representations that may not display the final outlook of the design. Its purpose is to validate and refine the functional and technical aspects of the final design. They may contain the actual materials used for the product, as well as enclosing the electrical and mechanical components. Engineering design prototypes comprise of experimental prototypes, system prototypes, final hardware prototypes, tooling prototypes and off-tool prototypes.

### **7.6.2.1 Experimental Prototype**

Experimental prototypes allow developers to investigate, optimise and evaluate the mechanical properties of a product (Otto and Wood 2001). They are used to ascertain the feasibility of a product's working parts during the



development stages. They do not resemble the final product and are used to obtain feedback on the functional performance (Ulrich and Eppinger 2003) (Figures 182, 183). Experimental prototypes are often low-cost and created as quickly. For this research, the experimental prototype is a 3D visual design representation that parameterises the layout or shape of a product, usually to replicate the actual product's physics. They are also known as design-of-experiment prototypes.



Figure 182: Experimental prototype for the Dyson vacuum cleaner (Bairstow *et al.* 1999)

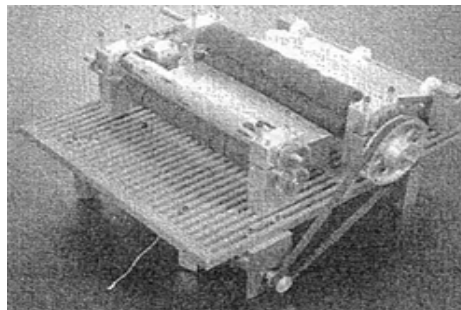


Figure 183: Experimental prototype for a printer (Otto and Wood 2001)

#### **7.6.2.2 System Prototype**

The system prototype brings together the various working components of the product (Evans 1992). It integrates the parts as a system, allowing engineering designers to achieve a holistic functional representation of the design that can be tested according to its abilities (Otto and Wood 2001). In a system prototype, off-the-shelf components may be used and the parts are roughly assembled (Figures 184, 185). For this research, the system

prototype is a 3D visual design representation that combines the numerous components specified for the final product to test and assess functional aspects such as mechanism and performance.

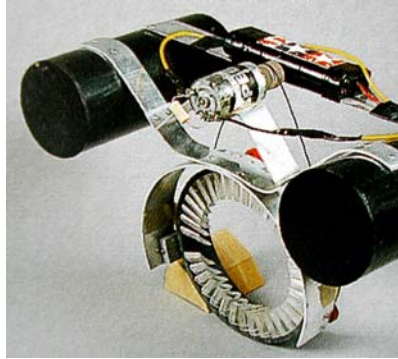


Figure 184: System prototype of a propulsion unit (Bairstow *et al.* 1999)

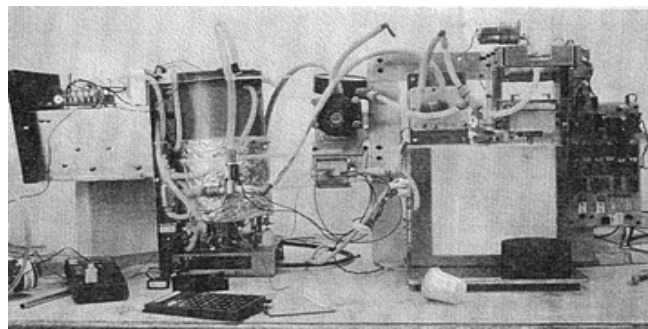


Figure 185: System prototype of a coffee brewer (Otto and Wood 2001)

### 7.6.2.3 Final Hardware Prototype

The final hardware prototype is an integrated representation containing the final working parts as a whole and allows engineering designers and other stakeholders to discuss fabrication and assembly issues (Otto and Wood 2001). At this stage, the internal components are set in place without an exterior shell (Figures 186, 187).



Figure 186: Final hardware prototype of the Cachet Chair (Haller and Cullen 2006)

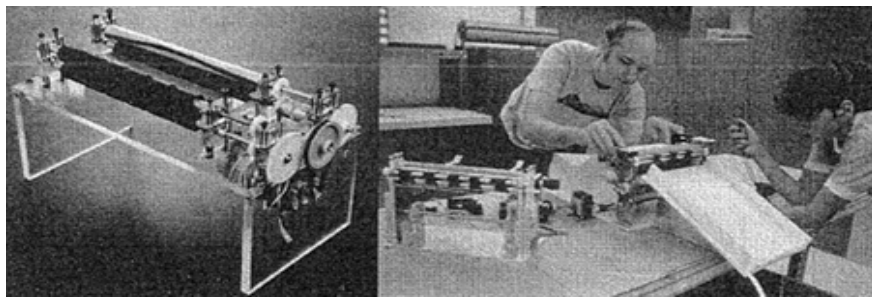


Figure 187: Final hardware prototype of an inkjet printer (Otto and Wood 2001)

They are different from beta or pre-production prototypes as a final hardware prototype does not represent the exterior outlook and aesthetics of the design. For this research, final hardware prototypes are 3D visual design representations used to assist in the design and evaluation of product fabrication and other assembly issues.

#### **7.6.2.4 Tooling Prototype**

According to Evans (1992), the tooling prototype is used to ensure that the pressed steel components or die castings for tooling are correctly made (Figure 188). This minimises errors as incorrect moulds and tooling parts are hugely expensive to manufacture and very complex to modify. For this research, the tooling prototype is a 3D visual design representation that allows the tooling to be made for the actual product and to enable potential problems to be intercepted before discrepancies in form or fit occur.



Figure 188: Tooling prototype of the Handy Paint Pail (Haller and Cullen 2006)

#### 7.6.2.5 Off-Tool Prototype

The off-tool prototype consists of parts produced from the actual tooling and materials intended for the final product. They are mainly used by engineering designers to validate fit and assembly, while they may sometimes be used by industrial designers to check the finishing of parts (Evans 1992) (Figure 189) For this research, off-tool prototypes are 3D visual design representations that consists of physical components produced from the actual tooling and materials intended for the final product.

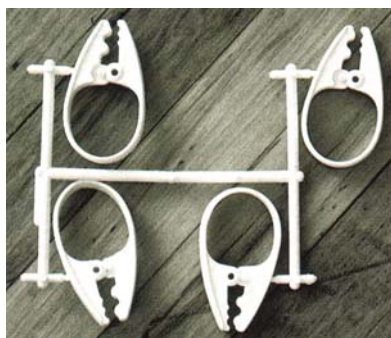


Figure 189: Off-Tool prototype for the Ekco Clip 'N Stay (IDSA 2003)

The earlier sections have described representations that were classed as 2D design representations comprising of sketches and drawings, and 3D visual design representations comprising of models and prototypes. The definition

for each prototype is summarised in Appendix 13.4.4. The next section discusses the topic of design information and its categories.

## **7.7            *Design Information***

This section provides an overview of design information concerned with the use of visual design representations. Design information is concerned with aspects such as the design intent (the purpose of a design), the visual character (the aesthetic qualities) and a products' usability and operation, etc. The level of design information required is influenced by the type of product. User-driven products that have high levels of user interaction, interface and outlook require more design information as opposed to more technical information needed for technology-driven products (Ulrich and Eppinger 2003; Burton 2005). The sub-categories of design information are now discussed.

### **7.7.1    Design Intent**

According to the Merriam-Webster dictionary (1994), the term 'intent' is the purpose, meaning and significance of something. For this research, 'design intent' refers to the purpose of the design, and how the features, dimensions and relationships of parts are planned and governed to work towards the solution of the design problem (Perez 2008). Another definition of design intent is 'the detailed explanation of the ideas, concepts and criteria that are defined by the designer to be important' (Castelvecchi 2002). It considers the requirements of the design, the existing conditions, as well as limitations of the project. They may be subsumed into the product design specifications or as part of the design brief. To help explain the design intent in a sketch, an industrial designer uses text annotations, arrows or shading for more emphasis (Figures 190 - 192). For this research, design intent refers to the intention of the design concept and product purpose including aesthetics, safety and usability.

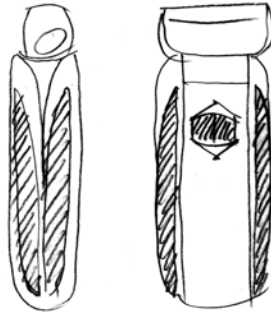


Figure 190: Concept of a Braun shaver showing shading lines that signify the use of different material for the grip (Pipes 2007)

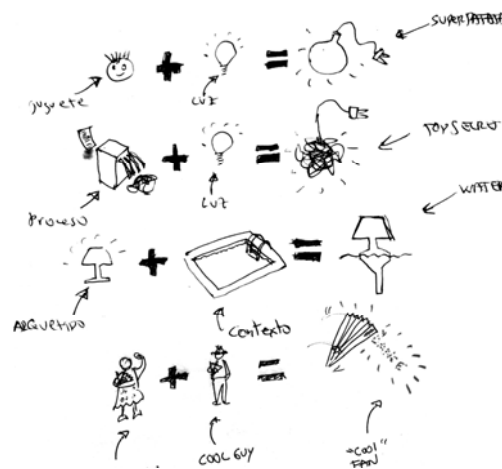


Figure 191: The design intent for Hector Serrano's pool lamp can be seen with use of words and symbols that illustrates his mind at work (Pipes 2007)

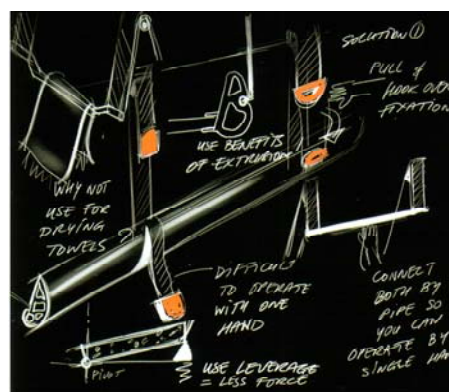


Figure 192: Use of text annotations show the design intent more clearly (Eissen and Steur 2008)

### 7.7.2 Form and Detail

The 'form' refers to the shape, structure and arrangement of an object and the relationship between them (Dictionary of Art Terms 2003). According to Eissen and Steur (2008), a 2D representation achieves its form and detail by means of outlining and shading (Figures 193, 194). Other supporting details such as a background image or a human figure provides better understanding of the product context as well as its scale and proportion. A physical model achieves its form and detail through use of sculpting tools and ready-made parts for realism. For this research, form and detail refers to the product's appearance with respect to form, in terms of structure, shape, proportion and size.

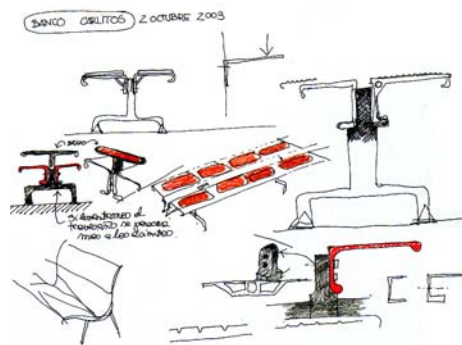


Figure 193: Carlitos bench by Oscar Tusquets with use of different profile views and colours to examine the design details (Pipes 2007)



Figure 194: Details of control buttons (Eissen and Steur 2008)

### 7.7.3 Visual Character

Visual character is concerned with the aesthetics of a product (AskOxford 2008). To increase realism, 2D visual design representations often employ



good use of light and shading to enhance the perceived volume and shape (Eissen and Steur 2008) (Figure 195. For this research, visual character refers to the product's personality or character that is conveyed to the user, usually through external form, materials, texture and finishing.



Figure 195: The use of colour, shading, outlining and details to show the visual character of a product concept (Eissen and Steur 2008)

#### 7.7.4 Usability and Operation

Usability refers to how well a product performs a function, ability or service (Longman Dictionary 2005); or the fact or state of a product in use (Merriam-Webster Dictionary 1994). The term 'operation' is concerned with 'the doing or performing of a practical work' (ibid); and the way that a machine or system works together (Longman Dictionary 2005). To show the usability and operation of a product, 2D visual design representations should draw attention to a product's use within its environment. For example, showing the hands to indicate its use and the scale of a product (Eissen and Steur 2008) (Figure 196).



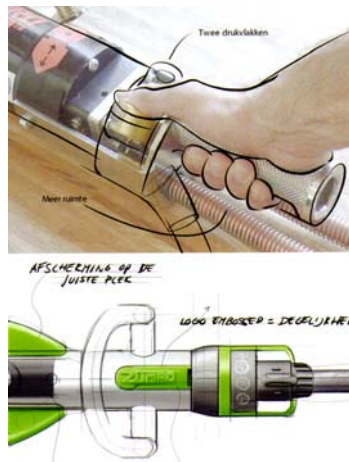


Figure 196: Hands are illustrated with the product to illustrate the scale, its relation to human hands and the intended use (Eissen and Steur 2008)

For larger products, human figures provide a reference to proportion such as the backpack in Figure 197 (Olofsson and Sjöln 2005). For this research, usability and operation refers to how well a product is capable of being used, including functional effectiveness, ergonomics and operational efficiency.



Figure 197: Illustration of a person carrying a backpack to represent the scale of the backpack (Olofsson and Sjöln 2005)

### 7.7.5 Scenario of Use

A 'scenario' is a situation that could happen (Longman Dictionary 2005). A Sketch or drawing that shows the scenario of use helps explain complex processes and how a product is utilised in a sequence of events. It includes

relationships between the user and the product, and may be created by means of structured drawings showing activities in a step-by-step or chronological manner (Olofsson and Sjöln 2005). To improve understanding, certain steps might include close-ups or cross-sections (Figures 198 – 200). For this research, the scenario of use describes how a product would be used in a projected sequence of events and may include relationships between the user, environment and product.

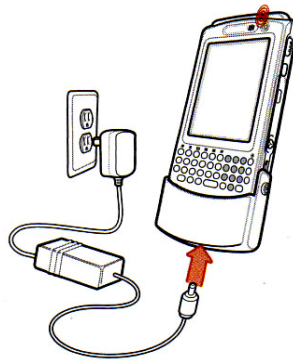


Figure 198: Plugging in an adaptor cable into a product (Buxton 2007)

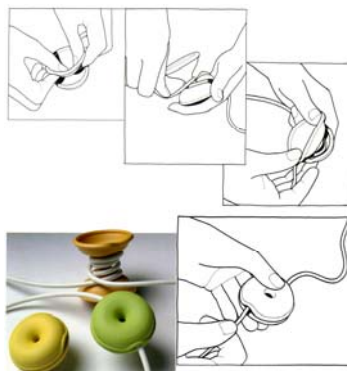


Figure 199: Working principle for the Cable Turtle (Eissen and Steur 2008)

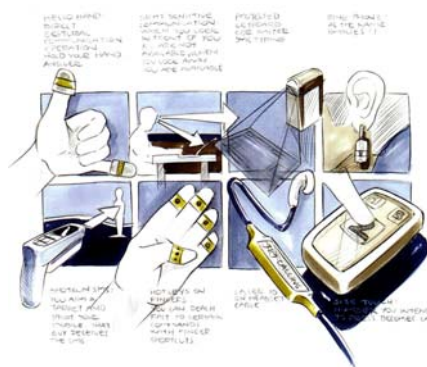


Figure 200: A chronological product scenario (Olofsson and Sjöln 2005).

### 7.7.6 Single Views

During the design process, several types of 2D visual design representations may be employed to communicate and clarify the design idea. They include contour sketches, side-view sketches and axonometric views. Contour sketches represent the general outline of an object (Bertoline 2002) (Figure 22201), while side view sketches shows the form in a side profile to suggest the product idea. These side view representations are popular among footwear designers as shoes are viewed by consumers in a store this way (Eissen and Steur 2008) (Figure 202).



Figure 201: A contour sketch (Bertoline 2002)



Figure 202: Side view drawings for shoe design (Eissen and Steur 2008)

Single views may also take place as an independent 3D image in the form of axonometric projections. They comprise of isometric, trimetric, diametric, oblique and perspective views (Lueptow 2000; Bertoline 2002) (Figure 203). For this research, single views comprise 2D visual design representations made up of contour sketches and side-views, as well as axonometric projections encompassing isometric, dimetric, trimetric, perspective and oblique views.

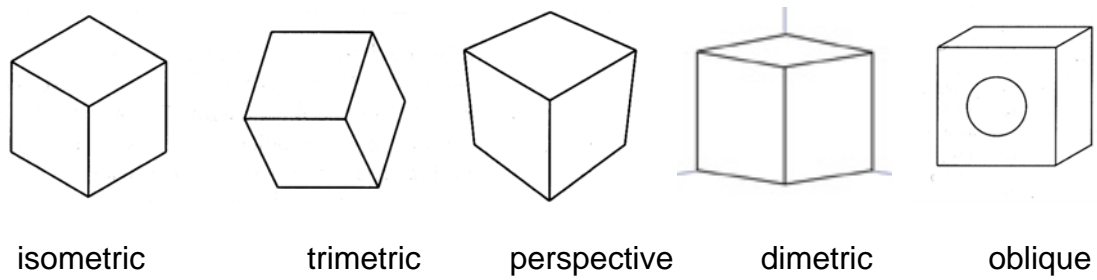


Figure 203: Various projection drawings (Lueptow 2000)

### 7.7.7 Multi Views

A multi-view representation (Figure 204) is an orthographic projection that represents the object in an imaginary box showing each view (Pipes 2007) (Figure 205). According to Garner (2006), the term 'orthographic' means being drawn straight-on to visualise a 3D object on a 2D medium with several different planes. The third-angle and first-angle projection are the two main ways of showing a multi-view representation. They differ in the position of the plan, front and side views and a fourth view is occasionally added if all the details are not yet shown (Raudebaugh and Newcomer 1999). Although most American companies adopt third-angle projections and European companies employ the first-angle, the choice is still very much dependent on the object itself (Pipes 2007). The type of projection used may be recognised by a symbol found at the bottom on a drawing (Figure 206). For this research, multi views comprise of first-angle or third-angle projections in which the form is flattened out with plans views, front elevations and end elevations.

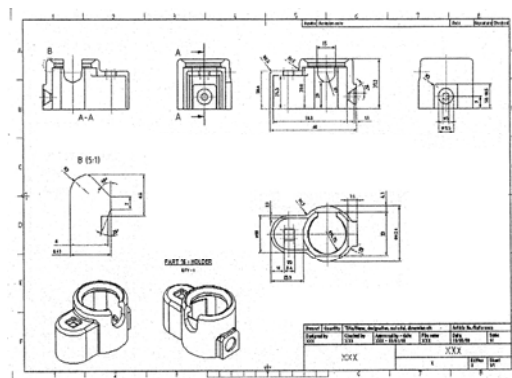


Figure 204: Multi-views shown in a general arrangement drawing (Lee 2008)

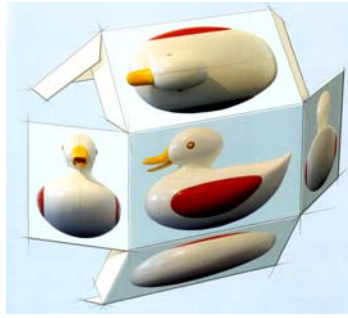


Figure 205: A multi-view representation shows several flat views of a 3D artefact on a 2D medium (Eissen and Steur 2008)

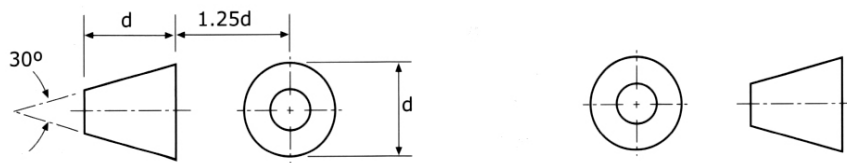


Figure 206: Symbol for a first-angle projection (left) and third angle projection (right)

### 7.7.8 Areas of Concern

In a complex product, there may be several areas that need to be looked at. According to Do (2005) re-examining an area in a 2D representation may take the form of over-tracing, redrawing, hatching and repeated outlining (figure 207, 208) to select, draw attention, or to explain something in detail. Other forms of activity that highlight areas of concern include shading (Figure 209) and close-ups (Figure 210). For this research, areas of concern refer to issues relating to the overall design concerning safety, usability and production.

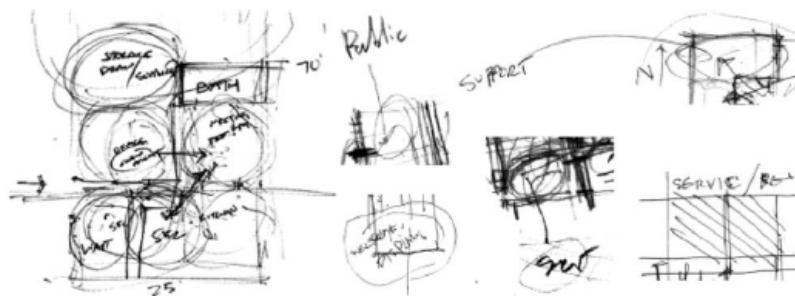


Figure 207: Repeated outlining and hatching (Do 2005)

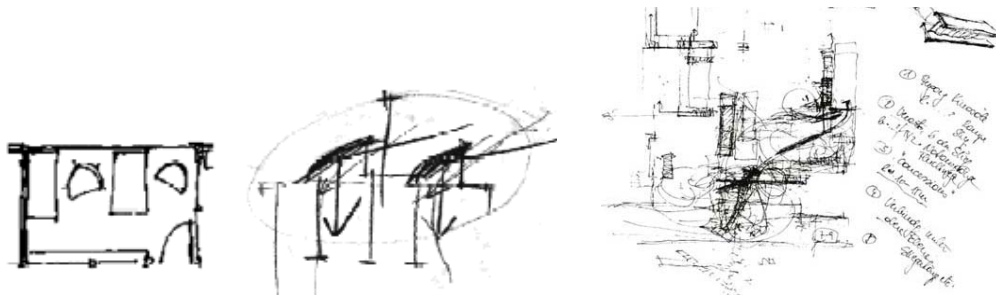


Figure 208: Darkened areas and use of arrows and text labels (Do 2005)

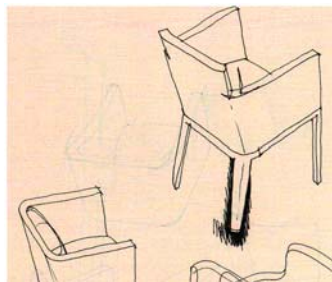


Figure 209: Use of shading to show areas of concern (Pipes 2007)

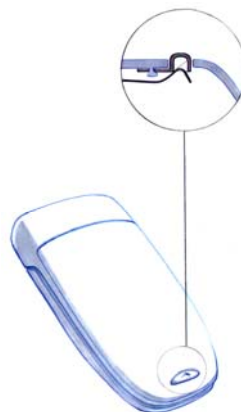


Figure 210: Magnified areas to explore details more fully (Pavel 2005)

### 7.7.9 Texture and Surface Finish

'Texture' refers to the tactile quality of a surface, whether it is rough, smooth, regular or irregular (Collins Dictionary of Art Terms and Techniques 1993). The surface finish is the coat applied to a product and when machining processes are involved, it is termed 'surface finish' or 'finish' (Tjalve *et al.* 1979b). The finishing is chosen based on aesthetics, functionality or production economy. The result may be described as a glossy finish, rough finish, smooth finish or matt finish. While industrial designers use informal

terms such as a rubberised or chrome finishing (Figures 211, 212); engineering designers adopt standardised specifications to convey the desired result with use of texture symbols (Figures 213, 214) or by referring to a texture chart (Figure 215). For this research, finishing refers to the texture (external surface perceived through touch) and surface finish (coating applied to the product) of a product.



Figure 211: Rendering of a rubberised bicycle seat (Eissen and Steur 2008)



Figure 212: Rendering of chrome metal tubes (Eissen and Steur 2008)

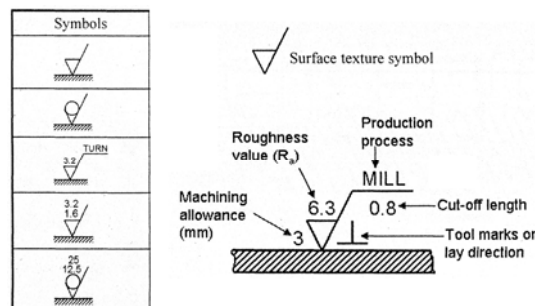


Figure 213: Technical texture symbol and its interpretation (Lee 2008)



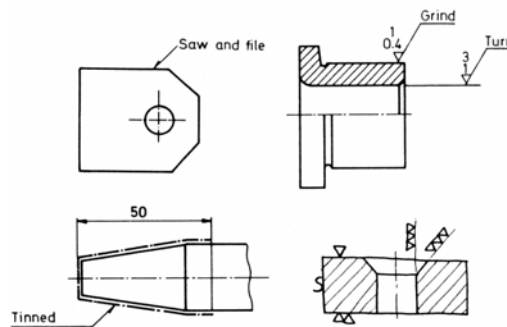


Figure 214: Example of a surface finish specification (Tjalve *et al.* 1979b)

Process	Roughness value Ra ( $\mu\text{m}$ )										
	25	12.5	6.3	3.2	1.6	0.8	0.4	0.2	0.1	0.05	0.025
Sand casting	■										
Forging		■									
Die casting (Pressure)		■									
			■								
Flame cutting	■										
Sawing	■										
Planing, shaping	■										
Drilling		■									
EDM		■									
		■									
Reaming			■								
			■								
			■								
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											■
Super-finishing										■	

Figure 215: Chart showing surface texture and roughness (Lee 2008)

### 7.7.10 Colour

‘Colour’ is a phenomenon of light or visual perception that occurs because of a response to certain wavelengths acting on the eye when light is reflected (Collins Dictionary of Art Terms and Techniques 1993). Some examples of sketches and drawings in colour are shown in Figures 216 and 217. Words used to describe the characteristics of a colour include hue, lightness and saturation. Dark colours are described as deep or rich; light colours are pale, soft or pastel; and bright colours are brilliant, vivid and garish (Longman



Dictionary 2005). For this research, colour refers to the visual attributes of the product's appearance in terms of hue, lightness and saturation.



Figure 216: The use of colour in sketches (Eissen and Steur 2008)

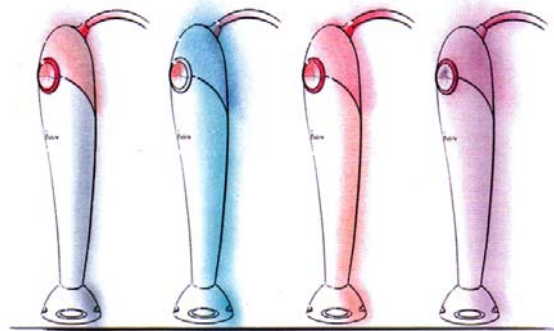


Figure 217: Various shades of colour created with biro pen and pastel for a kitchen blender (Pipes 2007)

The definition for the design information is summarised in Appendix 13.4.5. The next section discusses the topic of technical information and its categories.

## 7.8 Technical Information

Technical information is concerned with aspects such as dimensions, construction and assembly etc. Similar to design information, technology-driven products (e.g. a motorised pump) that are functional require a greater knowledge of technical information as opposed to user-driven products (e.g. a radio). (Ulrich and Eppinger 2003; Burton 2005). The sub-categories of technical information will now be discussed.

### 7.8.1 Dimensions

Dimensions include the physical properties of length, height, width, depth or the diameter of something (Longman Dictionary 2005). They are geometric elements in design or the magnitude of a quantity (Dictionary of Architecture and Construction 2000). Dimensions allow the object to be fabricated accordingly and its accuracy depends on the limits of fluctuation from the required dimension, known as the dimensional tolerance (Raudebaugh and Newcomer 1999). In addition, dimensioning should be made consistent by conforming to international ISO standards. Parts should be dimensioned only once and shown in a view that displays the shape of the feature. Dimensions should be labelled outside of an object and the dimension lines should not overlap each other (Figure 218). For this research, dimensions comprise the measurements of parts, including angles and tolerances with a specified unit of measurement.

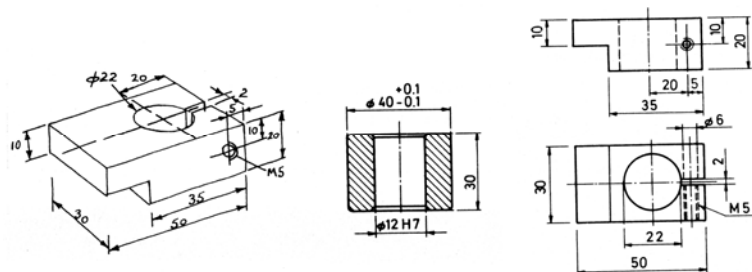


Figure 218: Modelling dimensions and tolerances (Tjalve *et al.* 1979b)

### 7.8.2 Construction

The term 'construction' refers to the art of forming, making and building (Collins Dictionary of Art Terms and Techniques 1993). It may also include information such as materials, fasteners, adhesives or fixing methods to show the process of making something. Describing a construction may take the form of a step-by-step sketch such as shown in Figure 219 (Lawson 1997), or with cut-away drawings (Figure 220) to further explain how the overall component is built. For this research, construction refers to the arrangement and composition of parts used to systematically form, make or build the product.

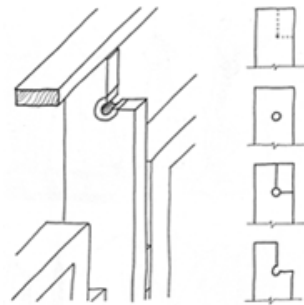


Figure 219: Construction sketch (Lawson 1997)

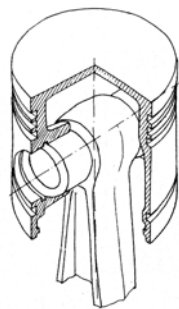


Figure 220: Cut-away drawings (Tjalve *et al.* 1979b)

### 7.8.3 Assembly

The term 'assembly' refers to the process of putting parts of something together (Longman Dictionary 2005); or the fitting of parts (Merriam-Webster Dictionary 1994). This can be described through an assembly drawing, with sub-assemblies referring to a section of the overall product. For more complex parts, the use of a 'sectioned assembly' shows a plane across the

components to provide a full view of how the parts are joined (Bertoline 2002) (Figures 221 - 223). Unlike construction, the assembly of a product is usually shown by means of a general arrangement drawing, technical drawing, or a pictorial assembly drawing (Bertoline 2002). For this research, assembly describes the process of how the manufactured parts and components are put together to make the completed product.

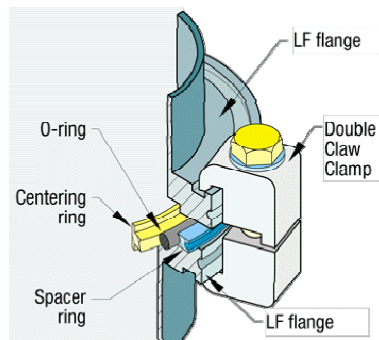


Figure 221: Sectioned assembly drawing of a vacuum seal

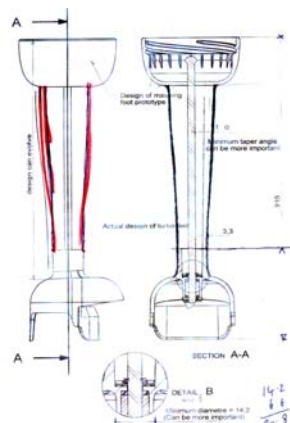


Figure 222: Section drawing of a hand mixer with a close-up (Pipes 2007)

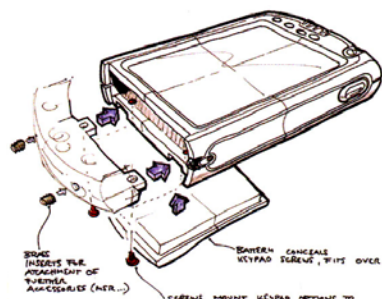


Figure 223: Example of an assembly drawing (Buxton 2007)

#### 7.8.4 Components

Components refer to the elements or parts that form the overall object, machine or system (Longman Dictionary 2005). In 2D visual design representations such as patent drawings, components are shown in great detail (Tjalve *et al.* 1979b). They may be illustrated as a cut-away image or through exploded-views (Figures 224 - 226). Labels are used to describe the parts and explain the arrangement of the components. For this research, components refer to the connected parts which when assembled form the overall working product and may be grouped as electrical or mechanical components, etc.

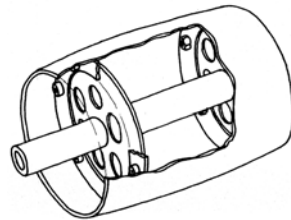


Figure 224: A cut-away illustration (Tjalve *et al.* 1979b)

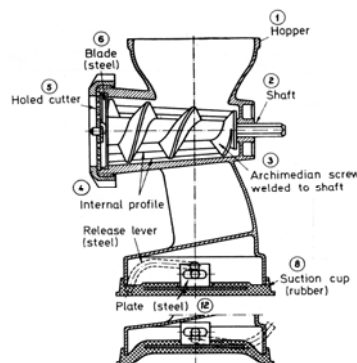


Figure 225: General components of a product (Tjalve *et al.* 1979b)

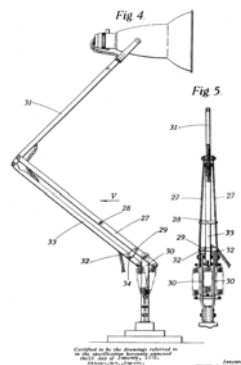


Figure 226: Patent drawing showing parts of an Anglepoise lamp (Pipes 2007)

### 7.8.5 Mechanism

The term ‘mechanism’ refers to a process or technique, limited to a mechanical operation for achieving a result (Merriam-Webster Dictionary 1994). It is also defined as part of a machine or a set of parts that does a particular job (Longman Dictionary 2005). The use of arrows and symbols help to visually explain the movement or operation of parts (Figures 227, 228). For this research, mechanism refers to the assembly of connected moving parts and its physical operation to perform a function.

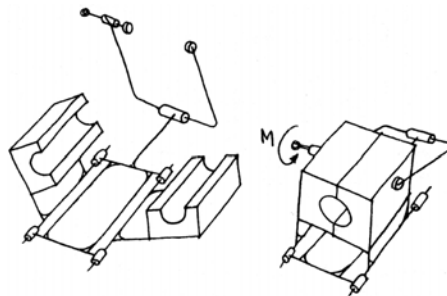


Figure 227: Section through a mechanical device which models the function (Tjalve *et al.* 1979b)

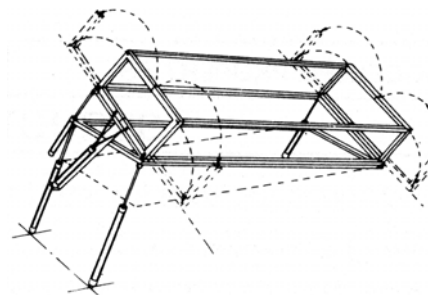


Figure 228: Symbolic description in a series of drawings (Tjalve *et al.* 1979b)

### 7.8.6 Part and Section Profile Lines

To ensure that an organic form is accurately visualised, the developer may incorporate fine lines along the product shape. They are defined as crown lines (Tovey *et al.* 2003) (Figure 2229), netting lines (Pavel 2005) or cross-section lines that describe the product's form (Olofsson and Sjöln 2005). Shading is also used to characterise the curvature of an area rather than blending the tones into each other (Figures 230, 231). Apart from specifying

the product form, these lines are also used to define sections of the product where the components are assembled together (Pavel 2005). For this research, part and section profile lines are used to delineate the form, section or area of a product and includes parting lines where two parts are assembled together or where moulding dies meet.

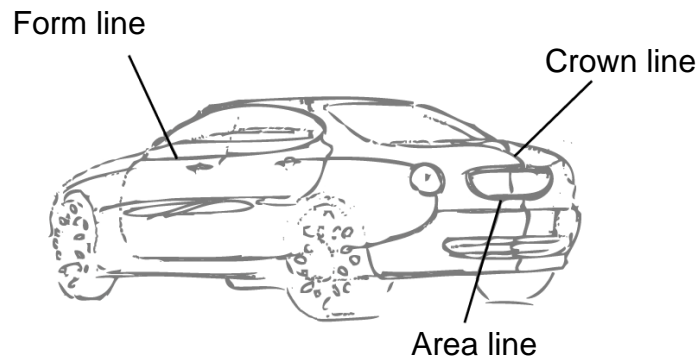


Figure 229: Types of lines within a sketch – note the use of crown lines (Tovey *et al.* 2003)



Figure 230: Profile lines of a mobile phone (Pavel 2005)

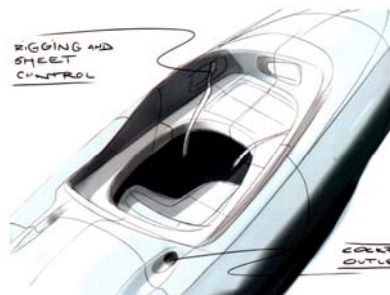


Figure 231: Profile lines of a sailing kayak (Olofsson and Sjölin 2005)

### 7.8.7 Exploded Views

Exploded views, exploded drawings (Tjalve *et al.* 1979b) or explosions (Pavel 2005) are used to show how parts of a product fit together. It shows how parts of the same scale are 'pulled out' along the axes in which they are assembled (Tjalve *et al.* 1979b) (Figure 232).

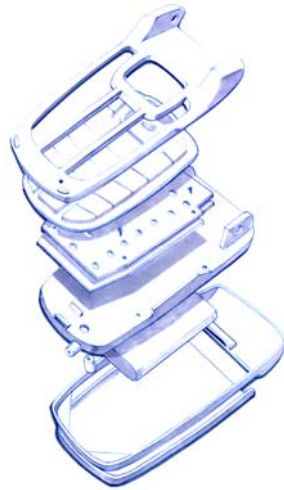


Figure 232: Exploded view of an electronics component (Pavel 2005)

Exploded views that are drawn by industrial designers emphasise the visual outlook of the product (Figures 233, 234), while engineering designers employ exploded views as a formal way to explain and understand the technical aspects and their mutual relationships (Figure 235). For this research, exploded views show part of a product slightly separated by distance to display the components contained within the assembly.

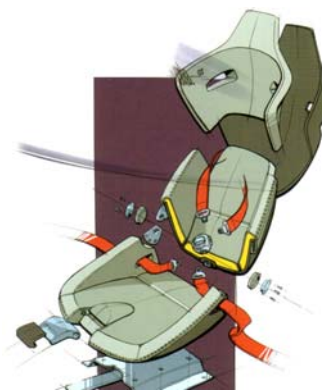


Figure 233: Industrial design rendering of an exploded view





Figure 234: CAD representation of an exploded view for the Dyson vacuum cleaner motor (Pipes 2007)

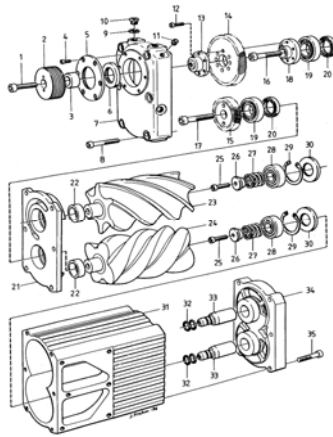


Figure 235: An engineering design exploded view drawing. (Pipes 2007)

### 7.8.8 Material

The material is defined as ‘constituent matter from which something is or can be made from’ (AskOxford 2008). For every component in a product, a material must be chosen so that it can be produced and function as intended. The choice of material is usually indicated on a general arrangement drawing or technical drawing. Informal codes may also be used to define the different materials for a product such as shown in figure 236. For this research, material refers to the substance from which the physical product part is made up of.

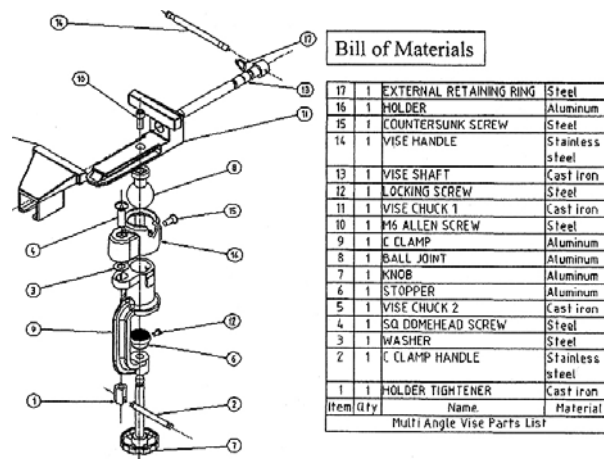


Figure 236: Example of an exploded view used by engineering designers (Tjalve *et al.* 1979b)

The definition for the technical information is summarised in Appendix 13.4.6.

## 7.9 Chapter Summary

This chapter forms the last part of an extensive literature review that has provided a comprehensive overview of four visual design representation groups comprising 9 sketches, 9 drawings, 8 models and 9 prototypes.

Sketches were defined as being preliminary, rough 2D visual design representations without detail; whereas drawings are a formal arrangement of lines that determine and verify a particular form. In contrast, models are 3D visual design representations used to reproduce the physical attributes of an intended product in a tangible form. Prototypes are full-scale 3D visual design representations that incorporate working components.

Bringing them together, a total of 35 visual design representations with 10 design and 8 technical information categories concerning new product development were subsequently compiled into a taxonomy. A tabulated summary of these representations can be found in Appendix 13.4.

## 8. INVESTIGATING THE USE OF VISUAL DESIGN REPRESENTATIONS

### 8.1 Chapter Overview

Chapter 5 identified that the use of visual design representations was a key problem area among industrial designers and engineering designers during new product development. Taking a step further, Chapters 6 and 7 provided a literature review concerning design representations and representation media. This knowledge was condensed in the form of a taxonomy comprising sketches, drawings, models and prototypes (Figure 237). The aim of this chapter is to further assess how visual design representations are used by industrial designers and engineering designers in new product development. The following sections discuss the investigation strategy and the reliability of data collection. It discusses the interview method and the findings, ending with an analysis and recommendations for the next phase of research.

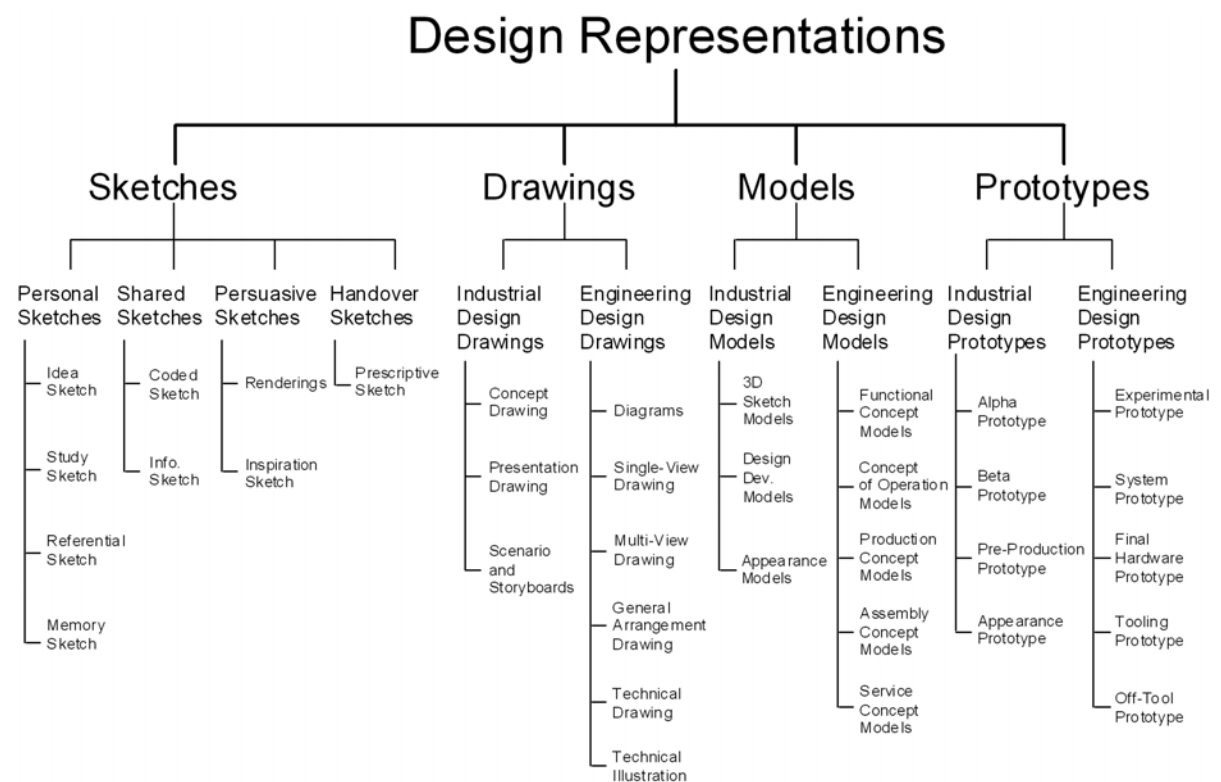


Figure 237: Taxonomy of Design Representations

## **8.2 Research Strategy, Reliability and Ethical Considerations**

During the first phase of empirical research that was discussed in Chapter 5, the use of qualitative methods in the form of semi-structured interviews and participant-observations provided a valuable insight into the research context. The literature also confirmed the advantages of linking qualitative and quantitative data and it was decided that this strategy would be adopted for the second phase of empirical research. According to Persson (2005b), while qualitative research allows the researcher to identify unknown phenomena and meanings, quantitative studies investigate how the properties and meanings may be distributed among different groups or situations. Therefore for this research, the qualitative approach by means of an interview would address the purpose of explaining how visual design representations are used by industrial designers and engineering designers in new product development. In order to gain a further understanding, quantitative methods would be used to complement the interview data so as to achieve a more holistic perspective.

In terms of choosing the qualitative method, interviews were used as they are generally flexible and easy to administer. Conducting the interviews in person allowed respondents to understand the research clearly and enabled a higher response rate as compared to a mail survey. Similarly to the first phase of empirical research, all participants were provided with a booklet (Appendix 13.3) in order to understand the nature of the research. The booklet also summarised the aims of the interview study with a list of visual design representations and the taxonomy. The participants were also informed that they had the right to end participation at any time without penalty and that their identities would be kept anonymous with no mention of the project or their organisation. To minimise memory loss, all interviews were transcribed on the same day and a copy of the transcript was emailed to the respondents within a day so that their input could be checked and verified by the respondents themselves.

Reliability was maintained by adhering to the same set of guidelines used during the first phase of interviews. A total of 90 letters requesting participation in this research were sent to over 80 companies in the United Kingdom over a 1 month period. The poor response rate of only five replies resulted in a decision to conduct the second Phase of empirical research in Singapore. For consistency, the investigations in Singapore were conducted with a range of industrial designers, engineering designers and project managers. The same participants from the first interviews were contacted and re-introduced to the second interview. As several months had passed, most respondents were no longer contactable, unavailable or did not wish to take part in the experiment. New participants were secured and a total of 27 participants came forward. Of these, there were 13 industrial designers, 10 engineering designers and four project managers. Of the 27 respondents, six were academics from their respective disciplines but they were all former industrial design or engineering design practitioners who had at least three years of work experience. By interviewing the industrial design and engineering design practitioners, it enabled first-hand accounts to be obtained; while interviewing the project managers allowed the research to obtain a management perspective. Including academics for this interview also enabled their views regarding the use of visual design representations to be obtained. All 27 respondents have at least 3 years of work experience. The interview statistics can be found in Table 37 and 38.

<b>Details of Interview Study R3</b>	
Total respondents conducted	27
Industrial designers interviewed	13
Engineering designers interviewed	10
Project Managers interviewed	4
Total number of companies	17

Table 37: Interview Statistics

No.		Respondent Code	Company	Profession
1.	M	R3-1	Company 1	Project Manager
2.	ED	R3-2	Company 2	Engineering Designer
3.	ED	R3-3	Company 3	Academic
4.	ID	R3-4	Company 4	Industrial Designer
5.	ID	R3-5	Company 4	Industrial Designer
6.	ED	R3-6	Company 4	Engineering Designer
7.	ED	R3-7	Company 5	Engineering Designer
8.	ID	R3-8	Company 6	Academic
9.	ED	R3-9	Company 7	Academic
10.	ID	R3-10	Company 8	Industrial Designer
11.	ED	R3-11	Company 8	Engineering Designer
12.	ID	R3-12	Company 9	Industrial Designer
13.	ID	R3-13	Company 10	Industrial Designer
14.	M	R3-14	Company 10	Project Manager
15.	ED	R3-15	Company 11	Engineering Designer
16.	ID	R3-16	Company 12	Industrial Designer
17.	ID	R3-17	Company 12	Industrial Designer
18.	ID	R3-18	Company 12	Industrial Designer
19.	ID	R3-19	Company 13	Industrial Designer
20.	M	R3-20	Company 13	Project Manager
21.	ED	R3-21	Company 14	Academic
22.	ID	R3-22	Company 15	Industrial Designer
23.	ID	R3-23	Company 15	Industrial Designer
24.	ED	R3-24	Company 15	Engineering Designer
25.	M	R3-25	Company 16	Project Manager
26.	ED	R3-26	Company 17	Academic
27.	ID	R3-27	Company 17	Academic

	Industrial Designer		Engineering Designer
	Project Manager		Academic

Table 38: Description of Company & Respondents Interviewed

### 8.3 Data Collection with Interviews

The aim of this study was to understand the application of design representations employed by industrial designers and engineering designers during new product development. Accordingly, the following objectives were set for the interview study: First, to validate the 35 visual design representations. Second, to identify visual design representations commonly used during each of the four stages of the design process. Third, to investigate the type of design and technical information present within a design representation. Fourth, to find out their preference for the toolkit format. The face-to-face interview was structured into four sections (Figure 238).

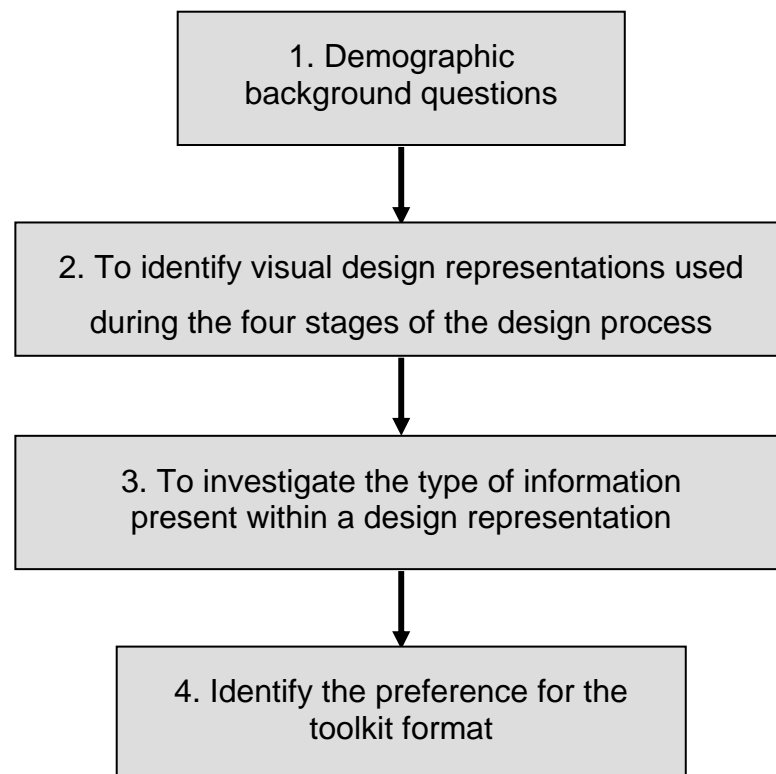


Figure 238: Objectives of the data collection with interviews

The purpose of the first section was to gather demographic data from the respondents about their background, job scope and projects undertaken. It was made up of the seven questions shown below.

A. Background questions:

1. Name
2. Company
3. Position
4. Role and Responsibility
5. Educational Background
6. Years of Experience
7. Type of design projects undertaken

Because this phase of the investigation was more specific in nature, it was decided that a structured format would be the best way of seeking answers from the respondents. To do so, the second section was structured in the form of a matrix (Figure 239) that required the respondent to indicate the visual design representations that were used during each of the four stages of the design process. The purpose was to validate if the 35 representations were recognised and if they were commonly used by the industrial designer and engineering designer at the concept design, concept development, embodiment design and detail design stages of the design process. The matrix shows rows of visual design representations adopted from the taxonomy (sketches, drawings, models and prototypes); while the columns were the four design stages. Recalling a project in mind as an example, the respondents had to decide that for a particular visual design representation, which stage of the design process was it used and then ticking the respective box. The second section typically took around 25 minutes to complete.



Name: \_\_\_\_\_

Date: \_\_\_\_\_

### The Matrix:

This matrix aims to understand which design representations are used during the design stages of the product development process.

### Instructions:

The matrix is divided into 4 rows of design stages and classified into columns of design representations.

By going through each stage at a time, tick the appropriate design representation if you have used it during that particular stage.

				DESIGN STAGE			
				CONCEPT DESIGN	CONCEPT DEVELOPMENT	EMBODIMENT DESIGN	DETAIL DESIGN
DESIGN REPRESENTATION	SKETCHES	Personal Sketches	Idea Sketch				
			Study Sketch				
			Referential Sketch				
			Memory Sketch				
		Shared Sketches	Information Sketch				
			Coded Sketch				
		Persuasive Sketches	Inspiration Sketch				
			Renderings				
		Prescriptive Sketches	Prescriptive Sketch				
	DRAWINGS	Industrial Design Drawings	Concept Drawings				
			Presentation Drawings				
			Scenarios & Storyboards				
		Engineering Design Drawings	General Arrangement Drawings				
			Technical Drawings				
			Technical Illustrations				
			Single-view Drawings				
			Multi-view Drawings				
			Tape Drawings				
			Diagrams				
		Industrial Design Models	Appearance Models				
			Design Development Models				
			Foam Models				
		Engineering Design Models	Functional Concept Models				
			Production Concept Models				
			Assembly Concept Models				
			Concept-of-Operation Models				
			Service Concept Models				
			Environment Concept Models				
	PROTOTYPES	Industrial Design Prototypes	Appearance Prototype				
			Alpha Prototype				
			Beta Prototype				
			Pre-Production Prototype				
		Engineering Design Prototypes	Experimental Prototype				
			System Prototype				
			Final Hardware Prototype				
			Tooling Prototype				
			Off-Tool Prototype				

Figure 239: Matching appropriate representations to the stage of product development

[illegible]

Working on one design representation at a time as shown in Figure 241, each respondent had to identify the design or technical information that might be present within a design representation. To allow the respondents to better recognise a representation, a thumbnail image was inserted above each column. All respondents also had access to the booklet that provided a larger visual example and the detailed description of each design representation. This section took around 45 minutes to complete. The interview sheets can be found in Appendix 13.5.



SKETCHES				
Personal Sketches				
	1			
		2		
			Idea Sketch <sup>1</sup>	Study Sketch <sup>2</sup>
DESIGN INFORMATION	Design intent			
	Form and Detail			
	Visual Character			
	Usability and Operation			
	Scenario of Use			
	Single View			
	Multi-view			
	Areas of Concern			
TECHNICAL INFORMATION	Dimensions			
	Construction			
	Assembly			
	Components			
	Mechanism			
	Part and Section Profile lines			
	Exploded Views			
	Colour match file			
	Texture (surface finish)			
	Pantone colour code			
	Material			

Figure 241: Matching appropriate design / technical information to a particular design representation

In the last section of the interview, the respondents were asked for their preferred format for a design toolkit (Figure 242). They had the option of a checklist, matrix, table of instructions, flowchart on a card, a mini-booklet, webpage, CD-ROM / DVD, software for a personal digital assistant, software for a laptop, or other formats. The purpose of this section was to find out suitable formats for the design tool. The results of the interviews are now discussed.

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Checklist	Matrix	Table of Instructions	Flowchart on a Card	Mini-Booklet
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Others (please describe)
Webpage	CD-ROM / DVD	Software for PDA	Software for laptops	

Figure 242: Choice of options for the toolkit format

## 8.4 Interview Findings

After filling out their background information, the second section in the form of a matrix aimed to assess the design representations that were used by both industrial design and engineering design respondents at each of the four stages of the design process. The interview results are shown in a quantitative format in Table 39, and converted into percentages (Table 40) and then into a bar-chart format (Table 41). To allow visual comparison, the results of the industrial designers and engineering designers were put together in Table 42.

It can be observed from the findings that most design representations have been generally employed by both disciplines, although some design representations were more commonly used by industrial designers and others more commonly used by engineering designers. For example, inspiration sketches were used by industrial designers and were never employed by engineering designers. Similarly, experimental prototypes were more commonly used by engineering designers as compared to industrial designers. A pattern can also be observed whereby the concept design and concept development stages show design representations to be used much more by industrial designers than engineering designers (refer to Table 42). In addition, sketches and drawings were used more commonly by industrial designers throughout the four design stages, while the engineering designers only sketched and drew mainly at the concept design and concept development

stages. Both industrial designers and engineering designers used models throughout the four stages of the design process. On the other hand, prototypes were seldom used by the industrial designers and were only employed by engineering designers at the embodiment design and detail design stages.

		Industrial Designers				Engineering Designers			
		Concept Design	Concept Development	Embodiment Design	Detail Design	Concept Design	Concept Development	Embodiment Design	Detail Design
1	Idea Sketch	17	5	3	3	7	1		
2	Study Sketch	13	6	3	3	8			
3	Referential Sketch	12	2			1			
4	Memory Sketch	13	3	1	1				
5	Information Sketch	10	13	2	1	1	1	1	
6	Coded Sketch	6	5	2		1			
7	Inspiration Sketch	1	2	1					
8	Renderings	2	8	1	1		1		
9	Prescriptive Sketch	2	11	6	6	4	6	1	
10	Concept Drawings	7	15	5	4	1	1		
11	Presentation Drawings	3	10	4	4		1	1	
12	Scenarios & Storyboards	11	9			1	1		
13	General Arrangement Drawings		3	4	5		2	1	
14	Technical Drawings		1	4	3	1		5	2
15	Technical Illustrations			2	3	1			
16	Single-View Drawings	3	6	4	3				
17	Multi-View Drawings	2	4	10	7	4	7	2	2
18	Tape Drawings								
19	Diagrams	2	4	1	1	2			
20	Appearance Models		3	10	8			3	1
21	Design Development Models	5	10	1				1	
22	Foam Models	4	11	5	1		1	2	
23	Functional Concept Models	3	5	5	3	4	5	2	
24	Production Concept Models								2
25	Assembly Concept Models		2		1			1	1
26	Concept of Operation Models	1	3	1	1	1	1	1	
27	Service Concept Models		1	1					1
28	Environment Concept Models								
29	Appearance Prototype	1	1	5	11			2	3
30	Alpha Prototype			2	2			1	1
31	Beta Prototype			2	1			1	
32	Pre-Production Prototype			1	4				2
33	Experimental Prototype		1	1	1	3	3	2	1
34	System Prototype				1		1	2	2
35	Final Hardware Prototype				1			1	3
36	Tooling Prototype			1	3			1	2
37	Off-Tool Prototype				1				2

Table 39: Results from the respondents showing the use of visual design representations used during the four stages of the design process

		% of Industrial Designers				% of Engineering Designers			
		Concept Design	Concept Development	Embodiment Design	Detail Design	Concept Design	Concept Development	Embodiment Design	Detail Design
1	Idea Sketch	94.4	27.7	16.6	16.6	77.7	11.1		
2	Study Sketch	72.2	33.3	16.6	16.6	88.8			
3	Referential Sketch	66.6	11.1			11.1			
4	Memory Sketch	72.2	16.6	5.5	5.5				
5	Information Sketch	55.5	72.2	11.1	5.5	11.1	11.1	11.1	
6	Coded Sketch	33.3	27.7	11.1		11.1			
7	Inspiration Sketch	5.5	11.1	5.5					
8	Renderings	11.1	44.4	5.5	5.5		11.1		
9	Prescriptive Sketch	11.1	61.1	33.3	33.3	44.4	66.6	11.1	
10	Concept Drawings	38.8	83.3	27.7	22.2	11.1	11.1		
11	Presentation Drawings	16.6	55.5	22.2	22.2		11.1	11.1	
12	Scenarios & Storyboards	61.1	50			11.1	11.1		
13	General Arrangement Drawings		16.6	22.2	27.7		22.2	11.1	
14	Technical Drawings		5.5	22.2	16.6	11.1		55.5	22.2
15	Technical Illustrations			11.1	16.6	11.1			
16	Single-View Drawings	16.6	33.3	22.2	16.6				
17	Multi-View Drawings	11.1	22.2	55.5	38.8	44.4	77.7	22.2	22.2
18	Tape Drawings								
19	Diagrams	11.1	22.2	5.5	5.5	22.2			
20	Appearance Models		16.6	55.5	44.4			33.3	11.1
21	Design Development Models	27.7	55.5	5.5				11.1	
22	Foam Models	22.2	61.1	27.7	5.5		11.1	22.2	
23	Functional Concept Models	16.6	27.7	27.7	16.6	44.4	55.5	22.2	
24	Production Concept Models								22.2
25	Assembly Concept Models		11.1		5.5			11.1	11.1
26	Concept of Operation Models	5.5	16.6	5.5	5.5	11.1	11.1	11.1	
27	Service Concept Models		5.5	5.5					11.1
28	Environment Concept Models								
29	Appearance Prototype	5.5	5.5	27.7	61.1			22.2	33.3
30	Alpha Prototype			11.1	11.1			11.1	11.1
31	Beta Prototype			11.1	5.5			11.1	
32	Pre-Production Prototype			5.5	22.2				22.2
33	Experimental Prototype		5.5	5.5	5.5	33.3	33.3	22.2	11.1
34	System Prototype				5.5		11.1	22.2	22.2
35	Final Hardware Prototype				5.5			11.1	33.3
36	Tooling Prototype			5.5	16.6			11.1	22.2
37	Off-Tool Prototype				5.5				22.2

Table 40: Results from the respondents showing the use of visual design representations used during the four stages of the design process converted to percentage

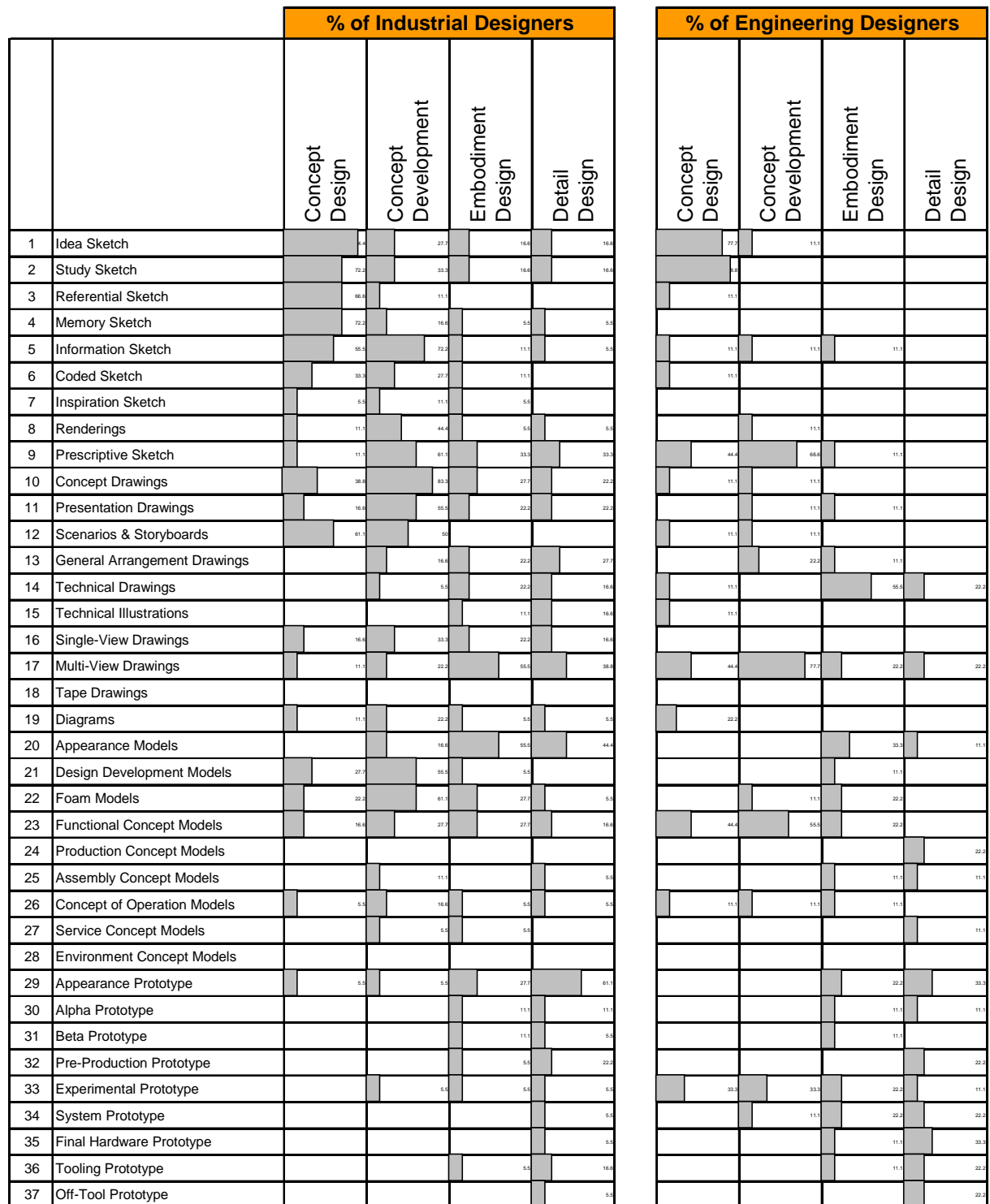


Table 41: Results from the respondents showing the use of visual design representations used during the four stages of the design process converted to percentage in a bar chart format

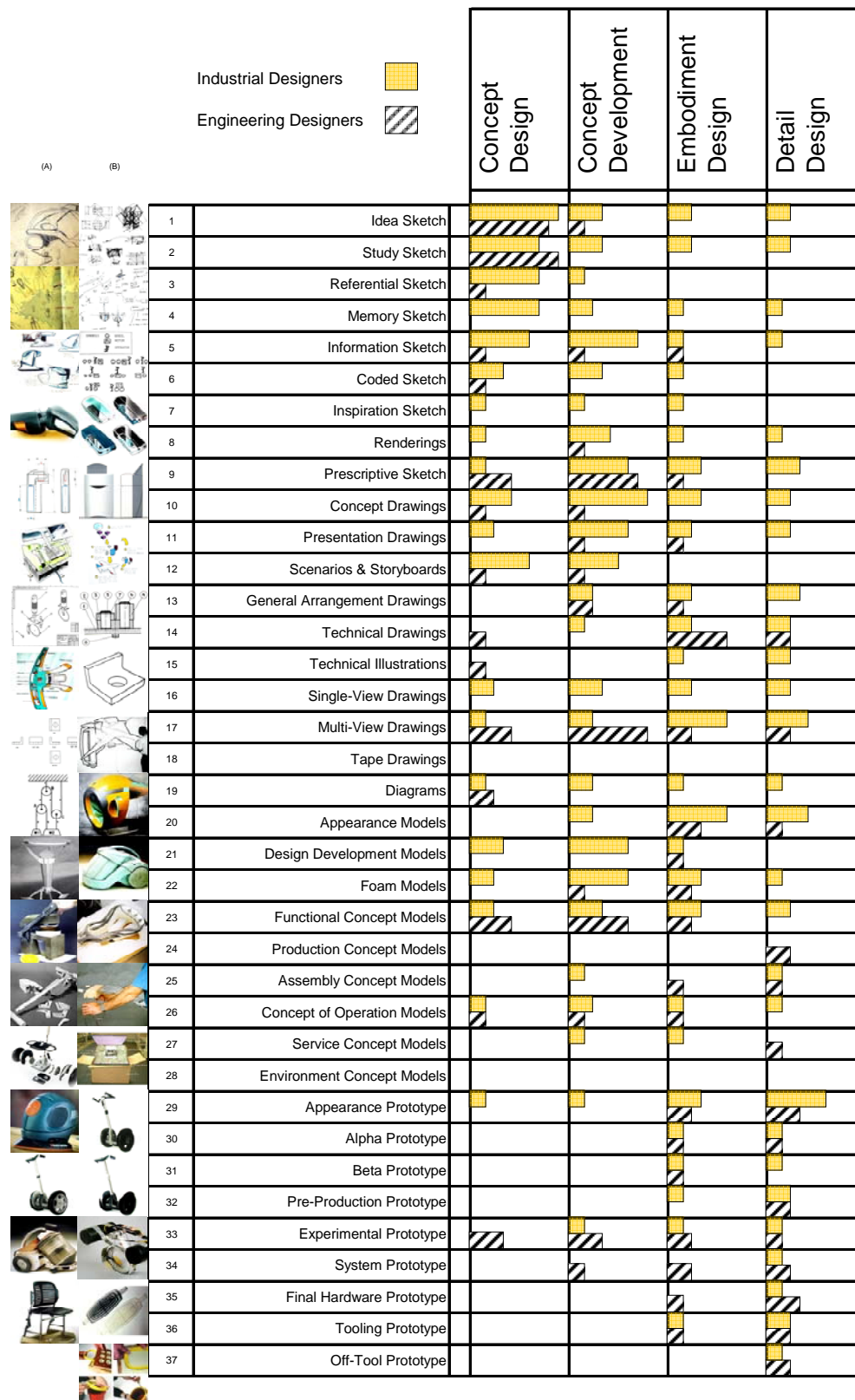


Table 42: Comparative results in a bar chart format



Very little research has been conducted to examine the design representations used by industrial designers and engineering designers. Some researchers including Romer, *et al.* (2001) undertook a small-scale survey that found industrial designers used sketches more commonly in the task clarification and conceptual stages of design, while simple and complex models were shown to be more frequently used during the later stages of design (refer to Section 6.6). Their survey findings are in line with the interview results. In addition, the interview results are reflected by those of Purcell and Gero (1998) and Buxton (2007) who established that less structured forms of representations such as sketches and models are more commonly used during the concept design stage, while detailed technical drawings and prototypes were more commonly used during the detail design stages of new product development. This would seem to confirm the more detailed findings of the current research.

It was identified that the work of other researchers investigating the characteristics of some design representations were also in line with the interview findings. For example, McGown, *et al.* (1998) showed that 2D perspective, isometric and axonometric drawings were commonly used by industrial designers in the concept development stages. In terms of models, Pipes (2007) described that physical models are used by industrial designers commonly in the embodiment stages; while appearance models and appearance prototypes would be more commonly used during the specification stages of the design process (Evans 2002). In summary, this empirical research has provided a deeper understanding in the application of design representations employed by industrial designers and engineering designers. The findings from the interview have gone beyond existing research and they are a contribution to knowledge.

The third section of the interview asked respondents to complete a matrix showing the type of design and technical information present within a design representation. The interview results are shown in a quantitative format where

results from the industrial designers can be found in Table 43, while Table 44 shows the same results as percentages. Results for the engineering designers are found in Table 45 and Table 46 shows their results as percentages. Table 47 brings the results of both industrial designers and engineering designers together in a graphical manner. Individual result sheets can be found in Appendix 13.6.




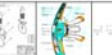
















		Level of Design Information present in Design Representations used by Industrial Designers																																						
		SKETCHES				DRAWINGS								MODELS				PROTOTYPES																						
		Personal Sketches	Shared Sketches	Persuasive Sketches	Technical Sketches	Industrial Design Drawings	Engineering Design Drawings	Industrial Design Models	Engineering Design Models	Industrial Design Prototypes	Engineering Design Prototypes	Industrial Design Prototypes	Engineering Design Prototypes	Industrial Design Prototypes	Engineering Design Prototypes	Industrial Design Prototypes	Engineering Design Prototypes	Industrial Design Prototypes	Engineering Design Prototypes	Industrial Design Prototypes	Engineering Design Prototypes	Industrial Design Prototypes	Engineering Design Prototypes	Industrial Design Prototypes	Engineering Design Prototypes															
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		Idea Sketch <sup>1</sup>	Study Sketch <sup>2</sup>	Referential Sketch <sup>3</sup>	Memory Sketch <sup>2</sup>	Information Sketch <sup>1</sup>	Coded Sketch <sup>2</sup>	Inspiration Sketch <sup>3</sup>	Renderings <sup>2</sup>	Persuasive Sketch <sup>1</sup>	Concept Drawings <sup>2</sup>	Presentation Drawings <sup>1</sup>	Scenarios & Storyboards <sup>2</sup>	General Arrangement Drawings <sup>1</sup>	Technical Drawings <sup>2</sup>	Technical Illustrations <sup>1</sup>	Single-view Drawings <sup>2</sup>	Multi-view Drawings <sup>1</sup>	Type Drawings <sup>2</sup>	Diagrams <sup>1</sup>	Appearance Models <sup>2</sup>	Design Development Models <sup>1</sup>	Foam Models <sup>2</sup>	Functional Concept Models <sup>1</sup>	Production Concept Models <sup>2</sup>	Assembly Concept Models <sup>1</sup>	Concept of Operation Models <sup>2</sup>	Service Concept Models <sup>1</sup>	Environment Concept Models <sup>2</sup>	Appearance Prototype <sup>1</sup>	Alpha Prototype <sup>2</sup>	Beta Prototype <sup>1</sup>	Pre-Production Prototype <sup>2</sup>	Experimental Prototype <sup>1</sup>	System Prototype <sup>2</sup>	Final Hardware Prototype <sup>1</sup>	Tooling Prototype <sup>2</sup>	Off Tool Prototype <sup>1</sup>		
DESIGN INFORMATION	Design intent	17	7	5	6	11	2	2	3	1	7	2																												
	Form and Detail	12	9	4	7	16		2	6	7	14	6				1	2	3	3				7	4	7						7	1		1					1	
	Visual Character	14	7	9	7	12		4	11	1	13	4	1									7	2	3	1							9	2	1	1					
	Usability and Operation	4	2	2	1	10	4					2	1	10							3	1	3	5	7			3			2	2	2	1	1					
	Scenario of Use	2		2	2	4				1	1	1	14									1	1	2	2			1			1									
	Single View (Perspective / Isometric)	3	2			5		1	2	1		6					1	8																						
	Multi-view (Orthographic Projection)		2								6	10	5			2																								
	Areas of Concern	2	10	2	4	5	1			1			2			1				1	1	6	6	1																
	Dimensions		1		4						13	12	3			5	6		8			6	2	3	2						8	1	2	2	1				1	1
	Construction		1		3						5	5		5	4	3			4		2	3	2	3							6	3	3	3	1				1	1
TECHNICAL INFORMATION	Assembly	1	2		1	3				3	5		4	4	3			3		1	2	2	3	2	2					4	2	2	2			1	1	2	1	
	Components		7	1	1	8	5		1	9	9	6		4	5	3		4		3	5	6	4	7		2	2	1		8	2	2	2	1	1	1	3	1		
	Mechanism	1	6		1	7	2			4	1	2				2	1		1	1	1	4	2	2			1	1		7	1	2	2	1	1	1	1	2	1	
	Part and Section Profile lines														1	1					1	1	1							2										
	Exploded Views		1			1				2		8		1																										
	Colour match file					1			1		1			1																		1	1	1	1				1	1
	Texture (surface finish)	1			1	13		4	10		16	2									9	1								11	2	2	2					2	1	
	Pantone colour code					11		3	8		13	1									7	1								9	1	1	1					1		
	Material	1	1		1	14		4	10	1	13	2			4						8	1								9	1	1	1				1	1		

Table 43: Level of Design Information present in Design Representations used by Industrial Designers (in numbers)

Level of Design Information present in Design Representations used by Industrial Designers																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
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Table 44: Level of Design Information present in Design Representations used by Industrial Designers (in percentage)

		Level of Design Information present in Design Representations used by Engineering Designers																																							
		SKETCHES				DRAWINGS								MODELS				PROTOTYPES																							
		Personal Sketches	Hand Sketches	Presentation Sketches	Analysis Sketches	Industrial Design Drawings	Engineering Design Drawings	Industrial Design Models	Engineering Design Models	Industrial Design Prototypes	Engineering Design Prototypes																														
	1																																								
	2																																								
		Idea Sketch <sup>1</sup>	Study Sketch <sup>2</sup>	Referential Sketch <sup>3</sup>	Memory Sketch <sup>3</sup>	Information Sketch <sup>4</sup>	Coded Sketch <sup>4</sup>	Inspiration Sketch <sup>5</sup>	Renderings <sup>6</sup>	Prescriptive Sketch <sup>6</sup>	Concept Drawings <sup>2</sup>	Presentation Drawings <sup>1</sup>	Scenarios & Storyboards <sup>2</sup>	General Arrangement Drawings <sup>4</sup>	Technical Drawings <sup>2</sup>	Technical Illustrations <sup>4</sup>	Single-view Drawings <sup>2</sup>	Multi-view Drawings <sup>1</sup>	Type Drawings <sup>2</sup>	Diagrams <sup>1</sup>	Appearance Models <sup>2</sup>	Design Development Models <sup>1</sup>	Foam Models <sup>2</sup>	Functional Concept Models <sup>1</sup>	Production Concept Models <sup>2</sup>	Assembly Concept Models <sup>1</sup>	Concept of Operation Models <sup>2</sup>	Service Concept Models <sup>2</sup>	Environment Concept Models <sup>2</sup>	Appearance Prototype <sup>1</sup>	Alpha Prototype <sup>2</sup>	Beta Prototype <sup>1</sup>	Pre-Production Prototype <sup>2</sup>	Experimental Prototype <sup>1</sup>	System Prototype <sup>2</sup>	Final Hardware Prototype <sup>1</sup>	Tooling Prototype <sup>2</sup>	Off-Tool Prototype <sup>1</sup>			
DESIGN INFORMATION	Design Intent	2	2	1		1														1	1	1	1																		
	Form and Detail	3	2			1				1												2	1	1															1		
	Visual Character	2				1															3																				
	Usability and Operation	3	1			1					1	2								1		1	2	7				3													
	Scenario of Use	1	1		1							1	2											2																	
TECHNICAL INFORMATION	Single View (Perspective / Isometric)																																								
	Multi-view (Orthographic Projection)		1																																						
	Areas of Concern	1	8																																						
	Dimensions		4		1			7	2				3	6			8			1				1	1						3	2	1	2	1	1	3	2	2		
	Construction	2	6		1	1		3	1				3	6			5					1	1	2	1						3	1	1	1	2	1	2	1	1		
	Assembly	2	6		1	1		4					3	4	1		5			2	1	1	2	2	1		1			3	1	1	1	2	1	2	1	1			
	Components	4	6	1		3	1		6	2			3	5	1		6			2	1	2	7				2			4	2	1	2	4	3	3	2	2			
	Mechanism	4	6			3	1		4				2	4			2			1				7			2			3	1	1	1	1	4	3	3	2	2		
	Part and Section Profile lines																1														1										
	Exploded Views																1	1																							
Colour match file																																									
Texture (surface finish)				3					2							1					3									4	2	1	2				1	1	2		
Pantone colour code				3					2							1					3									4	2	1	2				1	1	2		
Material		1		3				1	2				1	3	1						3								4	2	1	2					1	1	2		

Table 45: Level of Design Information present in Design Representations used by Engineering Designers (in numbers)












		Level of Design Information present in Design Representations used by Engineering Designers																																																																																																																																																																																																																																																																																								
		SKETCHES						DRAWINGS										MODELS						PROTOTYPES																																																																																																																																																																																																																																																																		
		Personal Sketches		Shared Sketches		Perspective Sketches		Technical Sketches		Industrial Design Drawings		Engineering Design Drawings				Industrial Design Models		Engineering Design Models				Industrial Design Prototypes		Engineering Design Prototypes																																																																																																																																																																																																																																																																		
																																																																																																																																																																																																																																																																																										

Table 46: Level of Design Information present in Design Representations used by Engineering Designers (in percentage)

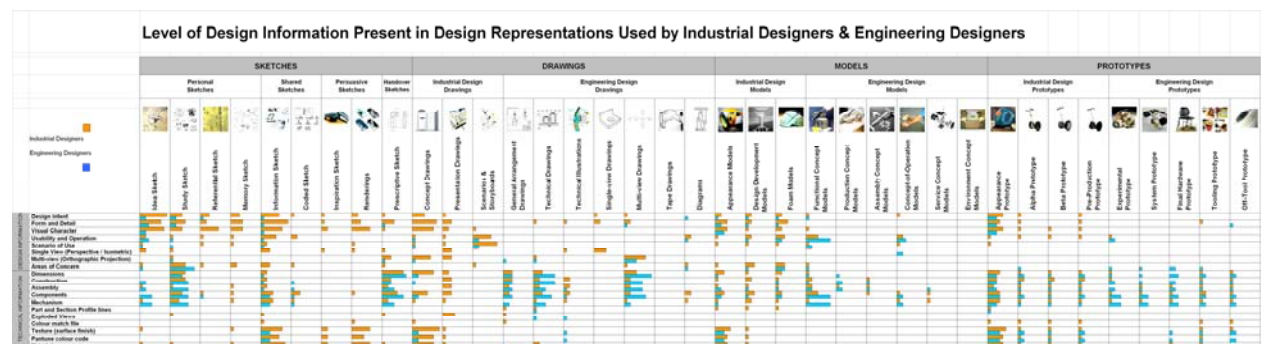


Table 47: Visual Summary of the Level of Design Information present in Design Representations used by Industrial Designers & Engineering Designers (in percentage)

From the analysis, a pattern was observed whereby in general, sketches, drawings and models provide a good balance of design and technical information, while prototypes were mainly concerned with technical

information. It can be observed that the design information is more commonly used by industrial designers as compared to engineering designers. Conversely, technical information has been more commonly used by engineering designers as compared to industrial designers.

While a number of researchers (Schön and Wiggins 1992; Koutamanis 1993; Suwa and Tversky 1997; Purcell and Gero 1998; Schweikardt and Gross 2000; Seitamaa-Hakkarainen and Hakkarainen 2000; Romer *et al.* 2001; Tovey *et al.* 2003; Goldschmidt and Porter 2004; Tohidi *et al.* 2006) have provided various reasons showing the importance of design representations, most of them referred to design representations broadly as either sketches, drawings or models. It was found that detailed empirical research on design representations has been minimal. For example, while research by Engelbrektsson and Soderman (2004), listed eight forms of design representations (handmade sketches, scale models, prototypes, mock-ups, construction design drawings, 3D CAD, rapid prototyping and virtual reality), their work was limited to only two uses of design representations (for general use, and for communication with customers). Another robust study was undertaken by Romer, *et al.* (2001). In their study, they covered four forms of design representations (sketches, simple models, complex models and CAD), and provided six usage attributes for the representations (for developing solutions, testing solutions, checking requirements, documentation, support of memory and support of communication). While their findings might have provided evidence in showing how certain representations were more purposeful than others, their work was limited to only sketches, models and CAD.

In the fourth section of the interview, respondents were asked what format would be suitable for a design toolkit. It was found that the checklist, flowchart and a matrix to be popular among both industrial designers and engineering designers, while several respondents provided suggestions including guidelines, project schedule format, a time-stage, email-based toolkit, Gantt

charts and a tracking list (Table 48). This information shall be used for the next stage of this research where the discussion will focus towards the development of the design tool.

	Industrial Designers	Engineering Designers
Checklist	11	3
Matrix	5	2
Table of Instructions	2	1
Flowchart	6	3
Mini-Booklet	1	-
Webpage	1	1
CD-ROM / DVD	1	-
PDA Software	1	1
Laptop Software	1	-
Others	Guidelines	Tracking List
	Project Schedule	
	Time-stages	
	Email	
	Gantt chart	

Table 48: Suggested Formats for the Toolkit

## 8.5 Chapter Summary

This chapter has provided information concerning three issues. Firstly, the interviews revealed visual design representations that have been used by industrial designers and engineering designers according to the concept design, concept development, embodiment and detail design phases of new product development. The findings showed that although the design representations were used generally by both disciplines, some of them were more commonly employed by industrial designers or engineering designers.

The results also revealed that during the concept design and concept development stages, design representations were used much more by industrial designers than engineering designers. The sketches and drawings were used by industrial designers across the four design stages, while the engineering designers only sketched and drew at the concept design and concept development stages. In terms of models, both industrial designers and engineering designers used them throughout the four stages of the design process, whereas prototypes were seldom used by the industrial designers and were only employed by engineering designers at the embodiment design and detail design stages.

Secondly, the interview findings also revealed the level of design and technical information present within a visual design representation by both disciplines. It was found that in general, sketches, drawings and models provided design and technical information, while prototypes were mainly concerned with technical information. It was also observed that design information was more associated with industrial designers as compared to engineering designers who were seen to be more concerned with technical information.

Thirdly, the interview findings revealed that the checklist, flowchart and a matrix were the most popular formats among industrial designers and engineering designers.

With the findings of this chapter in mind, the next stage shall discuss the tool development, justifying its need and concerns relevant to the formulation of the design aid.

## 9. DEVELOPING A TOOL FOR DESIGN COLLABORATION

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### 9.1 *Chapter Overview*

From the empirical research, it was identified that the use of visual design representations has been a problem area among industrial designers and engineering designers. While several design aids such as collaborative drawing systems have been developed (Section 4.5.2), most do not support the entire development process, are not commercially available, or are fraught with technical issues. It was therefore decided that this research should identify a suitable tool that would support collaboration through building a common ground in the use of design representations among industrial designers and engineering designers. The next section justifies the need for such a tool and analyzes design aids in the market showing their unsuitability in this area. The development of the tool is then discussed, specifying the design requirements, confirming the information structure and finalising the format. A scenario of use is also described to show how the tool might be used. The chapter ends with a series of user trials in the form of a pilot study.

### 9.2 *The Need for a Visual Representation Aid for Design Collaboration*

Chapter 4 discussed that collaboration has been difficult because of the different backgrounds, interests and perspectives of team members from different disciplines (Moenaert and Souder 1990; Griffin and Hauser 1996a). In addition, Moenaert, *et al.* (2000) stressed that the key problem is that members do not have the knowledge to understand the presented information and to interpret it accurately. Using different language and representations have complicated the creation of shared understanding among stakeholders (Bucciarelli 1988; Valkenburg and Dorst 1998). Kleinsmann and Valkenburg (2008) discussed the consequences of disciplines using their own jargon. They described how an electrical engineer had used drawings and



mathematical formulas to explain technical limitations, while an ergonomist employed theories and measurements of the human body. In the end, the discussion was deadlocked. Although both had valid arguments, the use of different jargons had caused irresolvable conflict. This occurrence has also been established by Griffin and Hauser (1996a) who cited that 'when separate thought worlds occur, barriers in language arise'. In this respect, Matthew (1997) proposed a solution where communication among different disciplines can be improved by having a common understanding of shared definitions. In addition, a common vocabulary should include the use of consistent communicative codes and language (Persson and Warell 2003b).

In terms of visual design representations, members of a design team often rely heavily on visual imagery. Problems arise when the representations are misinterpreted or when the original intention is wrongly understood (Eckert 2001). Kleinsmann (2006) highlighted that visual design representations are only useful when both sender and receiver share the same level of abstraction and know the intended purpose. This is similar to Chiu (2002) who stressed the importance of 'transmitting communication symbols precisely; effectively receiving the intended meaning; and reaching the right audience through accurate distribution'. Collaborative design is complex because different members use different representations for different purposes depending on the phase and design task (Van der Lugt 2002). In addition, the findings by Ostwald (1995) acknowledged that communication through visual design representations has become difficult as members have different workplace cultures and perceive the representations according to their worldviews. Dai (2003) described that each member has a unique view of the product due to their different cultural and technical backgrounds and skills. Even more challenging is to inform another person about their viewpoints, or to understand the perspective of others. While Kim (1990) has confirmed that different disciplines in new product development use different representations and revealed that each member has different priorities when using representations. Buxton (2007) raised the fact that creating and reading a sketch is a skill unique to designers. Therefore, industrial designers have to be aware that creating and viewing a design representation may not be the

same for others. Fulton Suri (2003) of the industrial design consultancy, IDEO stressed that the person creating a representation should always consider the viewer's or receiver's perspective. Failure to achieve a clear representation would hinder effective interpretation (Eckert *et al.* 2003). Other authors (Tjalve *et al.* 1979b; Lawson 1997; Maier *et al.* 2007; Visser 2007) have also stressed that the choice of a visual design representation is important because members from other disciplines interpret them according to their own worldviews.

Early studies by Searle (1969) stressed that there should be rules to regulate representations so that the intended meaning is retained and correctly interpreted. While disciplines such as engineering and architecture have drafting standards, there are no conventions for industrial designers except for functional representations such as technical drawings that adopt engineering rules (Saddler 2001). Saddler goes on to say that 'the industrial design profession uses representations that are ill-defined, imprecise and lacking in communicative power'. Other researchers including Baskinger (2008) proposed the inclusion of text when applying images, yet other scholars have argued that words may possess different meanings for different disciplines (Sparke 1996; Persson 2002c; Kleinsmann 2006). While engineers and designers from the same country may speak the same language, identical words may still take on a different meaning (Ashford 1969a).

Work by Söderman (2002) has shown that providing too much information within a design representation might be detrimental. For example, while realistic 3D CAD models could be rotated and magnified, it did not necessarily lead to a higher degree of understanding. Consequently, Söderman asked 'how would one know what features to emphasise in a product representation?' In another study, Brown (2003) questioned 'what would be the most appropriate form of representation for a particular audience and for a particular design stage?' Work by Visser (2006) also noted that apart from verbal confirmation, there were no available tools to determine the level of shared understanding within a group.

Kleinsmann, *et al.* (2005) raised the importance of shared understanding among disciplines. They cited that the lack of shared understanding arose because of the different responsibilities, different interests and dissimilar knowledge bases. This is in-line with Bucciarelli (1994) who stated that 'as actors in a design team use different representations of the design, it complicates collaboration'. In another study, Song *et al.* (2003) provided evidence to show that well designed products came from multi-disciplinary teams who create and possess shared understanding. This is supported by the findings from Valkenburg (1998) and Valkenburg and Dorst (1998) who suggested that design communication becomes efficient only when stakeholders have a shared understanding about the design content. Without a shared understanding, issues are unresolved and the quality of the final product is affected (*ibid*). The term 'object worlds' has been used by Bucciarelli (1988) to describe these problems in multi-disciplinary teams during collaborative design. An object world contains the individual beliefs, interests, knowledge and experience of actors. Different object worlds hamper joint work as members communicate at different levels. It prevents the achievement of shared understanding between actors. According to McDonagh and Storer (2006), because of the varied background of the stakeholders, communication needs to be appropriate through the careful use of images, textures, form, colour and shape so that a design concept can be understood within a social context. Olson *et al.* (1992) summed this up by commenting that 'communication about the design content is the most difficult kind of communication when trying to reach shared understanding'.

The careful application of visual design representations may help members to build a shared mental model of the product. It allows the group to share a joint vision. Consequently, Kleinsmann *et al.* (2007) proposed that to achieve this, members need to be specific about the information they need and the format of information exchange between them. The term 'shared understanding' is used to define when members have similar perceptions about how the design content should be conceptualised (Valkenburg and Dorst 1998). In the bigger picture, having shared understanding improves the atmosphere of the relationship, fosters commitment and enhances trust between partners.

(Bruce *et al.* 1995; Bstieler 2006). Another way to create shared understanding is to document the jargon used by various stakeholders (Hill *et al.* 2001).

In the context of information exchange, Reddy *et al.* (1993) pointed out that it involves developing common representations and providing a transparent access to information. For this to occur, the chosen representation has to incorporate the necessary information and making these available is a central factor for the success of design work (Badke-Schaub and Frankenberger 1999). Bucciarelli (2002) confirmed that shared understanding remains a challenge as members have different backgrounds and perspectives that may lead to contradictory responsibilities. Acknowledging that communication between industrial designers and engineering designers can fail because of the diverse mental pictures of a message, Duffy *et al.* (1993) proposed that members of a design team need to have a common understanding of the terminologies used. In addition, members should know 'what information to use, for what reasons, how this information is to be represented, and what it contains'. Of these, Sprow (1992) noted that one of the most challenging aspects in collaborative design is to agree on a 'shared ontology' to 'bridge the differences in abstractions and views'.

As the first step towards the development of a collaboration tool, the following statements helped produce the tool specification:

1. 'The industrial design profession has representations that are ill-defined, imprecise and lacking in communicative power' (Saddler, 2001).
2. 'As each discipline has a unique vocabulary, communication can be improved by having a common understanding of shared definitions' (Matthew 1997).
3. 'A common vocabulary can be built up with consistent communicative codes and language' (Persson and Warell, 2003).

4. 'This common vocabulary requires the transmission of communication symbols precisely; effectively receiving the intended meaning; and reaching the right audience through accurate distribution' (Chiu 2002).

### **9.3 Related Tools in the Market**

Understanding the concept of collaborative design has provided a clearer background of the issues faced by design teams and allows for the development of better-directed tools. Before discussing the objective of the design tool, it is necessary to first analyse current design aids in the market that have been found to be relevant:

1. Dictionary tools
2. Quality Function Deployment
3. Game-based tools
4. IDEO 51 Method Cards
5. Drivers of Change 2006 Cards
6. Mobility VIP Cards

#### **9.3.1 Dictionary Tools**

Dictionary tools in the form of a word list is not a new concept. It was proposed by Ashford (1969b) who claimed that because 'aesthetics has no language of its own, it has to borrow phrases and words used in other connections so as to provide meaning'. In the 'Preliminary study of the relationship between industrial design and engineering design' Holmes *et al.* (1995) was quoted as saying 'if there was a standard list of terms which both could use, it could eliminate confusion and increase communication links between the two fields.' Other academics including Smith (1997) also proposed a list of definitions that could be shared among the group where the dictionary could help members identify the jargon used during discussions. Other researchers (Giannini *et al.* 2006) suggested a dictionary compiling the

words used by designers in their daily activity. Despite these suggestions, no such tools have been found in the literature.

### 9.3.2 Quality Function Deployment

The Quality Function Deployment (QFD) is a formal method employed by organisations to identify customers' requirements and to transform them into actions and design parameters (QFD Institute 2008). The tool allows customer needs to be transformed and prioritised into engineering specifications for products or services. Figure 243 shows the six step-by-step areas that comprise the framework of QFD (ibid). First, the customer relationship box lists the customers' needs and problems. Second, the planning matrix box quantifies the customers' priorities and seeks their opinions on existing products. Third, technical requirements are concerned with aspects of the product such as performance and the technical details. Next, inter-relationships translate the customer requirements into technical characteristics of the product. Fifth, the roof examines whether the technical requirements would support or impede the design of the product, or whether engineering trade-offs are necessary. Lastly, the targets box summarises the overall matrix by summing up the technical priorities, benchmarking and targets for the product.

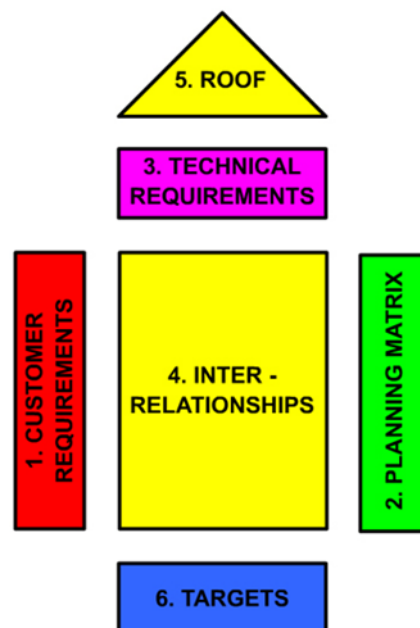


Figure 243: The main components of QFD

An example of a completed QFD matrix is shown in Figure 244. In summary, QFD is a highly systematised approach usually employed by engineers and is not aimed primarily at improving aspects of collaboration. However, the tool itself presents an interesting approach to problem solving with a clearly defined process.

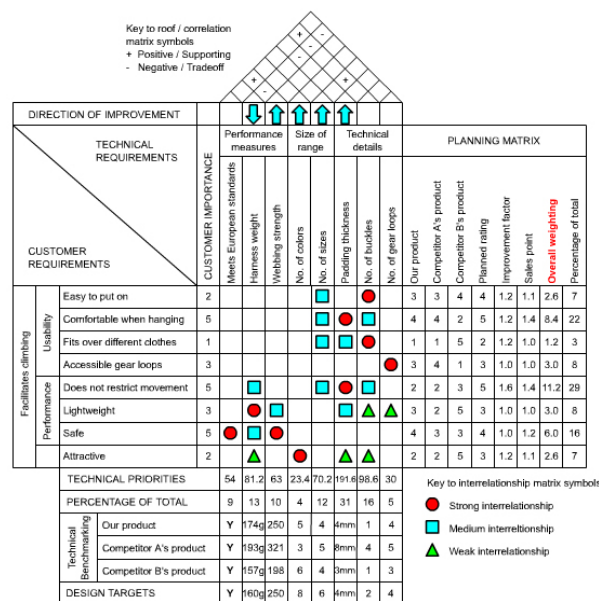


Figure 244: The Quality Function Deployment in use

### 9.3.3 Delta Design Game

The Delta Design role-playing game was designed by Bucciarelli (1994) requiring players to communicate and negotiate with each other when making decisions. The use of games is not new and other researchers including Habraken and Gross (1987) have developed other games to study how players manipulate and transform objects during interaction. Eva Brandt and Jörn Messeter (2004) also proposed a set of four unique scenario games (user game, technology game, landscape game and scenario game) (Figure 245) and Kleinsmann (2006) proposed a tool based on Bucciarelli's Delta Design game to be played with four participants. Each player assumes a unique role representing disciplines working together in collaborative design. The aim of the game is to achieve negotiation skills and to appreciate collaboration as a social process.



Figure 245: (from top-left, clockwise) The User-game, Landscape-game, Technology-game, Scenario game (Brandt and Messeter 2004)

### 9.3.4 IDEO 51 Method Cards

Another design tool available today is the IDEO 51 Method cards (Figure 246) developed in 2002 representing human-centric methods adopted by IDEO. The cards compile social research methods for investigating the experiences, behaviours, perceptions and needs of people. They do not prescribe solutions but encourage users to adopt new approaches to inspire better design (Best 2006). The 51 Method cards costing £25 contain visual images and information are structured in a clear manner, dividing information into four categories that represent ways to study people by learning, looking, asking and trying.

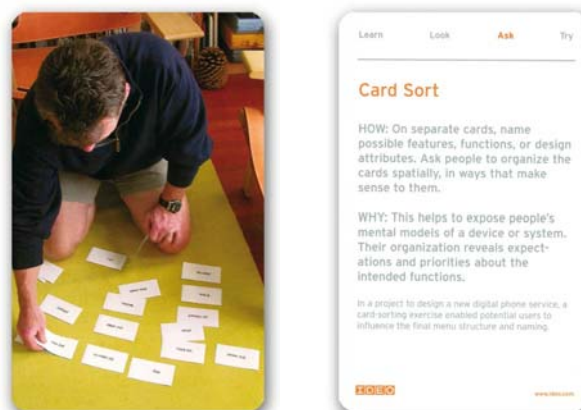


Figure 246: IDEO 51 Method Cards



### 9.3.5 Drivers of Change Cards

The Drivers of Change cards were developed in 2006 to depict scenarios of the year 2050 (Figure 247). These cards costing £19.95 were developed by the Foresight & Innovation team at Arup to explore emerging trends and how they might impact the business of Arup and its clients. The cards are divided into social, technology, environment, economic and political sets in a tabulated format. Each card is backed with statistics and are colour coded along the border.



Figure 247: Drivers of Change Cards

### 9.3.6 Mobility VIP cards

The Mobility VIP cards costing US\$50 were developed in 2007 by the Art Centre College of Design's Advanced Mobility Research and Graduate Industrial Design course (Figure 248). From a pack of 109 colour-coded cards, 11 random cards are used to create a scenario in the year 2040 by starting a discussion with impact questions concerning personal mobility. These random cards are based on 11 categories: enterprise, axiom, customer, constraint, energy, economy, society, ecology, technology, policy, and a wildcard.

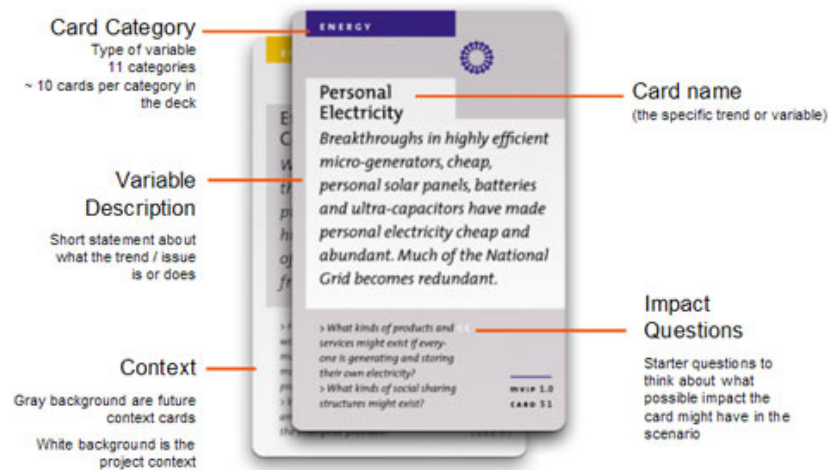


Figure 248: Mobility VIP Cards

From this review, it can be observed that the QFD and card tools have been highly structured according to themes and use of colours. The IDEO 51 Method cards and Drivers of Change cards incorporate large graphical images, and prompts are used as starting questions in the Drivers of Change and Mobility VIP cards. In terms of information graphics, the Drivers of Change cards incorporate statistics and all cards employ different sizes of text as a means of information hierarchy. It is important to note that all of these tools reviewed do not address the problem area of collaboration among industrial designers and engineering designers and no such tool in the market has been developed. With this review in mind, the next section discusses the development of the design aid.

#### 9.4 Development of the Design Aid

The aim of the proposed tool is to provide a generic source of information on the nature, role and significance of design representations (sketches, drawings, models and prototypes) used by industrial designers and engineering designers during new product development. When employed, the tool will facilitate the use of a common vocabulary, creating shared knowledge among industrial designers and engineering designers. By formalising the definition of design representations with a sample image, it minimises

misinterpretation and miscommunication. Key design and technical information available would further serve as a guide and help identify associated representations that are commonly used. From the knowledge gained from the literature review and empirical research, it was identified that the following criteria would be appropriate for the formulation of the tool. The criteria is summarised in Table 49.

The tool would:

1. Define the four stages of the design process (concept design, design development, embodiment design, detail design)
2. Identify the popularity of use for various design representations during the four stages of the design process
3. Define together (with an image) the design representations used by industrial designers and engineering designers
4. Define the types of design / technical information used within the design process
5. Identify the popularity of use for various design representations in the communication of specific design / technical information
6. Identify the level of design / technical information included in the communication capability of each design representation

Design Stages (4)	Design Information (10)	Technical Information (8)	Design Representations (35)	
Concept Design Concept Development Embodiment Design Detail Design	Design Intent Form & Detail Visual Character Usability & Operation Scenario of Use Single Views Multi Views Areas of Concern Finishing Colour	Dimensions Construction Assembly Components Mechanism Part & Profile Lines Exploded Views Material	Idea Sketch Study Sketch Referential Sketch Memory Sketch Coded Sketch Information Sketch Renderings Inspiration Sketch Prescriptive Sketch	3D Sketch Model Design Development Model Appearance Model Functional Concept Model Concept of Operation Model Production Concept Model Assembly Concept Model Service Concept Model
			Concept Drawing Presentation Drawing Scenario & Storyboard Diagram Single View Drawing Multi View Drawing General Arrangement Dwg Technical Drawing Technical Illustration	Appearance Prototype Alpha Prototype Beta Prototype Pre-Production Prototype Experimental Prototype System Prototype Final Hardware Prototype Tooling Prototype Off-Tool Prototype

Table 49: Key information to be shown in the design tool

Following the tool criteria, other things to consider include the target audience, the content and information structure, and the format and layout of the tool. The main users of the tool would be industrial designers and engineering designers, although it would be open to the other stakeholders in the design process including marketers, manufacturers and management. More importantly, the content and information structure should be kept as simple as possible and easy to read. In the earlier chapter, results from the fourth section of the interview (Table 50) found that the paper-based tools such as a checklist, flowchart and matrix were most popular among both industrial designers and engineering designers. These paper-based tools were more widely preferred as compared to software-based tools such as a webpage, CD-ROM or software. These electronic formats would also require the use of computers which would be limited by power and portability. While personal digital assistants (PDAs) or mobile phones presented portable options, the dissimilar operating systems (e.g. Windows Mobile, Symbian, Palm, Blackberry) and small screen size would create additional problems for information to be shared among users, and a web-based format would make the tool limited to only internet subscribers. In addition, a software tool would

require complex programming that would be too difficult and beyond the remit of this research project. For these reason, a decision was made to develop a paper-based tool.

	Industrial Designers	Engineering Designers
Checklist	11	3
Matrix	5	2
Table of Instructions	2	1
Flowchart	6	3
Mini-Booklet	1	-
Webpage	1	1
CD-ROM / DVD	1	-
PDA Software	1	1
Laptop Software	1	-

Table 50: Results showing preference for the tool format

While the paper-based tools such as the checklist, matrix and flowchart were indicated to be the most popular among the interviewees, these three formats were found to be limiting. For example, the checklist and flowchart format would be too systematic and lengthy to use. A decision was made to further explore other formats of paper-based tools. This would allow for more options and to permit greater flexibility for the tool design. Other paper-based formats that were shortlisted include the Autodex, index cards, jig-saw, Rolodex, Z-cards, trading cards and desk cubes (Figure 249). Of these, it was decided that a desk cube, an Autodex, a representation wheel, a matrix and a card format would be fabricated as mock-ups before selecting the final format for the tool. The next section looks at each of these formats.

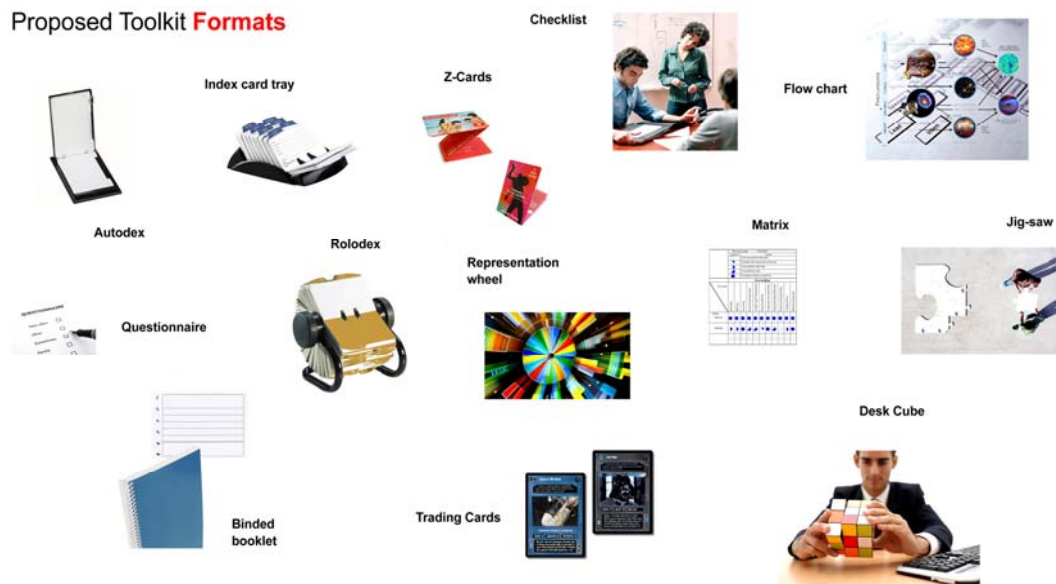


Figure 249: Various formats available for a toolkit

#### 9.4.1 Desk Cube

The Desk Cube is a popular format to show information. Examples of these include cube calendars and information cubes. The desk cube simplifies the information from the empirical research relating to the use of visual design representations presented on six sides of the cube. For the mock-up, the cube measuring 9.3cm x 9.3cm x 9.3cm was fabricated from cardboard (Figures 250, 251). This size was chosen for portability and each flattened cube could be shaped from a single piece of A4 paper. On each side of the cube, it would show:

1. The title 'Guidelines for Effective Design Representations between Industrial Designers and Engineering Designers'
2. Design Information and Elements in Industrial Design Representations
3. Design Information and Elements in Engineering Design Representations
4. Using Representations at the various Design Stages
5. Using Representations for Communication
6. Requirements and Request of Industrial Designers and Engineering Designers

Two versions were fabricated and evaluated by both supervisors of this research and the author to analyse the advantages and disadvantages. The two supervisors were academics with several years of academia experience and had both worked in the industry before. Their responses to this format are as follows:

Advantages:

1. Relatively cheap to produce
2. Can be distributed as a flat pack
3. Can be folded and stored when not used

Disadvantages:

1. The information in the form of words and images were too small to be read
2. The box started to crease after several uses
3. The amount of information on each side was very limited
4. No space was available to provide specific information about each design representation





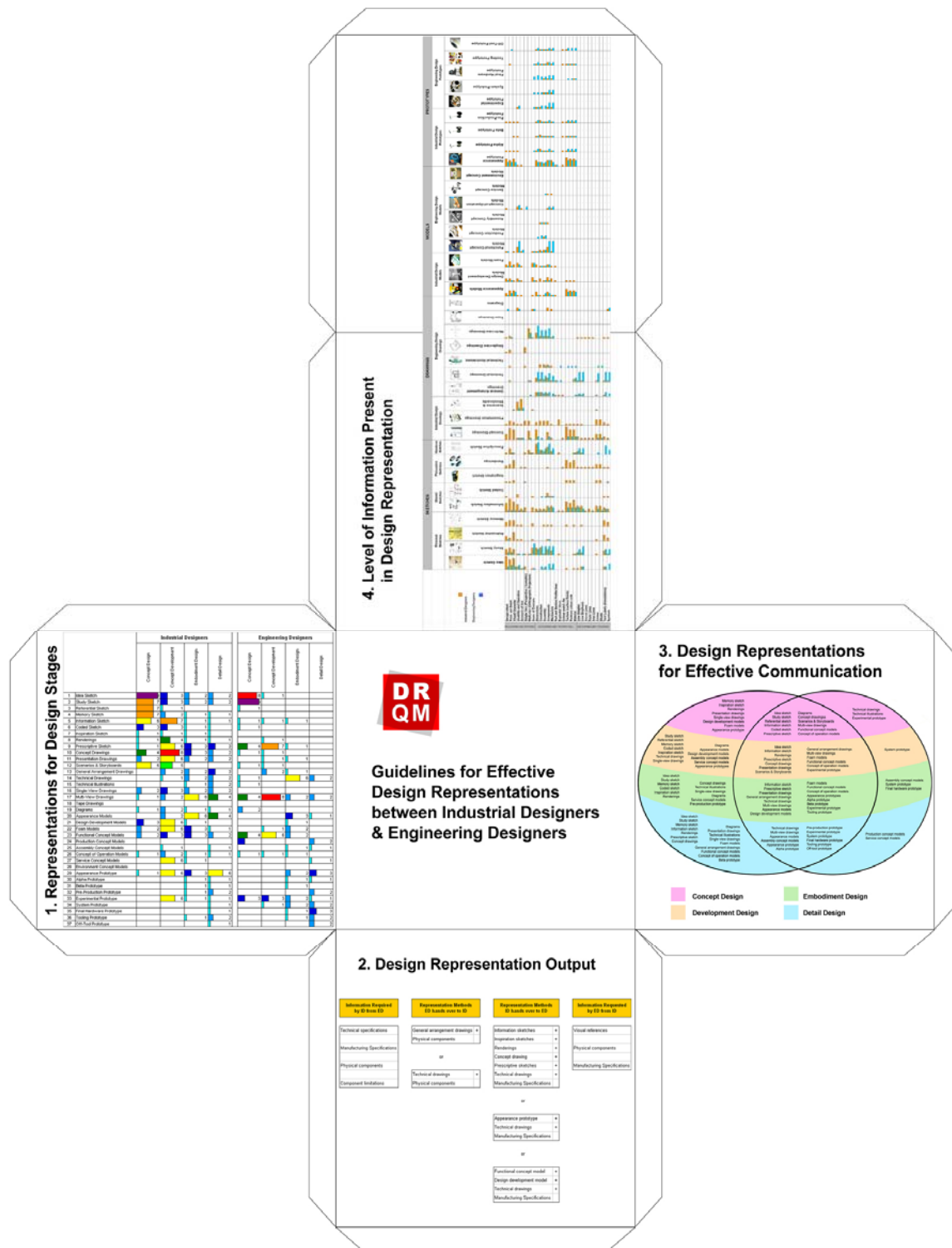


Figure 251: The Desk Cube (Version 2)

### 9.4.2 An Autodex

The Autodex is a phone directory book that opens up according to the alphabetical letter selected. Inside the Autodex is information for the design aid. It is an improvement to the manual Rolodex (Figure 252), a rotating device that stores cards in an indexed form. An Autodex was physically produced (Figures 253, 254) and evaluated by both supervisors of this research and the author to analyse the advantages and disadvantages.



Figure 252: A Rolodex



Figure 253: An Autodex

#### Advantages:

Allows information to be well organised

Allows data to be accessed quickly

#### Disadvantages:

Expensive to produce and die cut each sheet to fit into the Autodex

Time consuming to produce



Figure 254: Contents inside the Autodex

### 9.4.3 A Representation Wheel

The Representation Wheel represents information based on circular templates. The 'Wheel Base' in Figure 255 shows all the information concerning each design representation in a colour code. Wheels 1A, 2A, 3A or 1B, 2B, 3B are secured above each wheel base (Figures 256 and 257). The A series of wheels conceal the wheel base information to only reveal one design representation at a time. The B series of wheels allows the viewer to inspect a particular element across all design representations simultaneously. For example, using wheel 1A (Figure 258) presents design information concerning a particular design representation. Wheel 2A (Figure 259) presents technical information concerning a particular design representation. Wheel 3A (Figure 260) presents information concerning the use of a design representation according to the four stages of the design process. Using wheels 1B, 2B and 3B (Figures 261 - 263) allows the user to view the level of design intent across all design representations simultaneously. The representation wheels were physically produced and evaluated by both supervisors of this research and the author to analyse the advantages and disadvantages.

#### Advantages:

Allows information to be well organised

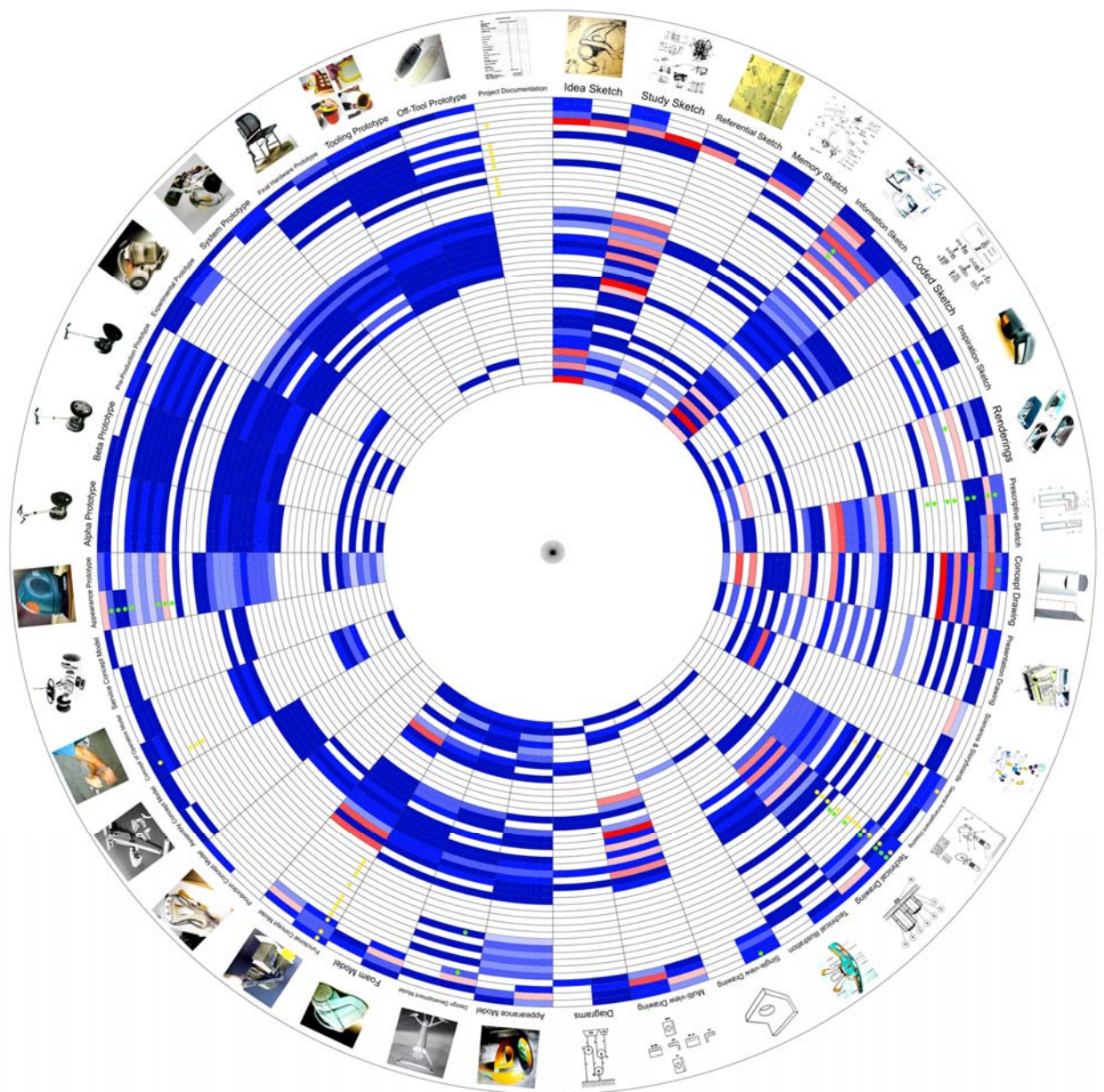
Allows data to be accessed easily

#### Disadvantages:

Expensive to produce each wheel

There was no space to provide information about each design representation

The information shown printed on the wheel may be too small



### Percentage Symbol



Figure 255: Wheel Base showing percentage colour code



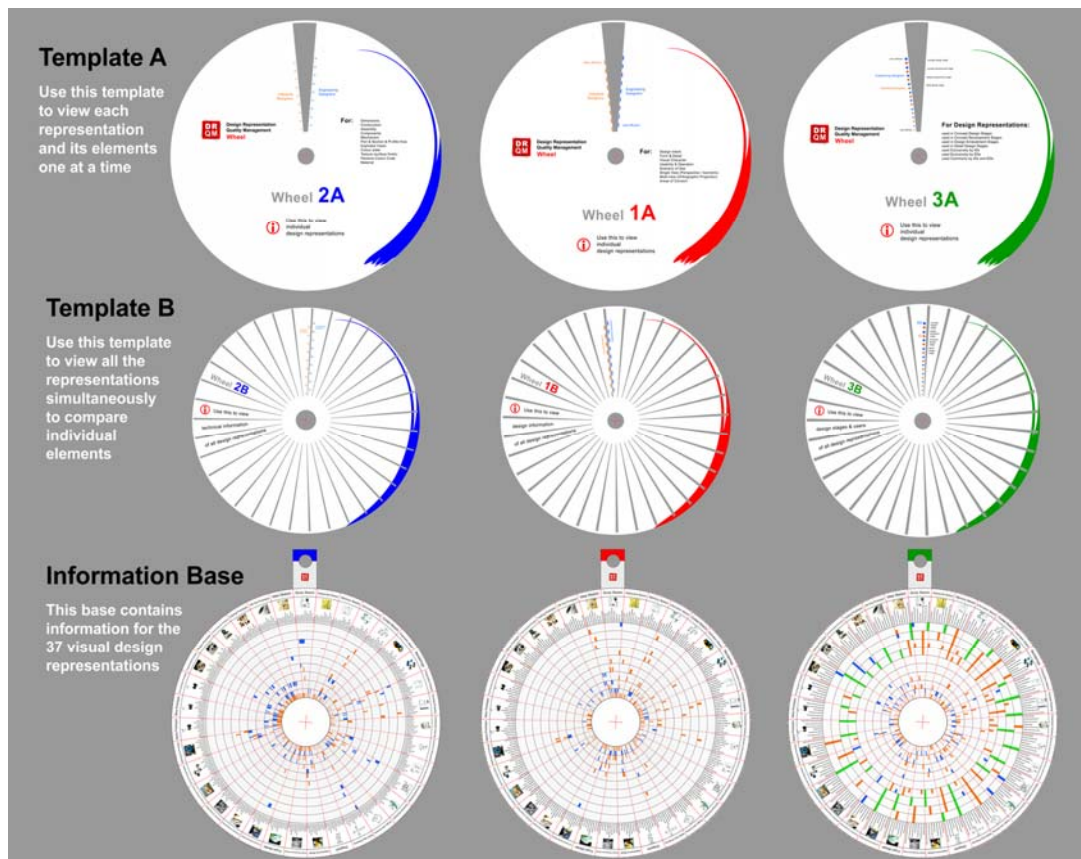


Figure 256: Components of the Representation Wheel (1)

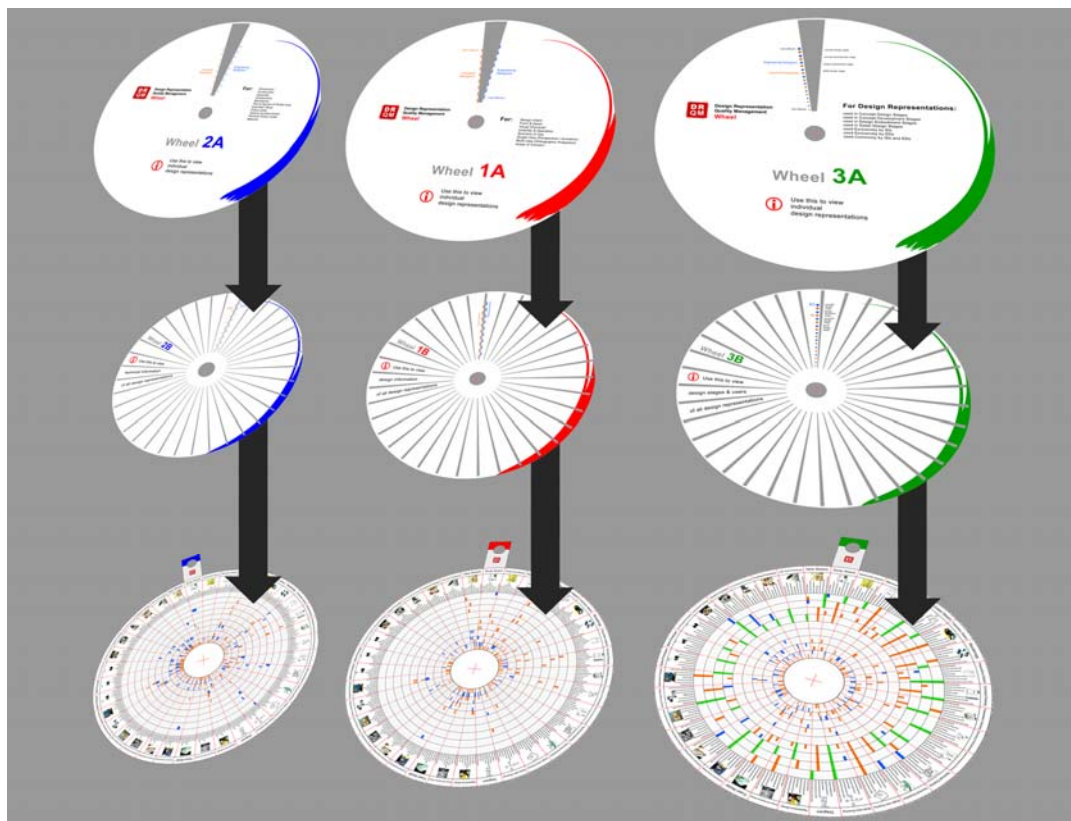


Figure 257: Components of the Representation Wheel (2)

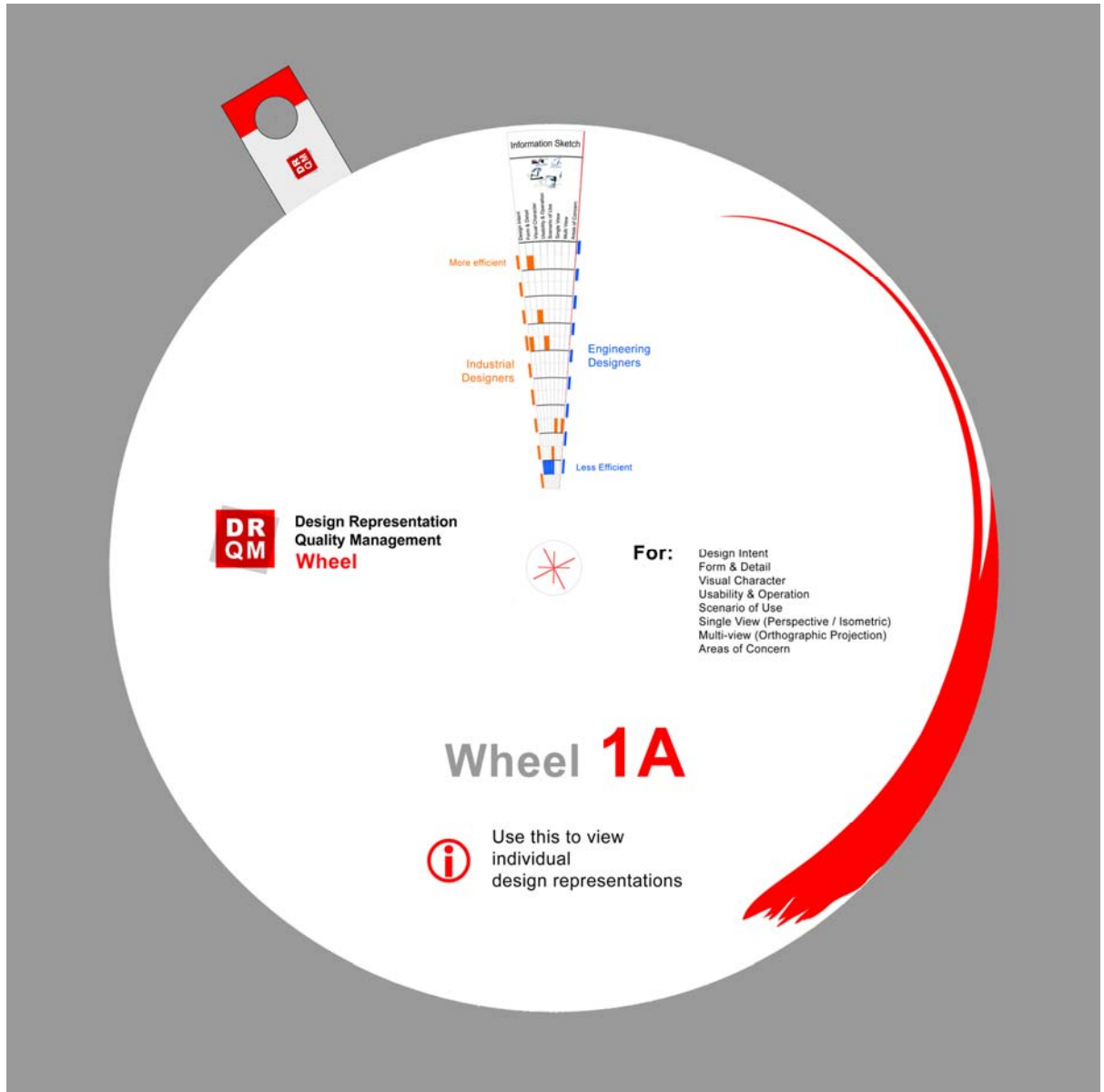


Figure 258: Wheel 1A

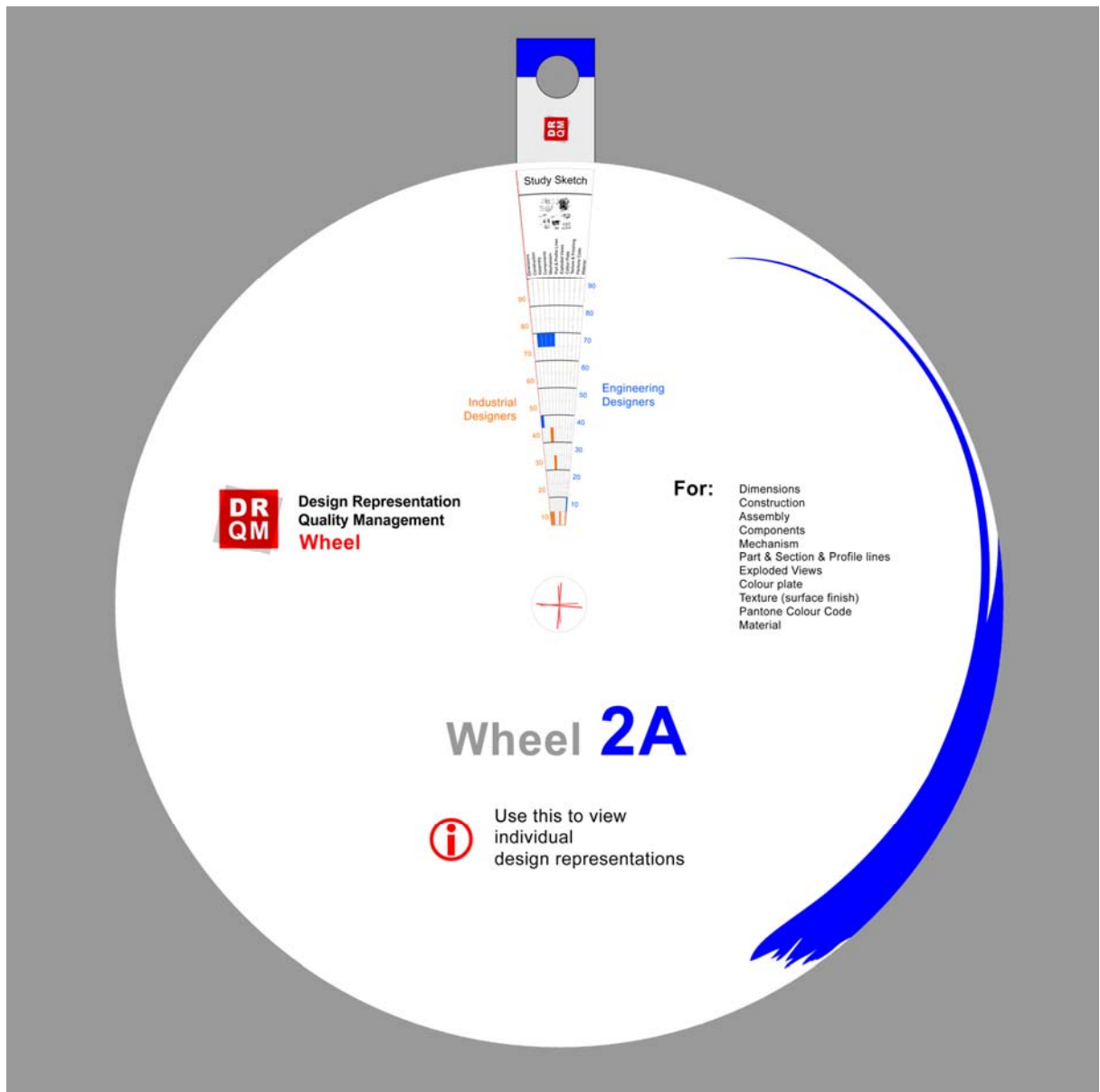


Figure 259: Wheel 2A



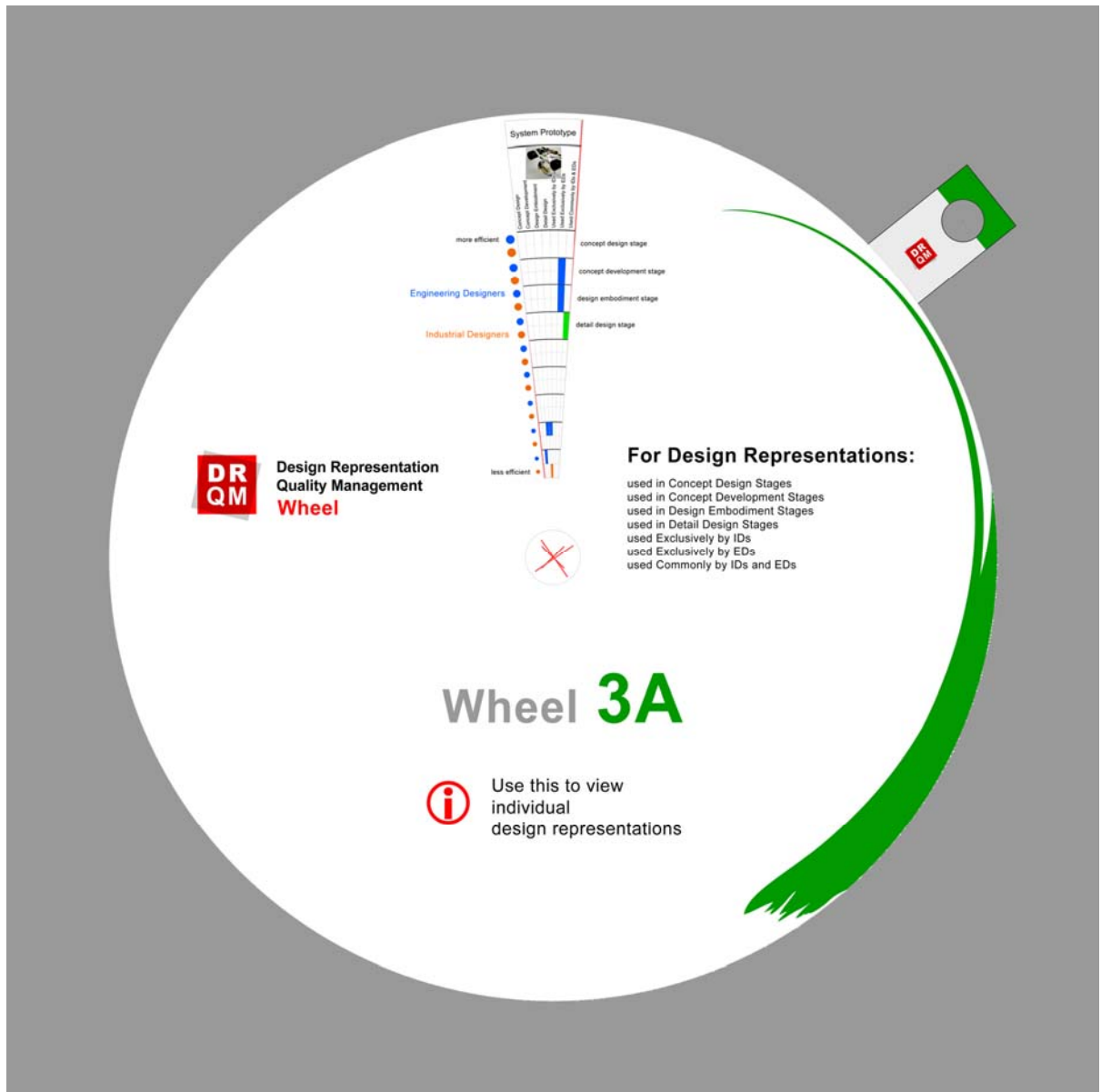


Figure 260: Wheel 3A





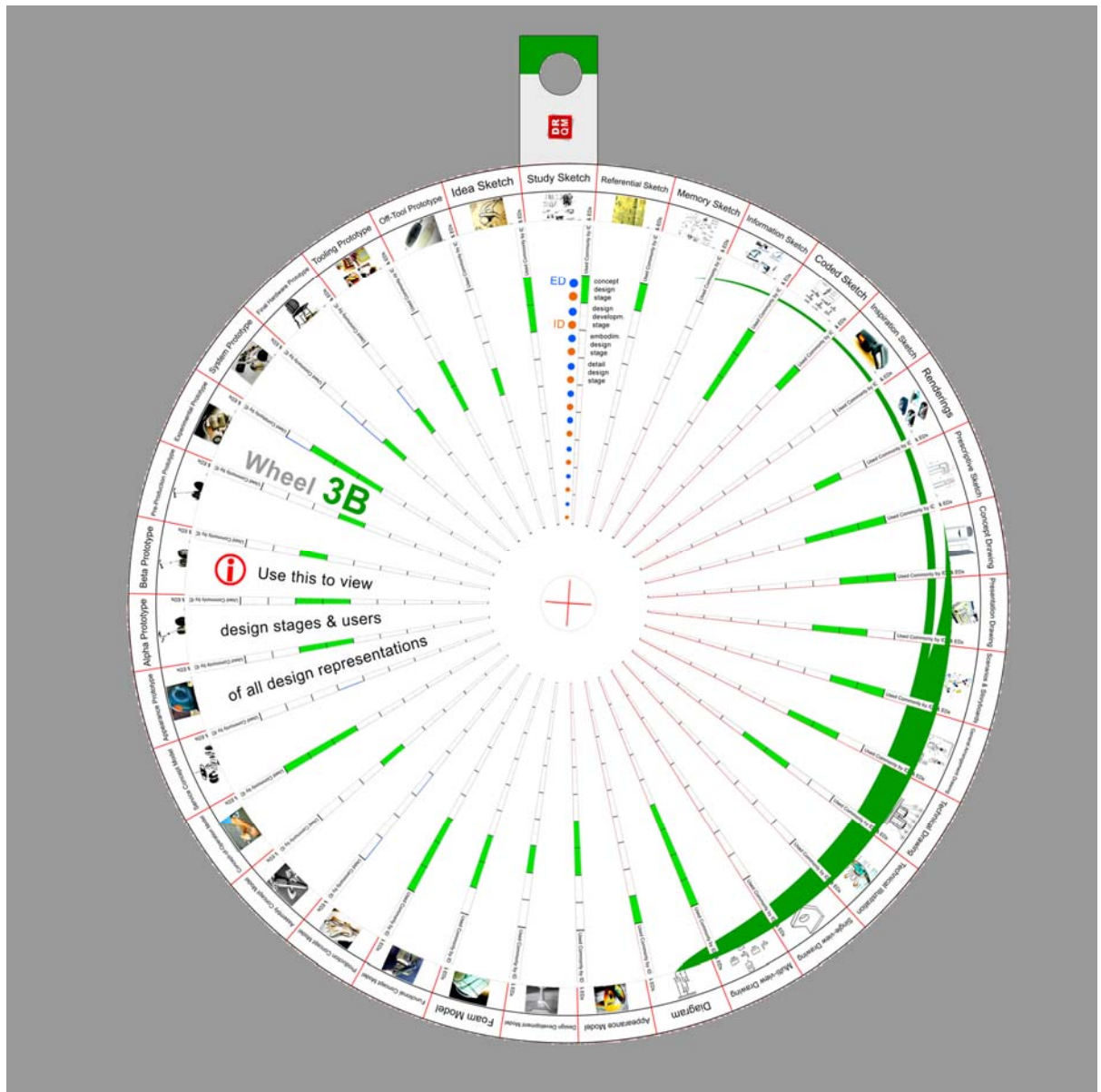


Figure 263: Wheel 3B

### 9.4.4 A Matrix

A matrix was developed from interview findings discussed in Section 8.4 (Figure 264). The data could be produced as a poster or folded into a card. Figures 265 and 266 show two possible formats of the matrix which were developed and then evaluated by both supervisors of this research and the author to analyse the advantages and disadvantages. A larger image of the matrix can be found in Appendix 13.7

Advantages:

Allows information to be spread out and to viewed at once

Relatively cheap to produce

Disadvantages:

Large format may be not be portable (unless folded)

Might be time consuming to screen the data

There was no space to provide information about each design representation

The information shown may be too small

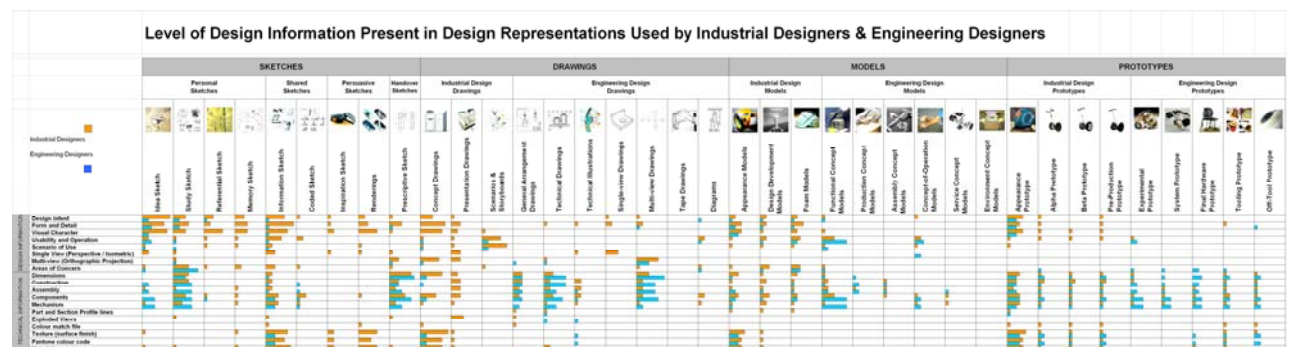


Figure 1: Visual Summary of the Level of Design Information present in Design Representations used by Industrial Designers & Engineering Designers (in percentage)



# UNDERSTANDING DESIGN REPRESENTATIONS OF INDUSTRIAL DESIGNERS & ENGINEERING DESIGNERS

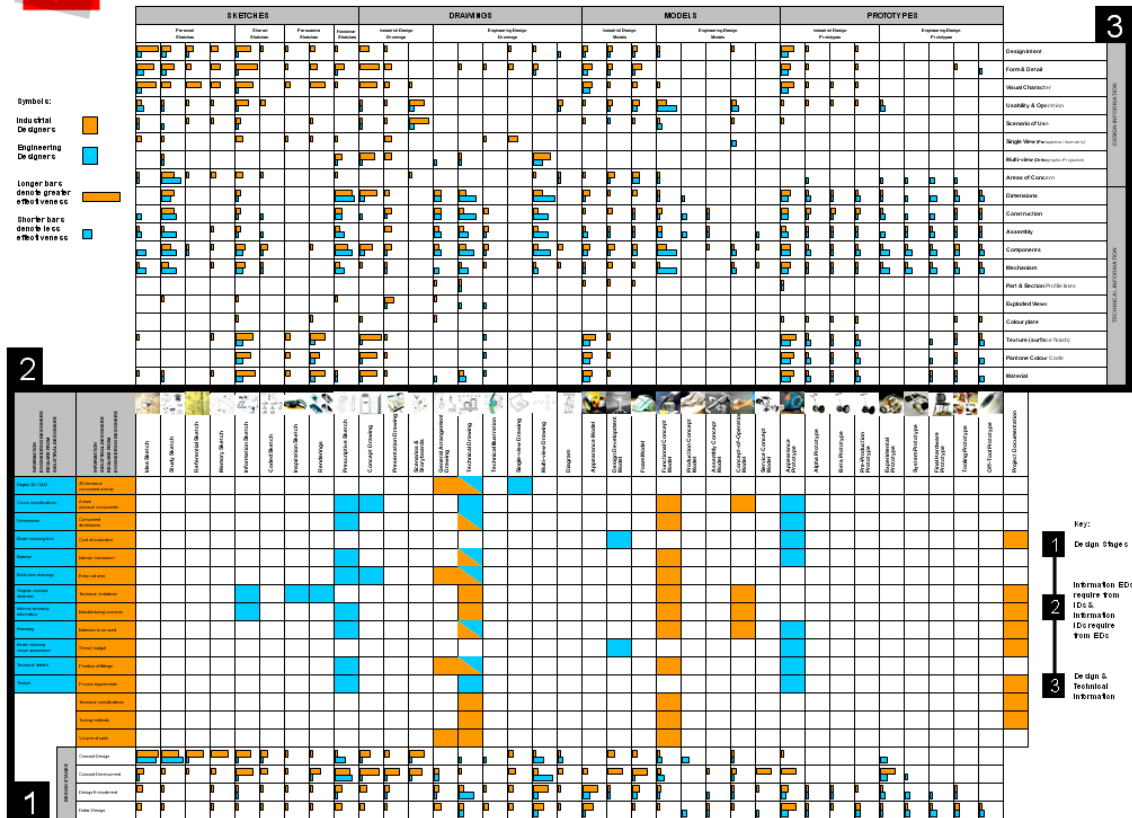


Figure 2: The Matrix format 1

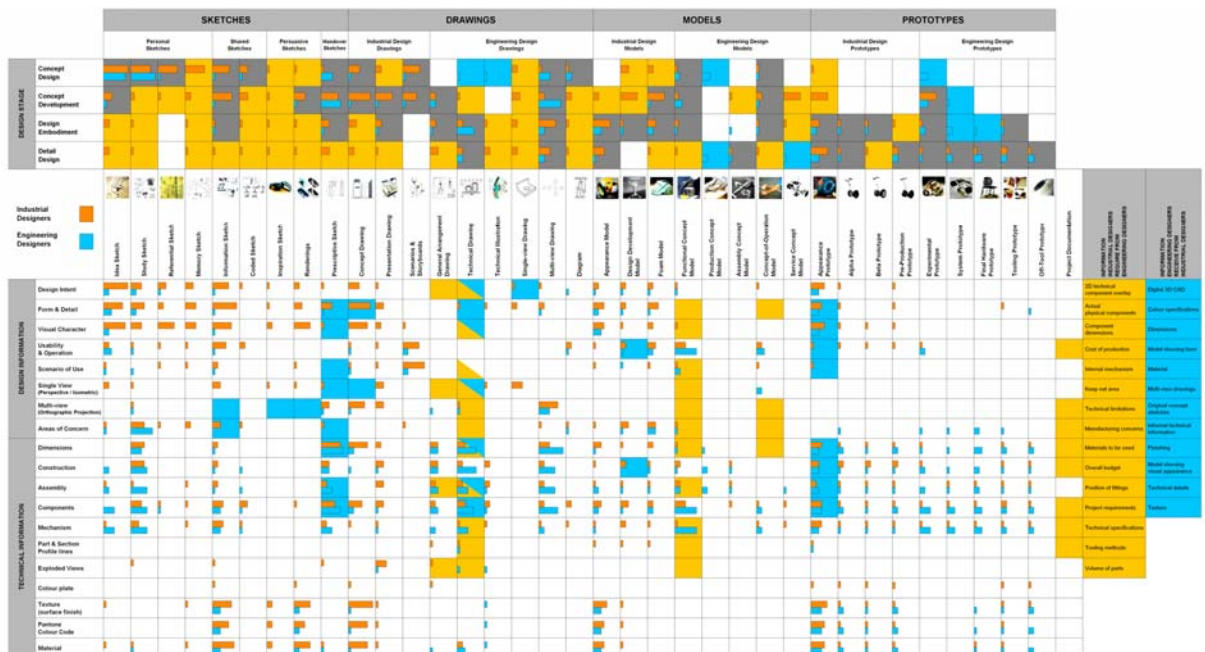


Figure 3: The Matrix format 2

### 9.4.5 Card Format

The use of cards provide an alternative presentation format. The front of each card shows information concerning each design representation, while the back of the cards show the design, technical information and stages associated with each design representation (Figures 267, 268). Several variations of the cards (Iteration 1) were developed (Figures 269 - 271) and they were evaluated by both supervisors of this research and the author to analyse the advantages and disadvantages of the format.

Advantages:

Allows information to be spread out

Relatively cheap to produce

Portable format

Disadvantages:

A large number of cards might be required to be produced

Might be time consuming to sort the information among the cards

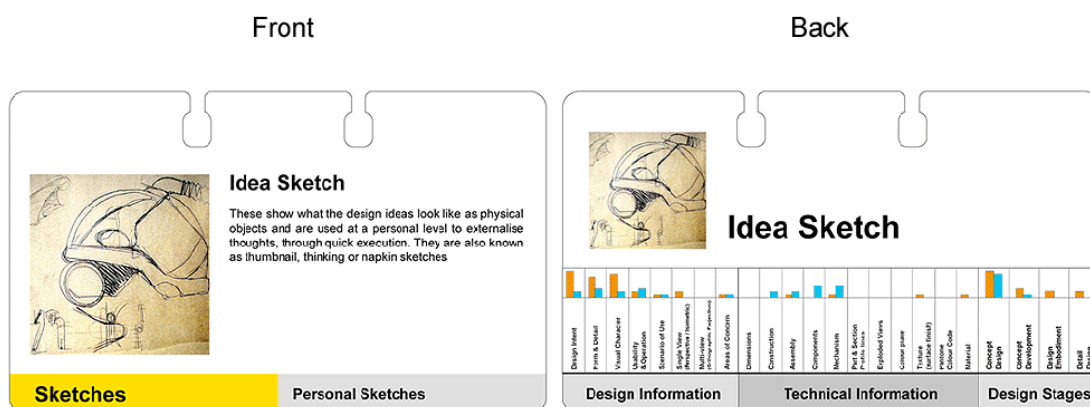


Figure 4: Front and back of the Cards



**Design Representation  
Quality Management**  
Toolkit Beta 2.0

## ILLUSTRATION OF AN INDEX CARD

(measures 3" x 5")

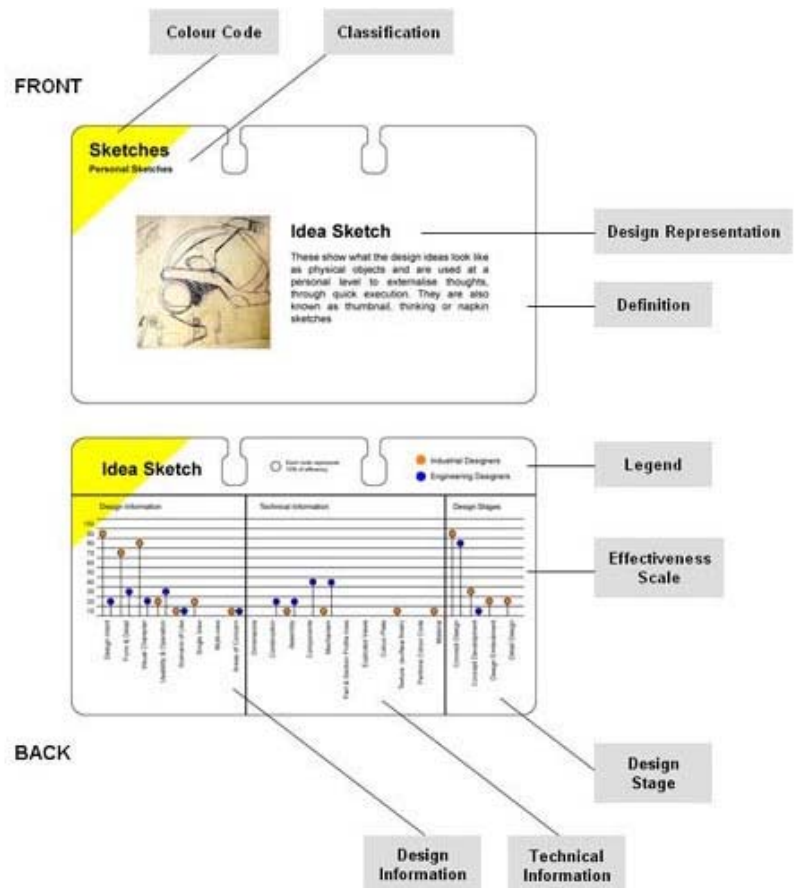


Figure 5: Explanation regarding the front and back of the Cards

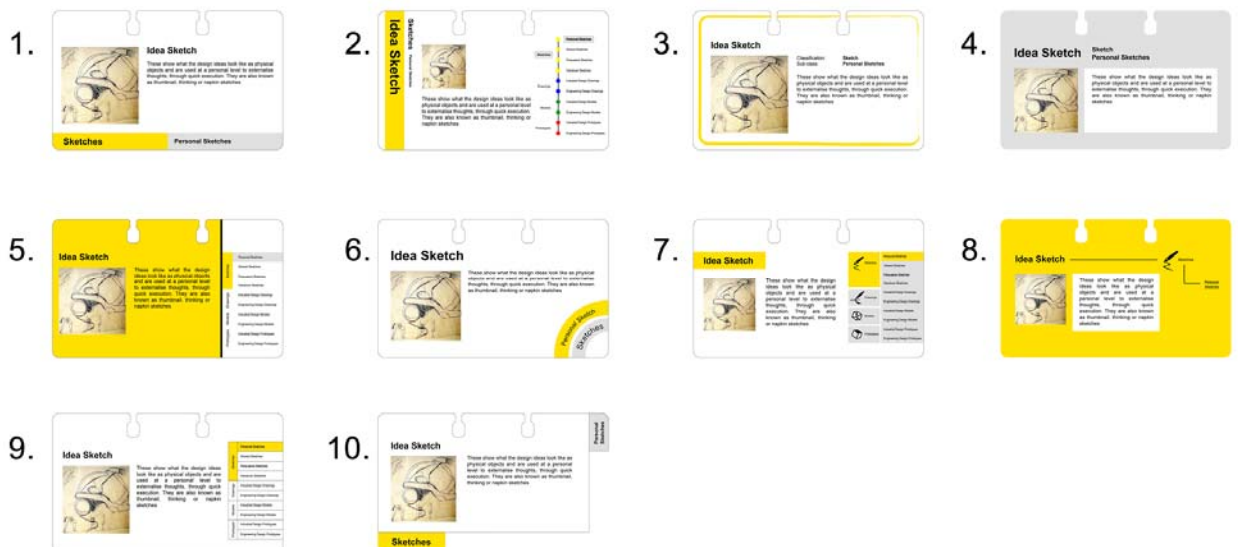


Figure 6: Front of the Card Format



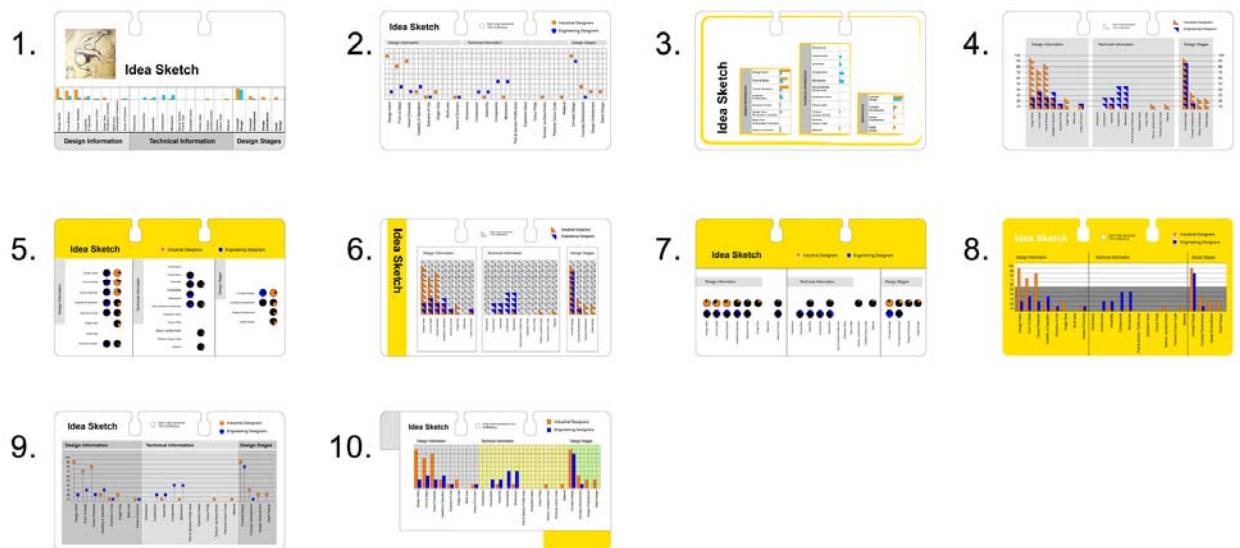


Figure 7: Back of the Card Format

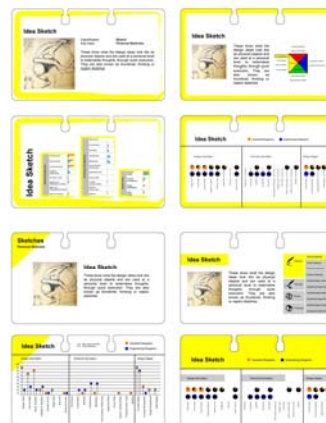
## Design Proposals for Index Cards



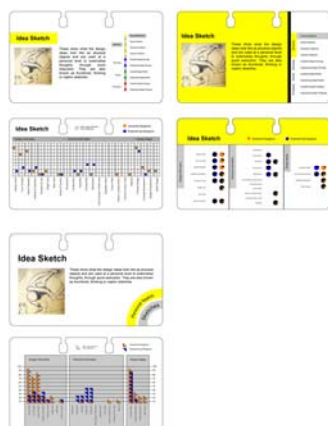
### Tab Series



### Border Series



### Colour Code Series



### Tone Series

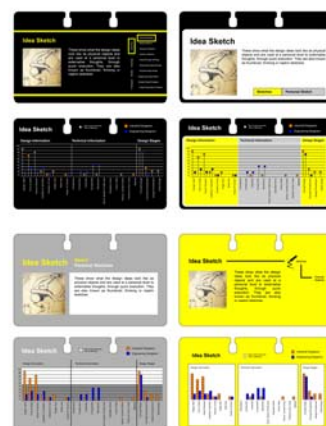


Figure 8: Variations of the cards

### 9.4.6 Tool Format Selection

Following mock-up and appraisal by both research supervisors, an industrial design academic and an engineering design academic with the author, it was unanimously decided that the physical card system had the advantage of portability to encourage interaction among users, and would provide instant access to information. The physical nature would allow the cards to be shared among members, facilitating socialisation and achieving shared knowledge towards collaboration. Card systems have also proved to be viable as design tools in other areas such as for creativity (IDEO Method cards), experience design (Experience Design cards), trend research (Drivers of Change cards) and scenario mapping (Mobility VIP cards).

### 9.5 Development of Card Tool

From the initial design of the cards, it was noted that too much information might result in low performance and too little information would make the tool irrelevant. A decision was therefore taken to improve the design with a more balanced information structure. The new design (Figure 272) would separate information into 2 sets belonging to each discipline for more accurate and faster access to data. In addition, the separated cards would encourage members to interact by comparing, analysing and building shared knowledge between them.

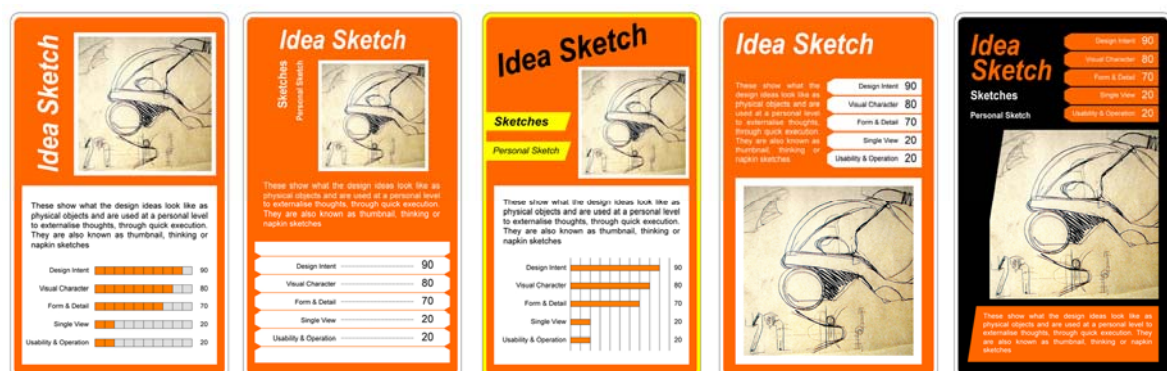


Figure 9: Variations of the cards

### 9.5.1 Iteration One

The redesigned 114 cards would be colour-coded in red (57 cards) to provide information on industrial design practice and in blue (57 cards) for engineering design practice. Each set was further divided into three packs containing different information for each discipline:

#### Pack One: Design Stages

The first pack (Figure 273) consisted of four cards from each colour showing key design stages of new product development as an introduction to the design process. The front of each card provided a definition of a design stage and the back showed information about design representations used for that stage, illustrated through bar graphs and numbers. The bar graphs and numbers show the popularity of use by practitioners for a particular design representation. The popularity is given as a percentage that was generated from responses by the practitioners interviewed during the second empirical research.



Figure 273: Pack One - Design Stages

## Pack Two: Design & Technical Information

The second pack (Figure 274) consisted of ten cards from each colour, showing key design information, and another eight cards of each colour showing technical information used by industrial designers and engineering designers. The front identified if the card was for design or technical information, and the back showed representations that are typically employed with bar graphs and numbers to indicate the popularity of use. Key design information would include form and detail, visual character and colour. Technical information would include data such as mechanism, assembly and construction.



Figure 274: Pack Two - Design & Technical Information

## Pack Three: Design Representations

The third pack (Figure 275) consisted of 35 cards of each colour, showing representations used by industrial designers and engineering designers. The front provided the definition of design representations and the reverse showed design and technical information. Details concerning the popularity of use of



the representation in each design stage here again were provided using numbers and bar charts.



Figure 275: Pack Three - Design Representations

### 9.5.2 Iteration Two

It was decided that the design of the cards could be further improved and a series of graphic design improvements were undertaken. The aim was to improve the readability of information and to package the cards with a feel of a gaming card format. By doing so, it would help create an informal use when the industrial designers and engineering designers employed the cards. Images of gaming cards (also known as Top Trumps trading cards) were compiled and used as a source of inspiration (Figure 276).

## Top Trumps Design Inspiration Board



Figure 276: Inspiration board for gaming cards

The complete set of iteration two of the cards can be found in Appendix 13.8 (Card Design Iteration 2), while Figures 277 and 278 show a sample of the redesigned cards.



Figure 277: Industrial Designers' set for Design Stages



Figure 278: Engineering Designers' set for Design Stages

## 9.6 Using the Cards as an Individual Industrial Designer

There was no pre-determined way of using the cards. These cards were designed to be a generic source of data to provide information on the nature, role and significance of design representations used during new product development. To provide an instance of its use, a scenario below shows how an engineering designer could know more about an industrial design 'Referential Sketch' and to identify the level of visual character present in such a sketch:

Step 1: Choose the right coloured set of cards

The engineering designer first chooses the red set referring to industrial design practice.

Step 2: Refer to the relevant pack

From the red set, the engineering designer finds the Design Representations pack where the 'Referential Sketch' card can be found (Figure 279).



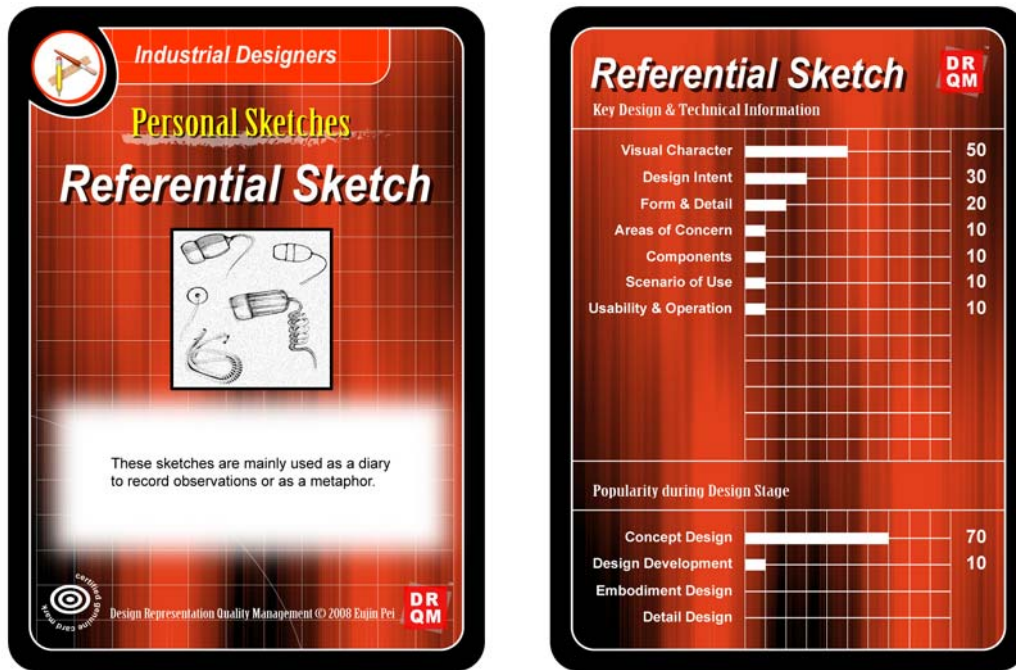


Figure 279: Card showing the Referential Sketch

### Step 3: Finding information within the card

The front of the 'Referential Sketch' card contains the definition and an accompanying visual to show what the sketch would look like. The back of the card shows that the emphasis of visual character is of utmost importance in a 'Referential Sketch' with 50% of industrial designers placing an emphasis on visual character in Referential Sketches (data collected from empirical research)

Following this sequence, the engineering designer now gains a clear definition of the 'Referential Sketch' with an example image of how it looks. He or she is also able to determine that visual character has the most emphasis in a 'Referential Sketch'.

### 9.6.1 Scenario when Not Using the Cards

To provide a holistic view of how the cards would be used during new product development, two distinct scenarios are considered. The first scenario was derived from the observations of the first empirical research, showing issues



occurring between the industrial designer and the engineering designer. In the first scene, the engineering designer requests concepts from the industrial designer. However, the industrial designer is unsure what deliverables are required (Scene 1 – Figure 280). Should the concepts be sketches, a 3D CAD model or a physical prototype? Likewise, the engineering designer is also uncertain what information the industrial designer needs (Scene 2 – Figure 281). After creating some sketches, the industrial designer passes them to the engineering designer who finds these sketches hard to understand (Scene 3 – Figure 282) and requests for multi-view drawings (Scene 4 – Figure 283). The industrial designer has to redraw his concepts (Scene 5 – Figure 284). However, the engineering designer still feels that the multi-view drawings lack detail and requires for prescriptive sketches (Scene 6 – Figure 285). Because the engineering designer is unable to visualise the complex geometry of the design, the industrial designer decides to create a 3D sketch model (Scene 7 – Figure 286). In his mind, the engineering designer felt that the industrial designer should have provided all of these right from the start. After much work, the design is finally complete (Scene 8 – Figure 287).

From this scenario, it is seen that the engineering designer was unable to understand the industrial design sketches. Consequently, the engineering designer did not specify what was required and therefore the industrial designer was not able to provide the relevant information required. The next scenario considers a scenario wherein the cards are used.

1.

At the start of a project, the project manager hands design brief to ID & ED. ID and ED meet to discuss issues.

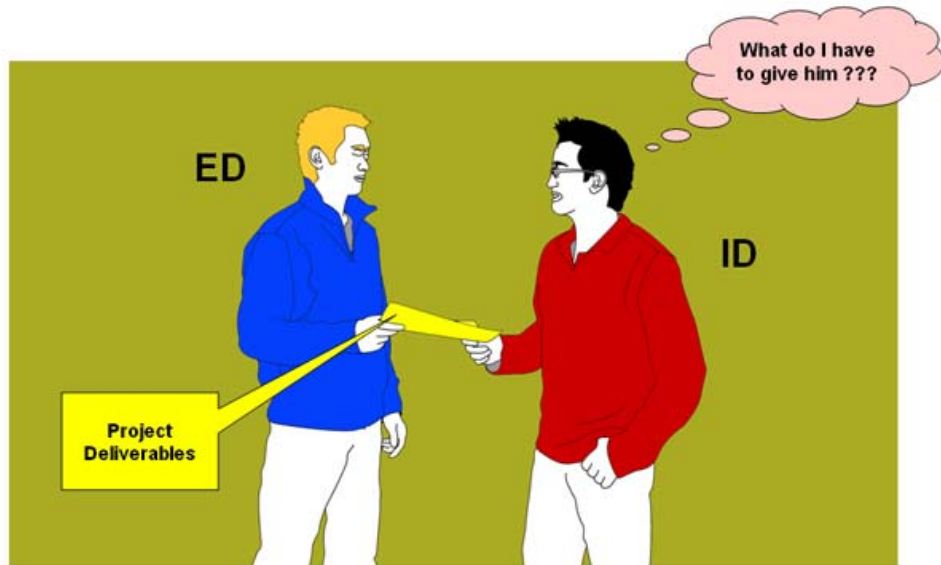


Figure 280: Scene 1 without the use of cards

2.

ED forms up technical specifications, gives technical drawings and physical components to ID to work on concepts



Figure 281: Scene 2 without the use of cards

3.

ID hands over his personal sketches to the ED.



Figure 282: Scene 3 without the use of cards

4.

ED returns the personal sketches to ID and requests for multi-view drawings instead.



Figure 283: Scene 4 without the use of cards

5.

ID redraws the personal sketches to multi-view drawings which the ED uses to translate into 3D CAD models.

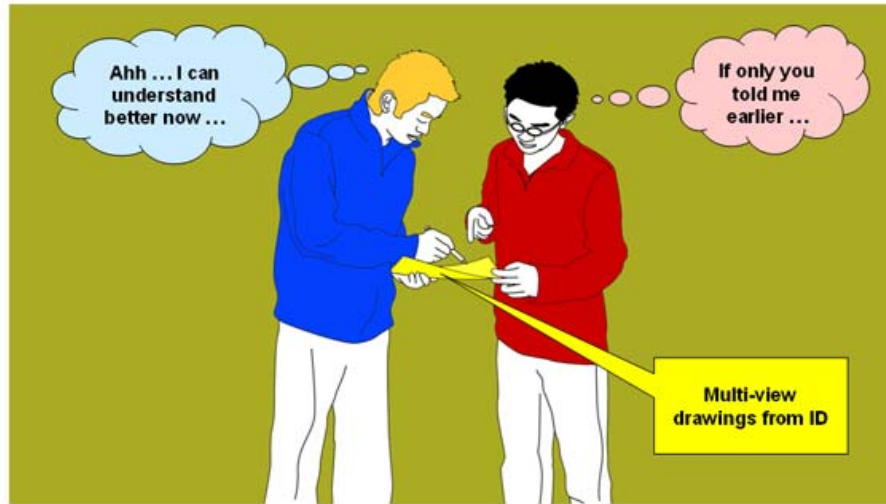


Figure 284: Scene 5 without the use of cards

6.

The multi-view drawings do not fully show design information such as texture or surface finish. ED requests for prescriptive sketches and asks the ID to sit with him while constructing the 3D CAD model.



Figure 285: Scene 6 without the use of cards

7.

ID provides a 3D sketch model to assist the ED in visualising the form more accurately.



Figure 286: Scene 7 without the use of cards

8.

The ED creates the 3D CAD model which is rendered as a concept or presentation drawing for the client.

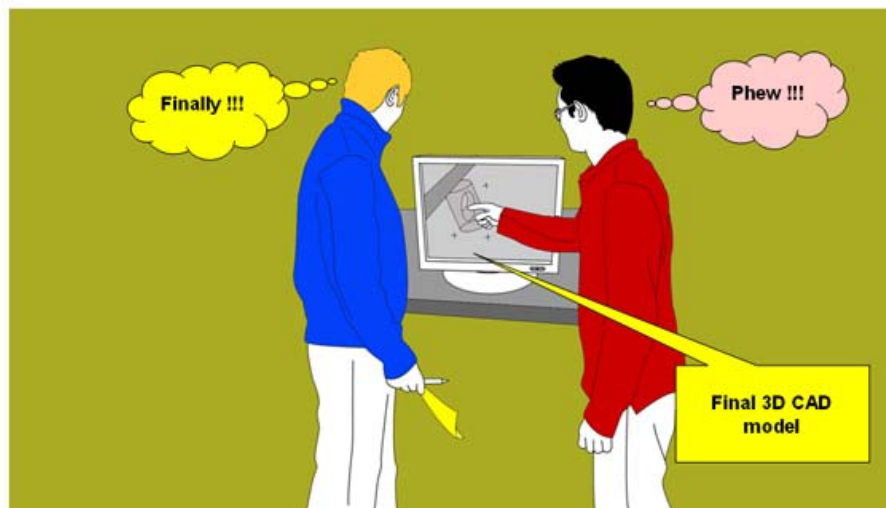


Figure 287: Scene 8 without the use of cards

### 9.6.2 Scenario with Use of Cards

In this scenario, the cards are introduced to the industrial designer and engineering designer at the start of the project (Scene 1 – Figure 288). The engineering designer looks at the industrial design pack of cards (Red Pack) showing the design stages (Figure 289) and reveals that Idea Sketches (Figure 290) will be useful at this stage (Scene 2 – Figure 291). To find out how the design aesthetics can be better communicated, the engineering designer (Scene 3 – Figure 292) takes out the Form and Detail card (Figure 293) which shows that Information Sketches and Concept Drawings are commonly used.

1.

Start of project, project manager hands design brief to ID & ED.  
ID and ED meet to discuss issues.

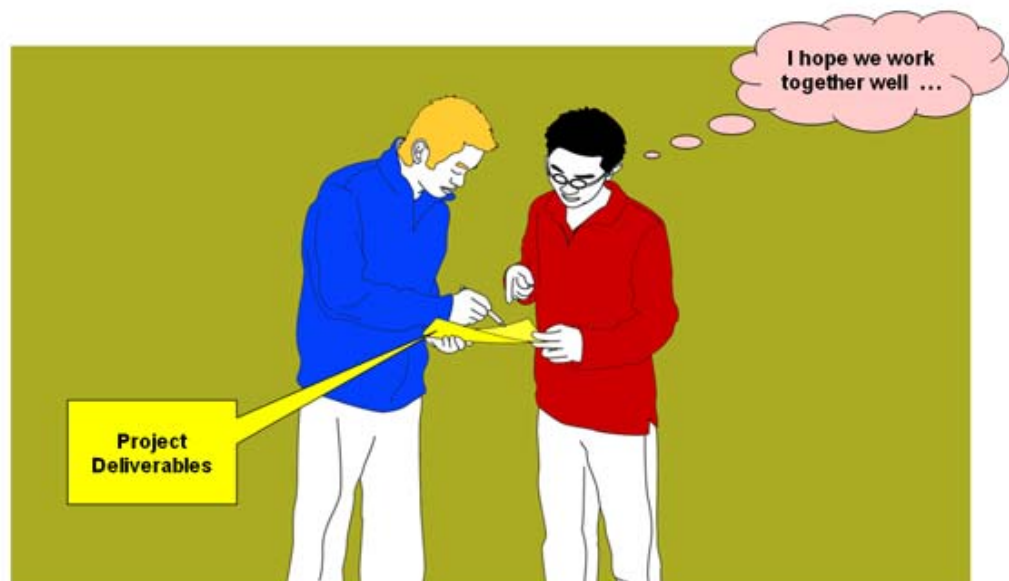


Figure 288: Scene 1 with use of the cards

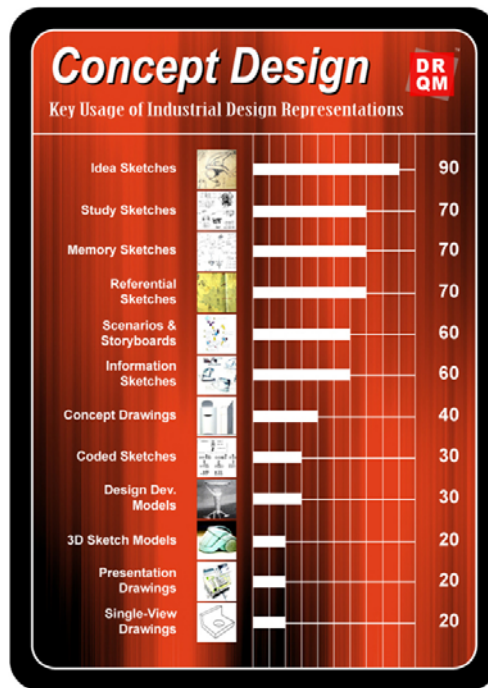


Figure 289: Card showing Concept Design stage

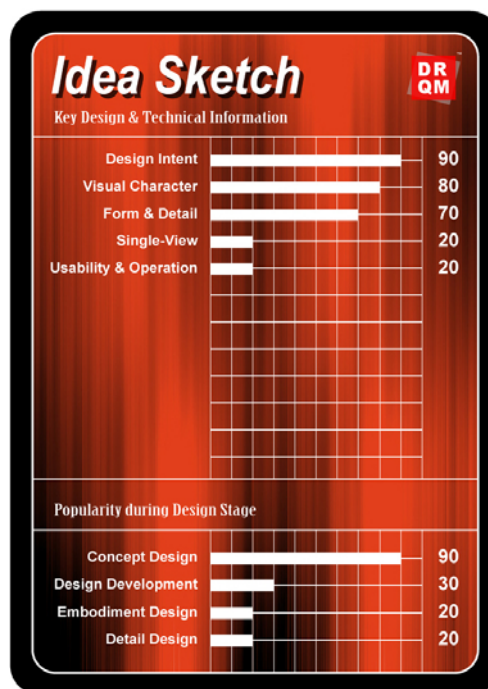


Figure 290: Card showing information from an Idea Sketch



2.

ED looks at the design stages card pack that suggests the industrial designer is most likely to provide idea sketches at this stage

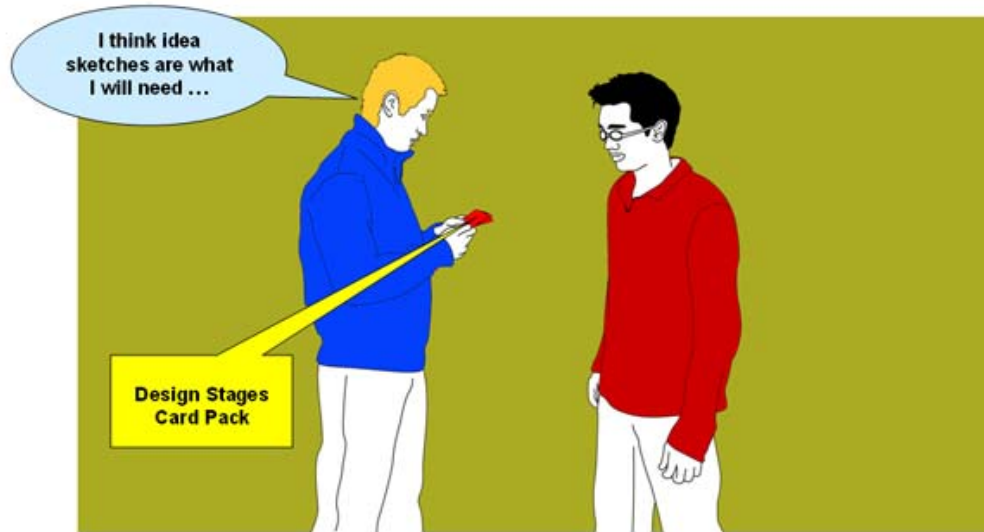


Figure 291: Scene 2 with use of the cards

3.

ED then looks up the design & technical information card pack which shows that he also needs information sketches and concept drawings.



Figure 292: Scene 3 with use of the cards



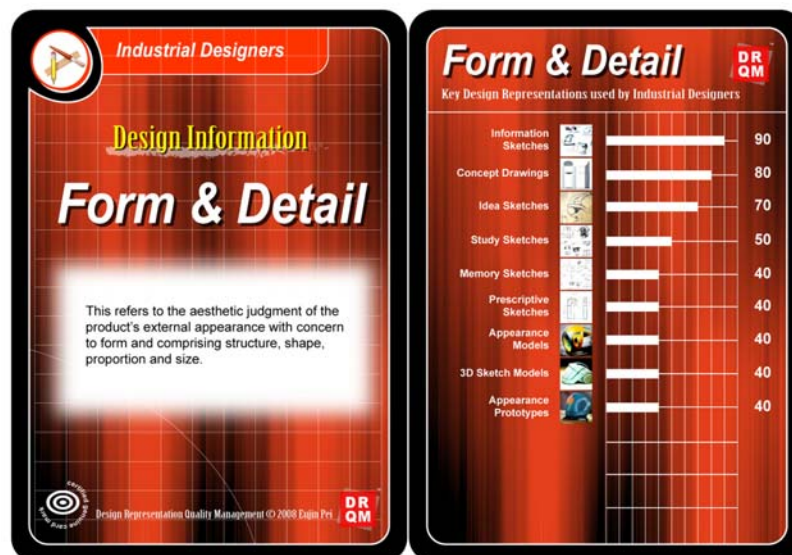


Figure 293: Form and Detail card

To confirm what needs to be shown to the engineering designer, the industrial designer refers to the Information Sketches card (Figure 294)(Blue Pack). It reveals that for prescriptive sketches, the industrial designer needs to indicate the components, colours and material (etc.) that are popularly employed by engineering designers (Scene 4 – Figure 295).

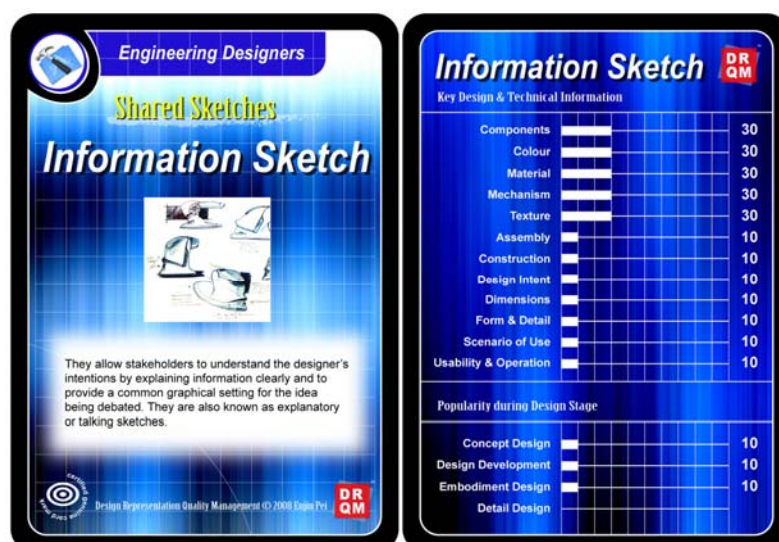


Figure 294: The Information Sketch Card

4.

ID looks up the design representation card pack which provides a clear definition of the deliverables.



Figure 295: Scene 4 with use of the cards

The final design is then quickly developed (Scene 5– Figure 296). From this scenario, it can be seen how the use of cards could have provided relevant and appropriate information concerning the use of design representations. The cards are able to facilitate the use of a common vocabulary and to create shared knowledge and empathy towards the related yet distinct working practices of industrial designers and engineering designers. The next section outlines the pilot study where the cards are subjected to practitioner feedback prior to the final validation.

5.

ED creates the 3D CAD model which is rendered as a concept or presentation drawing for the client.

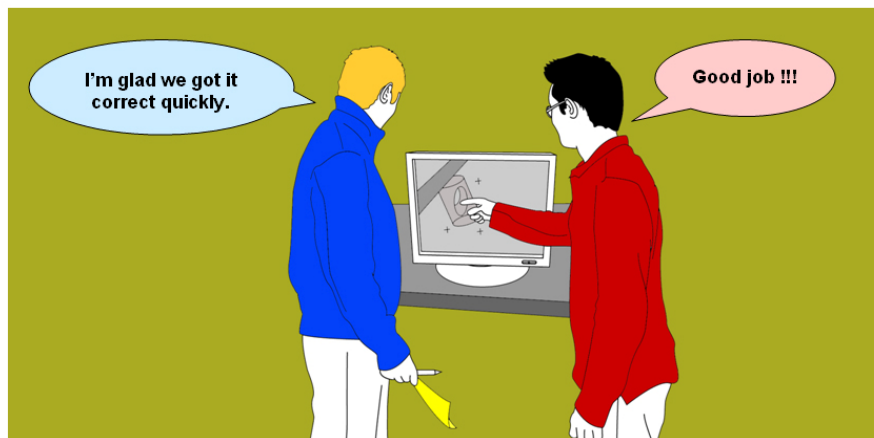


Figure 296: Scene 5 with use of the cards

### **9.7 Pilot Study on Use of the Cards**

A pilot study was conducted with ten experienced industrial design and engineering design practitioners and academics in the form of face-to-face interviews. As the aim of the pilot study was to have a small sampling, a decision was made to conduct the study in the United Kingdom, while the final validation would be undertaken in Singapore. The respondents were experts in their area with at least ten years of working experience. Tables 51 and 52 tabulate the sampling of respondents for the pilot study. They were from five different British industrial design consultancies and a British university. Although the small sampling does not allow any kind of generalisation, it provided initial feedback regarding the usefulness of the card system prior to a more formal validation.

Details of Interview Study R4	
Total respondents conducted	10
Industrial designers interviewed	4
Engineering designers interviewed	4
Industrial designer academic interviewed	1
Engineering designer academic interviewed	1
Total number of company / university	6

Table 51: Interview Statistics

No.		Respondent Code	Company / University	Profession
1.	ID	R4-1	Company 1	Industrial Designer
2.	ED	R4-2	Company 1	Engineering Designer
3.	ID	R4-3	Company 2	Industrial Designer
4.	ID	R4-4	Company 3	Industrial Designer
5.	ID	R4-5	Company 4	Industrial Designer
6.	ED	R4-6	Company 4	Engineering Designer
7.	ED	R4-7	Company 5	Engineering Designer
8.	ED	R4-8	Company 5	Engineering Designer
9.	A	R4-9	University 1	Academic
10.	A	R4-10	University 1	Academic




 Industrial Designer
  Engineering Designer
  Academic

Table 52: Description of Company & Respondents Interviewed

The interview was structured in two sections. The first section concerned demographic data based on eight questions.

A. Background questions:

1. Date of Interview:
2. Name:
3. Company / University:
4. Position :
5. Role and Responsibility:
6. Educational Background:
7. Years of Experience:
8. Type of design projects undertaken:

The second section asked research-specific questions relating to the content, design and usability of the cards.

B. Research-specific questions:

1. How do you feel about the gaming card format?

2. How do you feel about the physical size of the cards?
3. Are the textual content and pictorial data clear and easy to understand?
4. Do you think the cards would provide you with an enhanced understanding and clearer definition of design representations?
5. Do you think the cards would be effective in promoting understanding design representations between industrial designers and engineering designers?
6. Would the bar charts showing key design and technical information prove to be useful to you?
7. Would you be more able to identify the representation most commonly used during the different stages of the design process?
8. Do you think having accurately defined design representations would foster enhanced collaboration between industrial designers and engineering designers?
9. Do you think using the index cards will positively improve (your) design collaboration (with) other industrial designers / engineering designers?
10. Do you have any suggestions to help us improve the cards?

The interview sheet can be found in Appendix 13.9. The semi-structured interviews took around 45 minutes each to complete. The participants were informed that they had the right to end participation at any time without penalty and that their identities would be kept anonymous with no mention to their organisation in their feedback. The next section discusses the findings of the pilot study.

### **9.7.1 Findings from the Pilot Study**

From the semi-structured interviews, it was found that all ten industrial design and engineering respondents gave a positive response when asked if the cards would provide an enhanced understanding and clearer definition of the design representations (question 4). 70% of the respondents agreed that the cards would be effective in promoting the understanding of design

representations between industrial designers and engineering designers (question 5). 90% of them replied that they would be able to identify the representation most commonly used during the different stages of the design process (question 7). Most importantly, 90% of the respondents positively agreed that having an accurately defined design representation would foster enhanced collaboration between industrial designers and engineering designers and 70% felt that using the cards would positively improve their design collaboration with other industrial designers / engineering designers.

The qualitative responses from the pilot study were translated into six different headings by means of format, size, layout, content, information hierarchy and the search speed. Because of the small sampling, it was relatively easy to remove duplicate responses and those with the same feedback were subsumed into a general response and tabulated into Table 53.

	Issue	Actions to be Taken
Format	Doesn't have a professional feel to them - prefer rolodex cards or website	Improve graphic design
	Have a software option as well	Minimise messing up cards Further development might include a software version
	Not convinced it is the best method	
	Structure is ok but have 2 options – CD and cards	
	Website by subscription	
	Would like to see a different media used – Rolodex or PDA	
Size		
	Could be slightly bigger	Bigger size of cards
	More filofax-sized	
	Too small – should be about 100 x 150	

(Table 53 continued)

	Issue	Actions to be Taken
Content	Could be less cluttered	Remove unnecessary text
	Difficult to read information	Implement menu headings
	Have Menu headings and colour coded	Colour codes
	Pictorial data confusing	To reselect better pictures
	Pictures and fonts too small	Larger pictures and fonts
	Size of words could be bigger	Implement menu headings
	Spacing too cramped	More spacing
Usability	Cards do not improve understanding	Explain use of bar charts & percentages
	Define the rules to use the cards	Have handbook on how to use the cards
	Make it clear what bar charts mean so no misinterpretations	Structure activity into of tasks
	Finding is difficult – search function for quicker sorting	
	Have an order for the cards	
	Have dividers to sort the cards	Use dividers for cards

Table 53: Table showing issues and actions to be undertaken from the feedback

Details of each response is provided in a graphical format which can be found in Appendix 13.10. From the feedback, it can be summarised that there were three major issues to be addressed. Firstly, there was a need to increase the physical size of the cards as several respondents suggested that the cards could be made bigger. Secondly, the graphic design could be improved to use larger text and images. A clearer header should be used and colour coding could be implemented to distinguish the three packs of cards (design stages, design & technical Information and design representations). Thirdly, a navigation system could be implemented so that a particular card could be easily identified and to reduce mix up. The redesigned cards will be presented and discussed in the next chapter.

## **9.8 Chapter Summary**

In this chapter, several formats for the design tool were proposed including a desk cube, an Autodex, a representation wheel, a matrix and cards. Of these, the card format was suggested to be the most feasible and further iterations were developed. The cards serve to enhance collaboration between industrial designers and engineering designers by facilitating a common vocabulary when employing visual design representations. The cards define the four stages of the design process (concept design, design development, embodiment design, detail design) and identify the popularity of use for each design representation employed by the two disciplines. In addition, the cards also define key design and technical information employed during new product development.

Next, the cards were subjected to a pilot study, involving four industrial designers, four engineering designers and two academics. It was found that the card format was very well received and 90% of the respondents positively agreed that having accurately defined design representations would foster enhanced collaboration between the two disciplines. More importantly, 70% of them positively agreed that the tool would improve the level of collaboration with the other discipline.

The pilot study also identified three main areas to be reworked: to increase the physical size of the cards, to use larger text and images with clearer headings with colour coding, and to implement a navigation system to identify cards more easily. In the next chapter, the final design of the cards are presented which are then subjected to a more vigorous final round of validation.



## **10. FINAL TOOL DESIGN AND VALIDATION**

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### ***10.1 Chapter Overview***

In the previous chapter, design representation cards were introduced as a tool that would provide information on the nature, role and significance of design representations used by industrial designers and engineering designers during new product development. Following initial development, the cards were subjected to a pilot study with practitioners that led to several refinements.

This chapter presents the final graphic design of the cards being subjected to a three-phase validation. The first phase involved interviews with 18 final-year undergraduate students from industrial design and engineering design departments. Both groups had worked together on a live industrial project and the purpose was to enquire if the tool would have enhanced their working relationship. The second phase involved interviews with 43 industrial design and engineering design practitioners and academics with at least 5 years of work experience. In the third phase, the cards were employed in a real-life project with an industrial design consultancy. The cards were used by industrial designers and engineering designers and the observations were recorded with a design diary. The chapter ends with an analysis of the findings and a series of conclusions.

### ***10.2 Design Refinements to the Cards***

Following the pilot study, several suggestions were raised concerning three areas: the size of the cards had to be increased, larger images and words to be used, and to employ a navigation system so that a particular card could be easily identified and to reduce mixing up. Figures 397 and 398 show variations that were developed.



Figure 297: Variations to the new card design (1)



Figure 298: Variations to the new card design (2)

The following improvements were thus implemented:

1. The size of the cards were increased to ISO B8 size (a standard for playing cards). They now measure 62 mm by 88 mm, yet retaining a pocket size for portability.
2. All text and images were increased in area by at least 10%.
3. Images for the thumbnails were enhanced to improve clarity.
4. The definitions for each card were rephrased for clarity.
5. A more consistent colour hue (intensity of colour) for both industrial design (red) and engineering design (blue) cards was enhanced using the same level of saturation.
6. A numerical system was put in place to improve access to the cards. For instance, if a user wanted to know more about a particular type of information from the back of the cards, he could locate the card by referring to the unique number above the bar chart and locate the card number shown on the top right corner on the front face (Figure 299).
7. The tool was renamed 'CoLab' as an abbreviation for the term 'collaboration' which reflects its purpose as a comprehensive resource being able to support and enhance collaboration between industrial designers and engineering designers. To enhance the image of the tool, a logo was also designed to reflect its identity. Figure 300 shows examples of various designs for the logo. The design shown in Figure 301 was chosen by both supervisors of this research and the author as being the most appropriate for the logo.

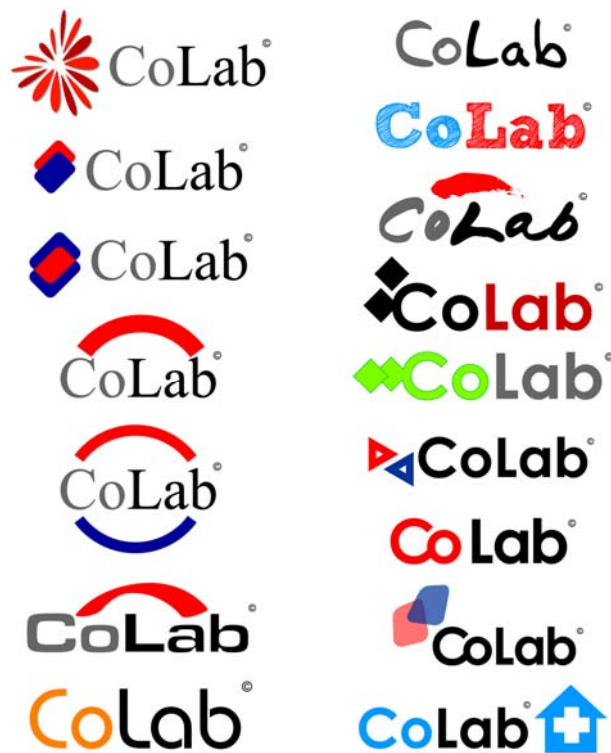
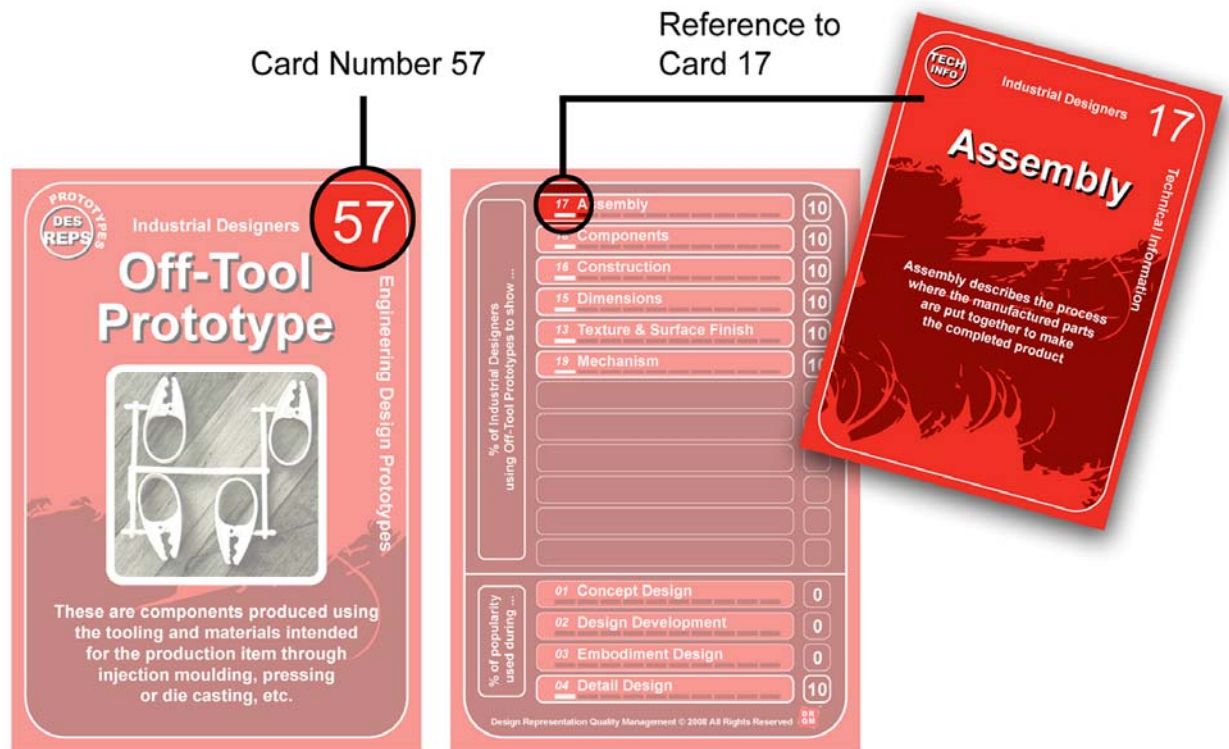


Figure 300: Logo design for the CoLab Cards





Figure 301: Chosen logo for the CoLab Cards

The following pages show other refinements to the card design. The image below in Figure 302 shows the new two-tone colour scheme (red and maroon) for the background. Figure 303 shows variations to the bar charts. The first variation on the top contained an opaque bar chart while the middle variation uses a grey background for the bar charts. Because some words (e.g. Usability and Operation) were long and overlapped the bar charts, it affected readability. The design at the bottom was made so that the bar chart was now below the text. The drawback was that the text had been scaled down. Other variations to the card design can be found in Figures 304 and 305.

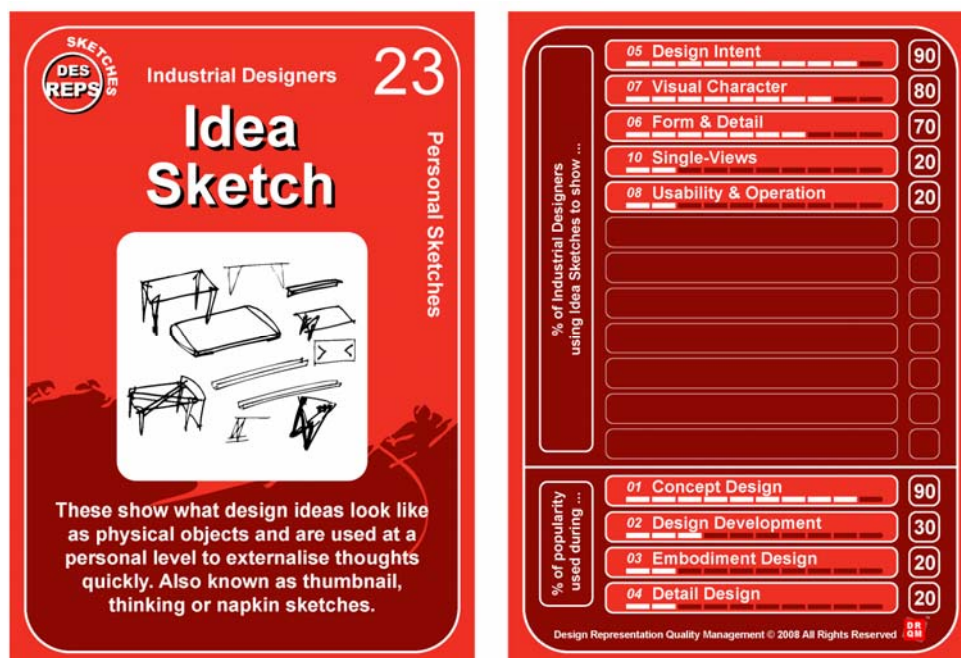


Figure 302: The redesigned cards



Figure 303: Development of the two tone colour scheme (bottom image as the chosen background) and the bar chart redesign



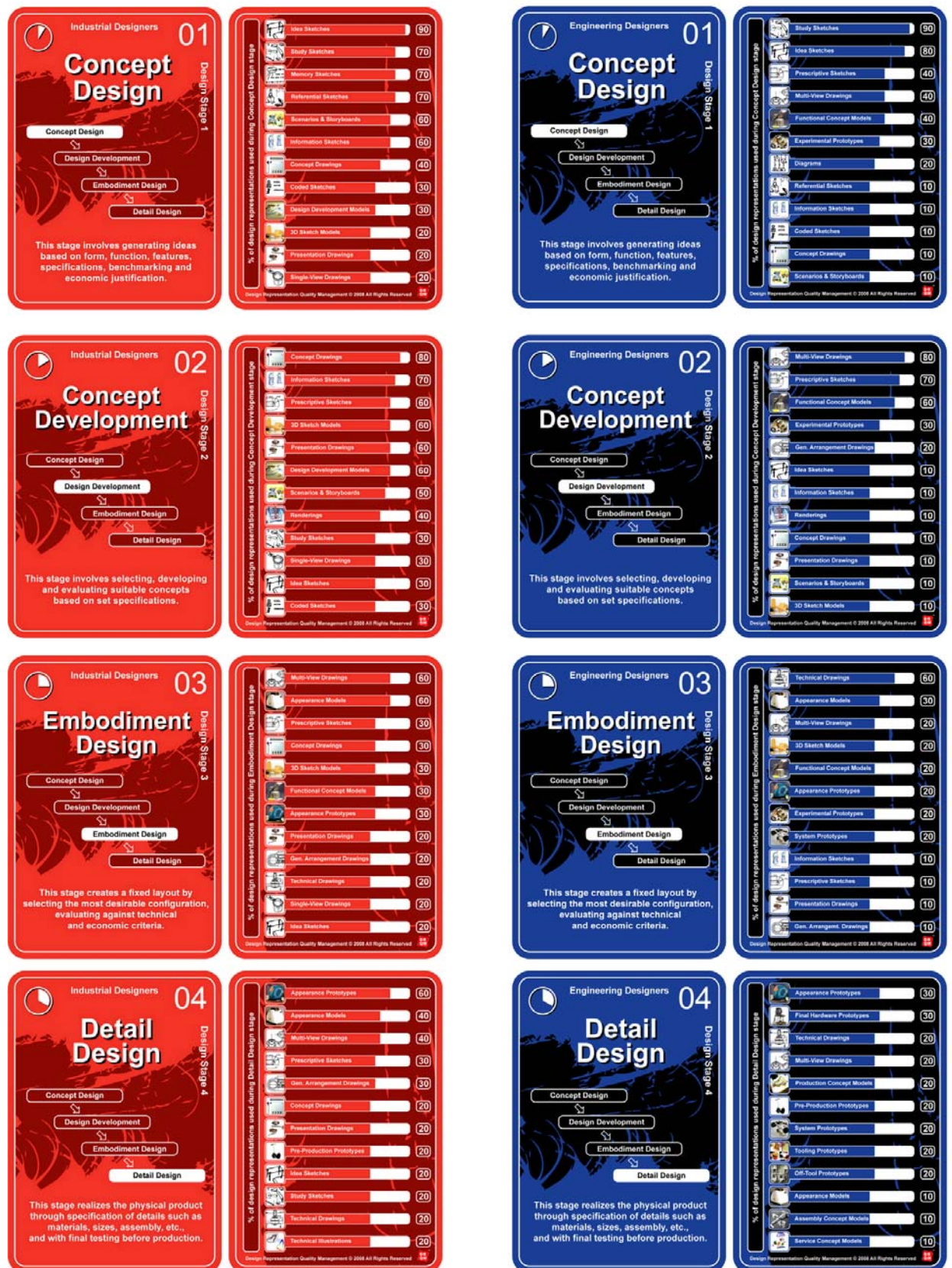


Figure 304: Other variations to the card design





Figure 305: Variations to bar chart design



The 57 cards, or 114 cards (57 x 2) for industrial designers and engineering designers were organised as follows:

**Pack One: Design Stages (4 x 2)**

1. Design Stages (4 x 2)

**Pack Two: Design and Technical Information (18 x 2)**

2. Design Information (10 x 2)
3. Technical Information (8 x 2)

**Pack Three: Design Representations (35 x 2)**

4. Sketches (9 x 2)
5. Drawings (9 x 2)
6. Models (8 x 2)
7. Prototypes (9 x 2)

These redesigned cards (Figure 306) were now subjected to a final round of validation that shall be discussed in the following section. The full set of redesigned cards may be found in Appendix 13.11 (Card Design Iteration 3).



Figure 306: The redesigned cards

### ***10.3 Validation Strategy and Reliability of Results***

The aim of the validation was to obtain feedback regarding the CoLab cards and to establish if the system would enhance collaboration between industrial design and engineering design students and practitioners. This validation was structured as a three-phase strategy. The first phase involved semi-structured interviews with 18 final-year undergraduate students from industrial design and engineering design departments who had recently worked together on an industrial project. The purpose was to enquire if CoLab would have enhanced the students' working relationship. The second phase utilised semi-structured interviews involving 43 industrial design and engineering design practitioners and academics. The third phase comprised a case-study employing a participant-observation approach that was used for the first empirical research (Section 5.4). The observations were noted with a design diary in which end-of-the-day thoughts and activities were recorded with details of why, how and where the cards were used, etc. Each of the validation processes will be discussed in the following sections.

In terms of reliability, the practitioner interviews involved large (more than 10 design staff), medium (between 6-10 design staff) and small industrial design consultancies (less than 5 designers) to allow sampling from a large pool of respondents. The respondents were made up of a balanced number of 22 industrial designers and 21 engineering designers with at least five years of work experience. Holistic feedback was achieved by including project managers to obtain the management's perspective, as well as including academics from industrial design and engineering design departments of educational institutions. Since the first and second empirical research was conducted in Singapore, a decision was made to undertake the final validation in Singapore. This would ensure consistency and to take advantage of existing contacts. The interview and case-studies covered a period of eight weeks with a total of 61 industrial design and engineering design respondents (practitioners, academics and students).

Prior to the interviews, the questions were pre-tested by both supervisors of this research and the author. Minor changes were made to improve the readability of the questions and to ensure consistency. All interviews were conducted with the same interviewer and subjected to the same process and interview questions. Although some of the respondents were participants from the earlier studies, every participant was still given a booklet (in Appendix 13.3) to provide them with latest information concerning the research and the interview process. The same booklet was also given to the case-study participants. The cards were demonstrated to each participant for them to fully understand and evaluate their use. The demonstration process is later described. For each completed interview, the data was transcribed and an email sent to the respondent at the end of the day to verify the record. By emailing the interview records to the respondents on the same day, memory loss was minimised. For the interviews, the main limitation was the respondents' lack of time. Although the interview sessions were pre-arranged, they did not have sufficient time to discuss details. The option to conduct interviews after work hours was not popular.

A semi-structured approach for the interviews by means of Likert-scales and open-ended questions was used. The five-point Likert scale allowed respondents to define their responses clearly according to excellent, good, neutral, poor, very poor. The median results were then tabulated into a matrix and represented as pie-charts. This method of calculating median scores has been considered appropriate when dealing with Likert scales to obtain overall feedback (Engelbrektsson and Soderman 2004). The respondents were also encouraged to provide additional information as supporting data. There were nine Likert-scale questions, ending with an open-ended question that asked for suggestions to improve the system.

The case study involved an industry project concerning the design of a consumer electronics product. By conducting the case study with the same industrial design consultancy observed during the first round of empirical research, the project members who were involved earlier had a better understanding of the research. They were also able to communicate better

with the same researcher. In addition, contemporaneous notes were recorded whenever the cards were used or when pertinent events looked significant. Despite these advantages, the main limitation was that photographs or video recordings were not allowed because of confidentiality. However, the management gave permission to allow some of the design work to be used, provided that the client or company logo and other sensitive information was omitted.

In terms of ethical conduct, all respondents were briefed about the nature of interviews or the case-study observations. They were told what was expected and that they had the right to end their participation at any point of time without penalty. They were told that the research complied with Loughborough University's policy on data collection and storage based on the 1998 Data Protection Act (<http://www.lboro.ac.uk/admin/committees/ethical/gn/dcas.htm> October 2008). The identities and organisation of the respondents was kept anonymous. All participants were assigned a reference number and the data was stored against this number rather than their names.

In summary, reliability was achieved by ensuring multiple sources and making the conduct of the validation process transparent. In addition, the validation also involved a balanced number of industrial designers and engineering designers, including practitioners, academics and students. Lastly, both interviews and case-study observations were conducted in line with Loughborough University's policy on ethical conduct concerning human participants.

#### ***10.4 Data Collection with Student Interviews***

The first phase of validation involved interviews with final-year industrial design and engineering design undergraduates over a period of 2 weeks. The 4 industrial design students and 14 engineering design students were from an established university in Singapore and had recently worked together for an academic semester (four months) regarding an industry-based project (Tables

54, 55). As the projects were organised by the mechanical engineering department, there were less industrial design participants. Following their multi-disciplinary experience, the students were interviewed to find out if their collaborative relationship would have been enhanced if they had used the CoLab cards. Although the student projects involved fewer real-life constraints, their exposure to multi-disciplinary group work would provide relevant feedback from their experience. All 18 students were given a presentation about the research and a demonstration of the CoLab cards. To maintain consistency, the same 5-point Likert scale interview questions, interview process and the same interviewer were employed.

<b>Details of Interview Study with Students R5</b>	
Total number of students	18
Industrial design students interviewed	4
Engineering design students interviewed	14

Table 54: Student interview statistics

<b>No.</b>		<b>Respondent Code</b>	<b>Profession</b>
1.	ID	R5-1	Student
2.	ID	R5-2	Student
3.	ID	R5-3	Student
4.	ID	R5-4	Student
5.	ED	R5-5	Student
6.	ED	R5-6	Student
7.	ED	R5-7	Student
8.	ED	R5-8	Student
9.	ED	R5-9	Student
10.	ED	R5-10	Student
11.	ED	R5-11	Student
12.	ED	R5-12	Student

(table 55 continued)

No.		Respondent Code	Profession
13.	ED	R5-13	Student
14.	ED	R5-14	Student
15.	ED	R5-15	Student
16.	ED	R5-16	Student
17.	ED	R5-17	Student
18.	ED	R5-18	Student



Industrial Designer



Engineering Designer

Table 55: Description of student respondents Interviewed

Prior to each interview, the respondents were given a presentation about the research and a demonstration of the CoLab cards. Each presentation lasted ten minutes and comprised of:

#### 1. Introducing the research

This explained the research background, the current findings and aims and objectives of the interviews.

#### 2. Presenting the CoLab cards

The cards were shown to the participant, explaining the red set for industrial designers and the blue set for the engineering designers. Each set was further divided into design stages, design information, technical information and design representation. Each card had a unique number that could be found at the top right hand corner on the front face which also contained a visual example and the definition. The back of the cards showed the popularity of use for a design representation or a design / technical information.

### 3. Demonstrating how the cards may be used.

A PowerPoint presentation was shown to the respondents showing two scenarios. The first represented a typical scene during new product development highlighting issues between the industrial designer and the engineering designer. The scenario was obtained from Section 9.6.1. The second scenario showed how the CoLab cards might be used from Section 9.6.2.

The interviews were structured into two parts. The first section gathered demographic data from the respondents, concerning their background and job scope, made up of seven questions. The interview sheet can be found in Appendix 13.12.

#### A. Background questions:

1. Name
2. Company
3. Position
4. Role and Responsibility
5. Educational Background
6. Years of Experience
7. Type of design projects undertaken

The second section consisted of ten questions. The first nine questions were made up of a five-point Likert scale (Figure 307) with sufficient space for additional comments. The use of Likert scale was easy to construct, administer and score and also easier to quantify as compared to a completely open-ended question (Gadsden 2006). The last question was open-ended asking for suggestions and improvements to the cards.



1. Excellent	2. Good	3. Neutral	3. Poor	4. Very Poor
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure 307: The five-point Likert scale

B. Research-specific questions:

1. How do you generally feel about the card format?
2. How do you feel about the physical size of the cards?
3. How would you rate the clarity and understandability of the textual content and pictorial data?
4. How would you rate the ability of the cards to provide you with an enhanced understanding and clearer definition of design representations?
5. How do you feel about the effectiveness of the cards to provide a common understanding of design representations between IDs and EDs?
6. How would you rate the use of bar charts that show key design and technical information?
7. How would you rate the ability of the cards to help you identify the representation most commonly used during different stages of the design process?
8. How do you feel about the ability of the cards to foster enhanced collaboration between IDs and EDs?
9. How do you feel about the ability of the cards to improve design collaboration between yourself and other industrial designers / engineering designers?
10. Would you have any suggestions or additional feedback to help us improve the cards?

### 10.4.1 Student Interview Findings

The response for each student interview was subjected to the same procedure used for the practitioners. The results can be found in Appendix 13.11.1. The data was first encoded into Excel sheets and for each question, the Likert-scale values for each point (Excellent, Good, Neutral, Poor, Very Poor) were calculated and the median values in percentage were obtained for the 18 students (Table 56). The average scores were then tabulated into a matrix and represented as pie-charts.

	Students Only	Excellent	Good	Neutral	Poor	Very Poor
Question 1	Industrial Designers	1	3	0	0	0
	Percentage	25.00%	75.00%	0.00%	0.00%	0.00%
	Engineering Designers	4	9	0	1	0
	Percentage	28.60%	64.30%	0.00%	7.10%	0.00%
Question 2	Industrial Designers	2	2	0	0	0
	Percentage	50.00%	50.00%	0.00%	0.00%	0.00%
	Engineering Designers	7	4	3	0	0
	Percentage	50.00%	28.60%	24.10%	0.00%	0.00%
Question 3	Industrial Designers	0	3	1	0	0
	Percentage	0.00%	75.00%	25.00%	0.00%	0.00%
	Engineering Designers	5	8	1	0	0
	Percentage	35.70%	57.20%	7.10%	0.00%	0.00%
Question 4	Industrial Designers	1	3	0	0	0
	Percentage	25.00%	75.00%	0.00%	0.00%	0.00%
	Engineering Designers	4	8	2	0	0
	Percentage	28.60%	57.20%	14.20%	0.00%	0.00%
Question 5	Industrial Designers	1	2	1	0	0
	Percentage	25.00%	50.00%	25.00%	0.00%	0.00%
	Engineering Designers	4	5	4	1	0
	Percentage	28.60%	35.70%	28.60%	7.10%	0.00%
Question 6	Industrial Designers	1	1	2	0	0
	Percentage	25.00%	25.00%	50.00%	0.00%	0.00%
	Engineering Designers	1	6	6	1	0
	Percentage	7.10%	42.90%	42.90%	7.10%	0.00%
Question 7	Industrial Designers	1	3	0	0	0
	Percentage	25.00%	75.00%	0.00%	0.00%	0.00%
	Engineering Designers	4	9	1	0	0
	Percentage	28.60%	64.30%	7.10%	0.00%	0.00%
Question 8	Industrial Designers	0	4	0	0	0
	Percentage	0.00%	100.00%	0.00%	0.00%	0.00%
	Engineering Designers	1	11	1	1	0
	Percentage	7.10%	78.70%	7.10%	7.10%	0.00%
Question 9	Industrial Designers	0	3	1	0	0
	Percentage	0.00%	75.00%	25.00%	0.00%	0.00%
	Engineering Designers	1	10	3	0	0
	Percentage	7.10%	71.50%	21.40%	0.00%	0.00%

Table 56: Results from student interviews

The first question asked how the students felt about the card format. From the industrial design students, 1 of them (25%) responded excellent, 3 (75%) responded good, none responded neutral, none responded poor and none responded very poor (Figure 308).

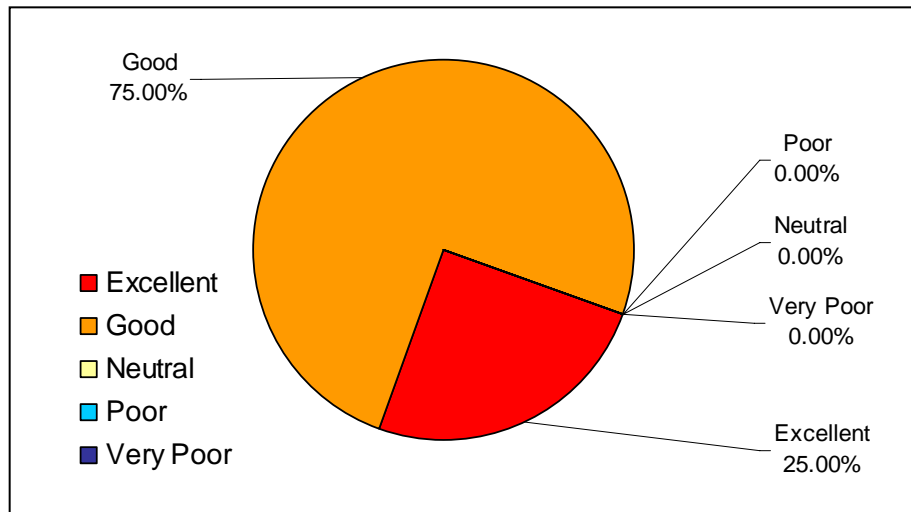


Figure 308: Results of Question 1 from industrial design students

From the engineering design students, 4 of them (28.6%) responded excellent, 9 (64.3%) responded good, none responded neutral, 1 (7.1%) responded poor and none responded very poor (Figure 309).

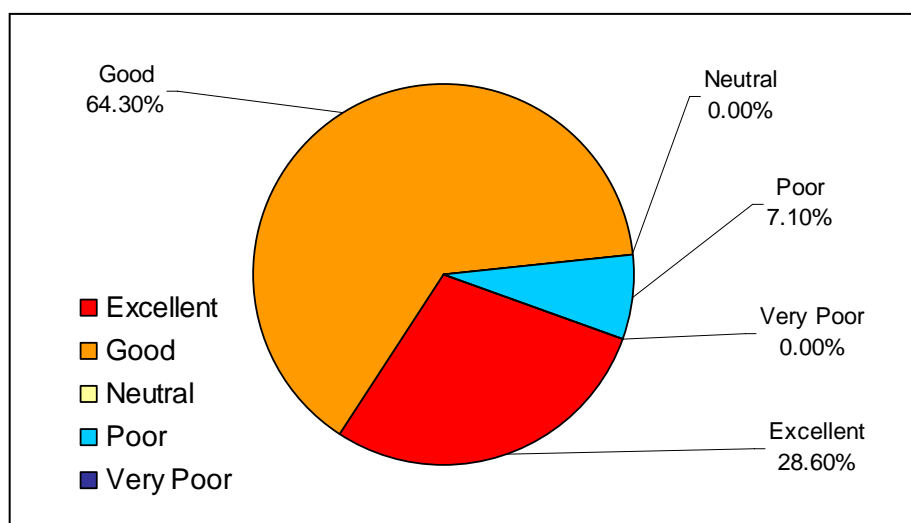


Figure 309: Results of Question 1 from engineering design students

From the median scores of the industrial design and engineering design students' responses, 5 of them (26.8%) responded excellent, 12 (69.65%) responded good, none responded neutral, 1 (3.55%) responded poor and none responded very poor (Figure 310). Nearly all the respondents who commented said that the cards were a fresh approach that would allow both industrial designers and engineering designers to interact and understand each other. However, one respondent commented that having too many cards could be troublesome to use.

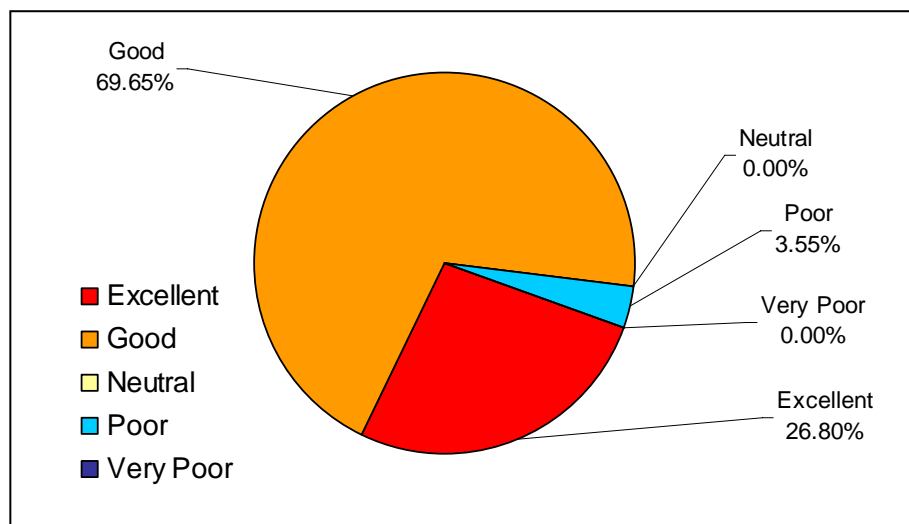


Figure 310: Results of Question 1 from the industrial design and engineering design students

The second question asked the students about the physical size of the cards. From the median scores of the industrial design and engineering design students' responses, 9 of them (50%) responded excellent, 6 (39.3%) responded good, 3 (10.7%) responded neutral, none responded poor and none responded very poor (Figure 311). Nearly all the respondents commented that the card portable format was 'handy'. There were no negative comments.

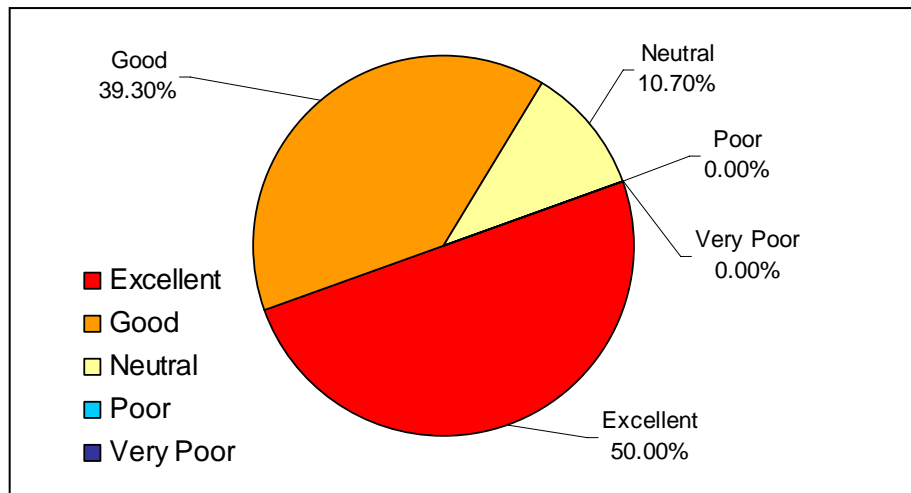


Figure 311: Results of Question 2 from the industrial design and engineering design students

The third question asked the students to rate the clarity and understandability of the text and pictures. From the median scores of the industrial design and engineering design students' responses, 5 of them (17.85%) responded excellent, 11 (66.1%) responded good, 2 (16.05%) responded neutral, none responded poor and none responded very poor (Figure 312). In terms of clarity and understandability of the words and pictures, one respondent commented that the cards were simple and easy to understand, whereas other respondents felt that the text was cluttered. They also felt that the text could be more concise to improve understanding.

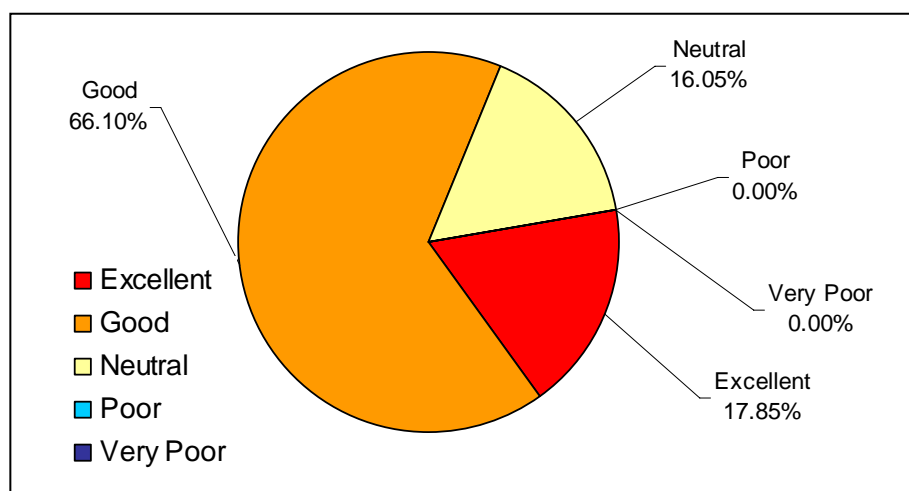


Figure 312: Results of Question 3 from the industrial design and engineering design students

The fourth question asked the students how they rated the ability of the cards to provide them with an enhanced understanding and clearer definition of design representations. From the median scores of the industrial design and engineering design students' responses, 5 of them (26.8%) responded excellent, 11 (66.1%) responded good, 2 (7.1%) responded neutral, none responded poor and none responded very poor (Figure 313).

For this question, the students who commented gave positive responses by saying that the tool would aid in enhancing understanding and providing a clearer definition of design representations. They commented that the cards were informative and would be useful during the design process.

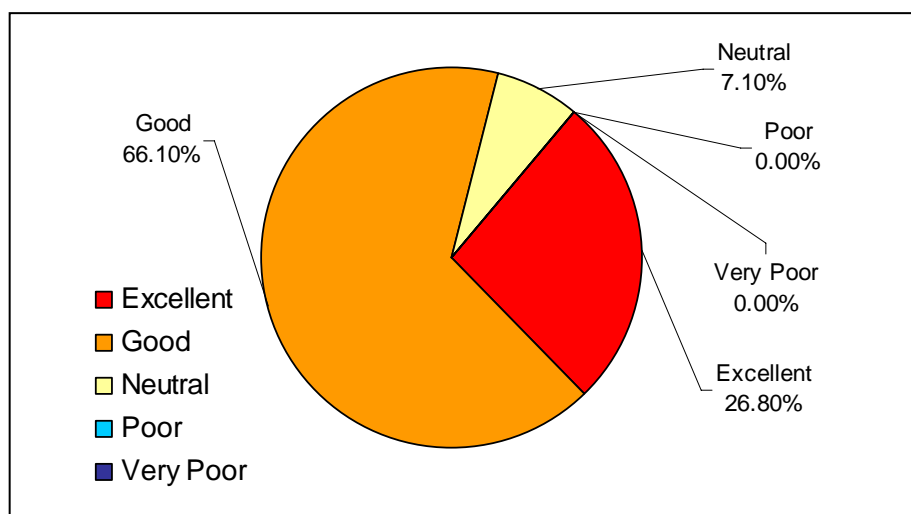


Figure 313: Results of Question 4 from the industrial design and engineering design students

The fifth question asked the students about the effectiveness of the cards to provide them with a common understanding of design representations between industrial designers and engineering designers. From the median scores of the industrial design and engineering design students' responses, 5 of them (26.8%) responded excellent, 7 (42.85%) responded good, 5 (26.8%) responded neutral, 1 (3.55%) responded poor and none responded very poor (Figure 314).

One of the respondents commented that at times she was not able to understand what the engineering design students were talking about and believed that the cards would have helped. Other respondents mentioned that it would be a good communication tool to bridge the gap between them, even though another respondent was sceptical as he felt that it might take up time and effort to learn about the cards.

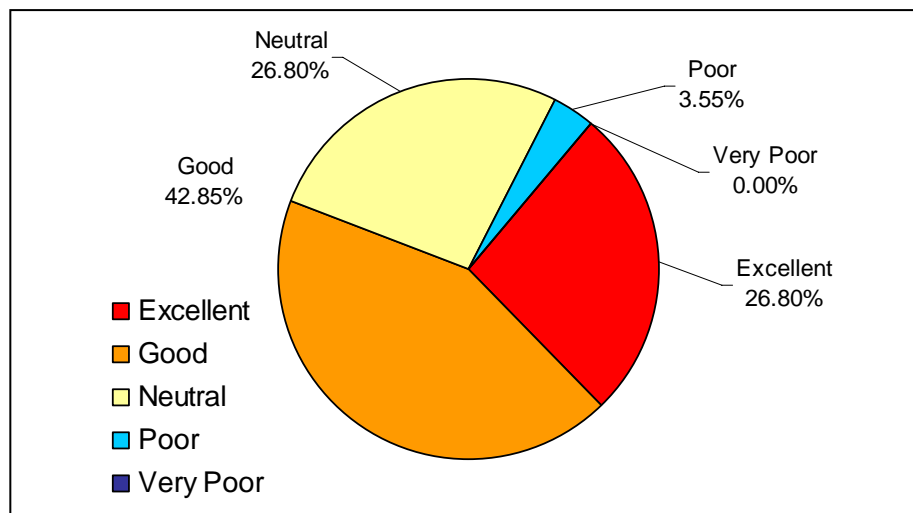


Figure 314: Results of Question 5 from the industrial design and engineering design students

Question 6 asked the students how they rated the bar charts that showed key design and technical information. From the median scores of the industrial design and engineering design students' responses, 2 of them (16.05%) responded excellent, 7 (33.95%) responded good, 8 (46.45%) responded neutral, 1 (3.55%) responded poor and none responded very poor (Figure 315).

There were three respondents who felt that the bar charts were not purposeful. They felt that the numbers were sufficient enough to convey the necessary information. Two other respondents felt that they preferred the use of the bar charts instead of the numbers to show the level of design or technical information, while other respondents simply felt that either the use of the bar chart or the numbers would be good enough,

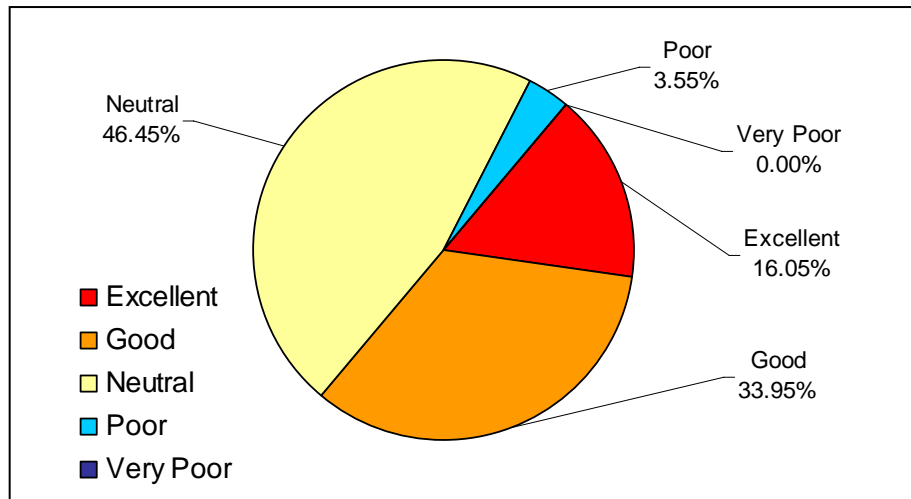


Figure 315: Results of Question 6 from the industrial design and engineering design students

Question 7 asked the students how they rated the ability of the cards to identify representations most commonly used during different stages of the design process. From the median scores of the industrial design and engineering design students' responses, 5 of them (26.8%) responded excellent, 12 (69.65%) responded good, 1 (3.55%) responded neutral, none responded poor and none responded very poor (Figure 316).

From the comments, one of the respondents felt that the cards had helped her understand better about the design stages and design representations. Another respondent felt that the cards provided a good overview of the design process.

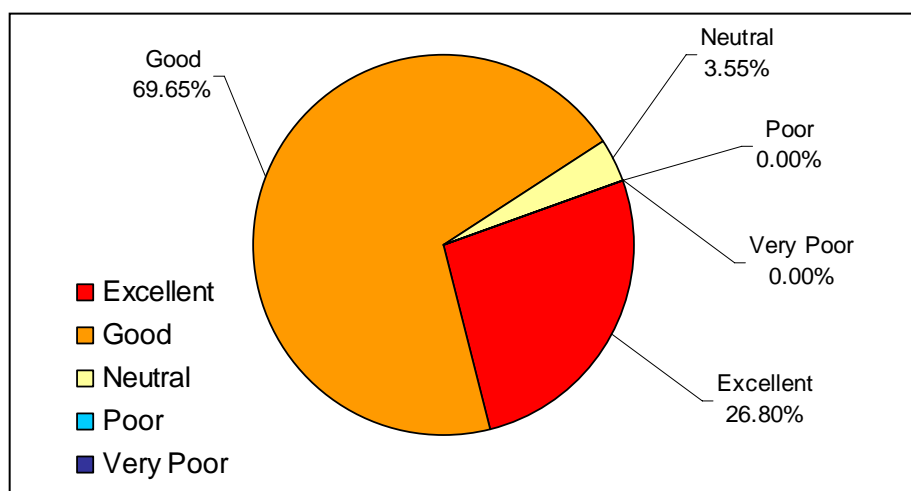


Figure 316: Results of Question 7 from the industrial design and engineering design students



Question 8 asked the students how they felt about the ability of the cards to foster enhanced collaboration between industrial designers and engineering designers. From the median scores of the industrial design and engineering design students' responses, 1 of them (3.55%) responded excellent, 15 (89.35%) responded good, 1 (3.55%) responded neutral, 1 (3.55%) responded poor and none responded very poor (Figure 317).

When asked about the ability of the cards to foster enhanced collaboration between the two disciplines, some of them felt that it would be especially useful for use in schools as a reference guide. Another respondent was confident that the cards would provide her with a better understanding of the design process, although another respondent was concerned that it would require time to fully learn from the cards and that it might be troublesome to use.

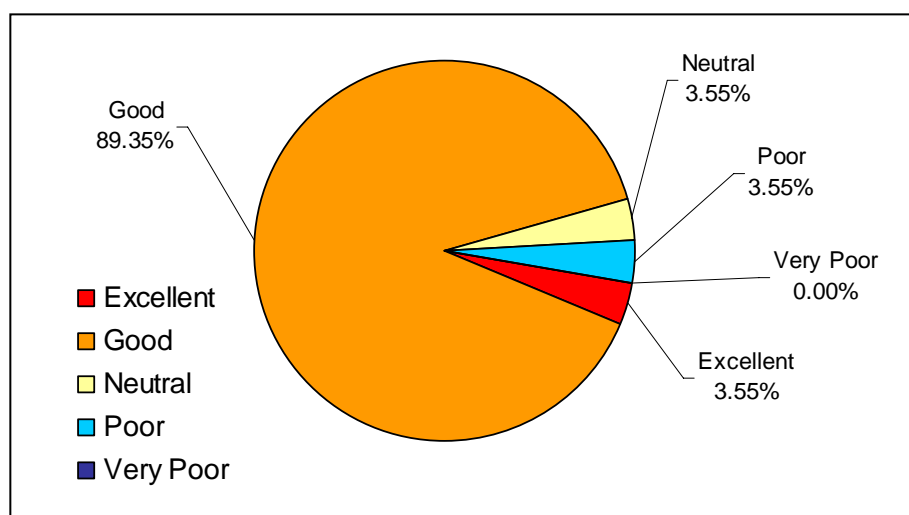


Figure 317: Results of Question 8 from the industrial design and engineering design students

Question 9 asked the students about the ability of the cards to improve design collaboration among themselves and other industrial designers / engineering designers. From the median scores of the industrial design and engineering design students' responses, 1 of them (3.55%) responded excellent, 13 (73.25%) responded good, 4 (23.2%) responded neutral, none responded poor and none responded very poor (Figure 318).

One of the students felt that the cards could help their group work more effectively, while another felt that it was a useful tool as a reference guide when communicating with a member from another discipline. Another respondent felt that the tool would help reduce confusion during the design process.

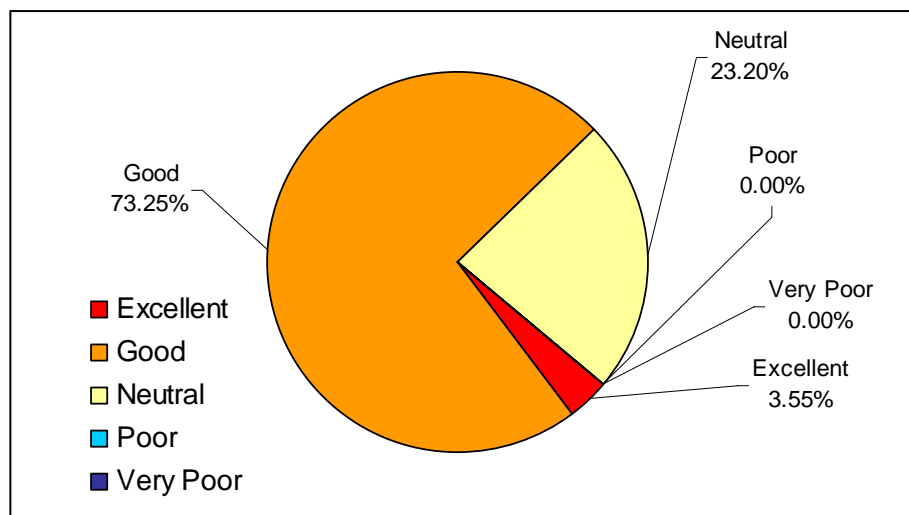


Figure 318: Results of Question 9 from the industrial design and engineering design students

Question 10 asked the students for feedback to improve the cards. Of the 18 students, 4 of them felt that there were too many cards and it might be helpful to combine or to reduce the amount of information. Other respondents felt that having a digital alternative might be useful. Another respondent also felt that there could be an instruction sheet or a content list so that he could understand the overview of the system.

One significant difference between the industrial design and engineering design students can be observed in question 3 that asked them to rate the clarity and understandability of the text and pictures. Although no industrial design students responded excellent, 35.7% of the engineering design students responded excellent. Another significant difference in responses can be observed in question 4 that asked the students how they rated the ability of the cards to provide them with an enhanced understanding and clearer definition of design representations. Although 75% of the industrial design

students responded good, a lower percentage of 57.2% was recorded from the engineering design students. Question 5 asked the students about the effectiveness of the cards to provide them with a common understanding of design representations between industrial designers and engineering designers. While 66.1% of the industrial design students responded good, a lower percentage of 35.7% of engineering design students was recorded. Question 6 asked the students how they rated the bar charts. While 25% of the industrial designers gave an excellent response, only 7.1% of the other group gave an excellent response. The next section discusses the data collection with the practitioners.

### ***10.5 Data Collection with Practitioner Interviews***

To ensure that the companies selected for the practitioner interviews were similar, the industrial design consultancies had to employ both industrial designers and engineering designers during the design process. In addition, the firms had to be involved with new product development concerning consumer electronics to maintain consistency. Participants from the first and second empirical research were contacted and those available were re-introduced to the research. A total of 22 industrial design 21 engineering design practitioners and academics were interviewed and a total of 15 industrial design consultancies and academic institutions were visited to obtain their views on the usefulness of the proposed tool (Tables 57, 58). The same interview process and interview questions were employed for the practitioner interviews. The findings are now discussed.

Details of Interview Study with Practitioners R6	
Total number of practitioners	43
Industrial designers interviewed	22
Engineering designers interviewed	21
Project Managers interviewed	4
Academic interviewed	12
Total number of companies	15

Table 57: Practitioner interview statistics

No.		Respondent Code	Company	Profession
1.	ID	R6-1	Company 1	Academic
2.	ID	R6-2	Company 1	Industrial Designer
3.	ID	R6-3	Company 1	Industrial Designer
4.	ID	R6-4	Company 1	Academic
5.	ID	R6-5	Company 1	Industrial Designer
6.	ED	R6-6	Company 1	Academic
7.	ED	R6-7	Company 1	Academic
8.	ED	R6-8	Company 1	Academic
9.	ED	R6-9	Company 1	Academic
10.	ED	R6-10	Company 1	Academic
11.	ED	R6-11	Company 1	Academic
12.	ED	R6-12	Company 1	Academic
13.	ED	R6-13	Company 1	Academic
14.	ED	R6-14	Company 1	Academic
15.	ID	R6-15	Company 2	Industrial Designer
16.	ED	R6-16	Company 2	Engineering Designer
17.	ED	R6-17	Company 2	Engineering Designer
18.	ED	R6-18	Company 3	Project Manager
19.	ID	R6-19	Company 3	Industrial Designer

(table 58 continued)

No.		Respondent Code	Company	Profession
19.	ID	R6-19	Company 3	Industrial Designer
20.	ID	R6-20	Company 4	Industrial Designer
21.	ED	R6-21	Company 5	Engineering Designer
22.	ED	R6-22	Company 6	Engineering Designer
23.	ID	R6-23	Company 6	Industrial Designer
24.	ID	R6-24	Company 6	Industrial Designer
25.	ID	R6-25	Company 6	Industrial Designer
26.	ED	R6-26	Company 6	Engineering Designer
27.	ID	R6-27	Company 6	Industrial Designer
28.	ID	R6-28	Company 7	Industrial Designer
29.	ID	R6-29	Company 7	Project Manager
30.	ID	R6-30	Company 7	Industrial Designer
31.	ID	R6-31	Company 8	Industrial Designer
32.	ED	R6-32	Company 8	Engineering Designer
33.	ED	R6-33	Company 8	Engineering Designer
34.	ID	R6-34	Company 9	Project Manager
35.	ID	R6-35	Company 9	Academic
36.	ED	R6-36	Company 10	Engineering Designer
37.	ID	R6-37	Company 11	Project Manager
38.	ID	R6-38	Company 11	Industrial Designer
39.	ED	R6-39	Company 12	Engineering Designer
40.	ID	R6-40	Company 13	Industrial Designer
41.	ED	R6-41	Company 13	Engineering Designer
42.	ID	R6-42	Company 14	Industrial Designer
43.	ED	R6-43	Company 15	Engineering Designer





	Industrial Designer		Engineering Designer
	Project Manager		Academic

Table 58: Description of company & respondents Interviewed

### 10.5.1 Practitioner Interview Findings

The response for each practitioner interview (the results can be found in Appendix 13.11.2) was first encoded into Excel sheets. For each question, the Likert-scale values for each point (Excellent, Good, Neutral, Poor, Very Poor) were calculated and the median values in percentage were obtained for the 43 practitioners (Table 59). Similar to the student interviews, the average scores were then tabulated into a matrix and represented as pie-charts.

	Practitioners Only	Excellent	Good	Neutral	Poor	Very Poor
Question 1	Industrial Designers	5	14	2	0	1
	Percentage	22.70%	63.70%	9.10%	0%	4.50%
	Engineering Designers	8	11	2	0	0
	Percentage	38%	52.50%	9.50%	0%	0%
Question 2	Industrial Designers	3	15	4	0	0
	Percentage	13.60%	68.20%	18.20%	0%	0%
	Engineering Designers	5	12	3	1	0
	Percentage	24%	57%	14%	5%	0%
Question 3	Industrial Designers	2	14	5	1	0
	Percentage	9.10%	63.70%	22.70%	4.50%	0%
	Engineering Designers	5	15	1	0	0
	Percentage	24%	71%	5%	0%	0%
Question 4	Industrial Designers	7	12	3	0	0
	Percentage	31.90%	54.50%	13.60%	0%	0%
	Engineering Designers	6	13	2	0	0
	Percentage	28.50%	62%	9.50%	0%	0%
Question 5	Industrial Designers	3	16	2	1	0
	Percentage	13.60%	72.80%	9.10%	4.50%	0%
	Engineering Designers	8	10	2	1	0
	Percentage	38%	47.50%	9.50%	5%	0%
Question 6	Industrial Designers	6	12	3	1	0
	Percentage	27.30%	54.50%	13.60%	4.60%	0%
	Engineering Designers	6	10	5	0	0
	Percentage	28.50%	47.50%	24%	0%	0%
Question 7	Industrial Designers	5	14	3	0	0
	Percentage	22.70%	63.70%	13.60%	0%	0%
	Engineering Designers	7	12	2	0	0
	Percentage	33.50%	57%	9.50%	0%	0%
Question 8	Industrial Designers	2	13	6	1	0
	Percentage	9.10%	59.10%	27.30%	4.50%	0%
	Engineering Designers	4	10	7	0	0
	Percentage	19%	47.50%	33.50%	0%	0%
Question 9	Industrial Designers	2	15	4	1	0
	Percentage	9.10%	68.20%	18.20%	4.50%	0%
	Engineering Designers	5	12	4	0	0
	Percentage	24%	57%	19%	0%	0%

Table 59: Results from practitioner interviews

The first question asked how the respondents felt about the card format. They were told several versions including digital formats were considered, but the card format was chosen because of portability and ready access to information. From the industrial design practitioners, 5 of them (22.7%) responded excellent, 14 (63.7%) responded good, 2 (9.1%) responded neutral, none responded poor and 1 (4.5%) responded very poor (Figure 319).

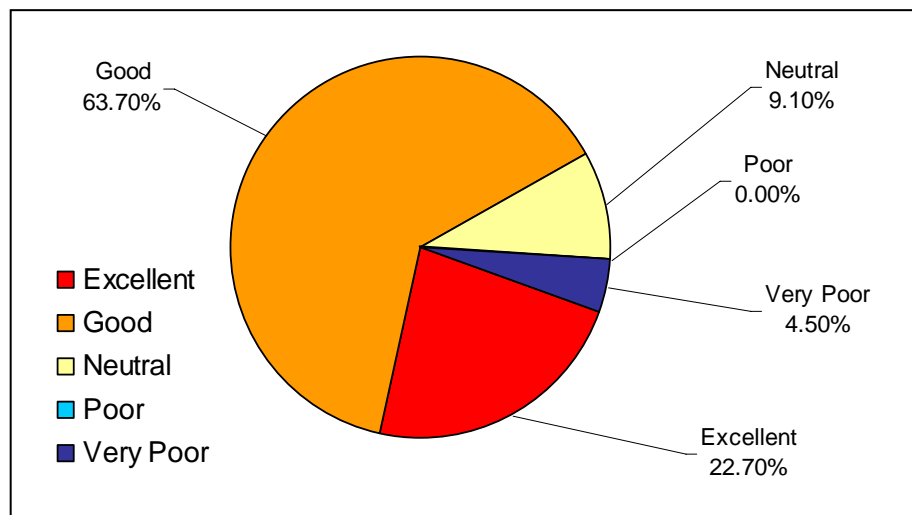


Figure 319: Results of Question 1 from industrial design practitioners

From the engineering design practitioners, 8 of them (38%) responded excellent, 11 (52.5%) responded good, 2 (9.5%) responded neutral, none responded poor and none responded very poor (Figure 320).

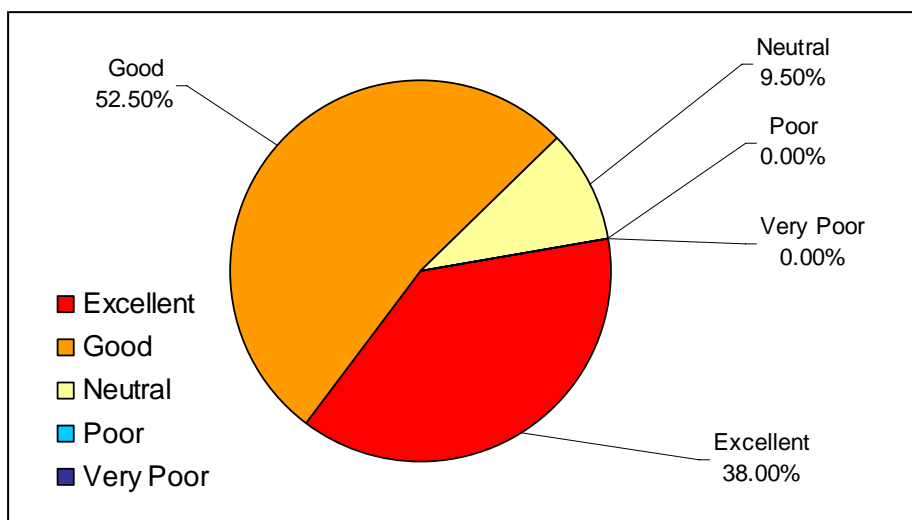


Figure 320: Results of Question 1 from engineering design practitioners

For the first question, the median scores for the industrial design and engineering design practitioners' responses were obtained. 13 of them (30.4%) responded excellent, 25 (58.1%) responded good, 4 (9.3%) responded neutral, none responded poor and 1 (2.3%) responded very poor (Figure 321).

From the first question, most respondents gave positive comments saying that the cards were a novel and interesting approach. Two respondents liked the hands-on approach and saw it as well organised and having potential as a group-based tool. Some negative comments were that the cards could get mixed up easily. There were four participants who wanted to have a digital or web-based format available.

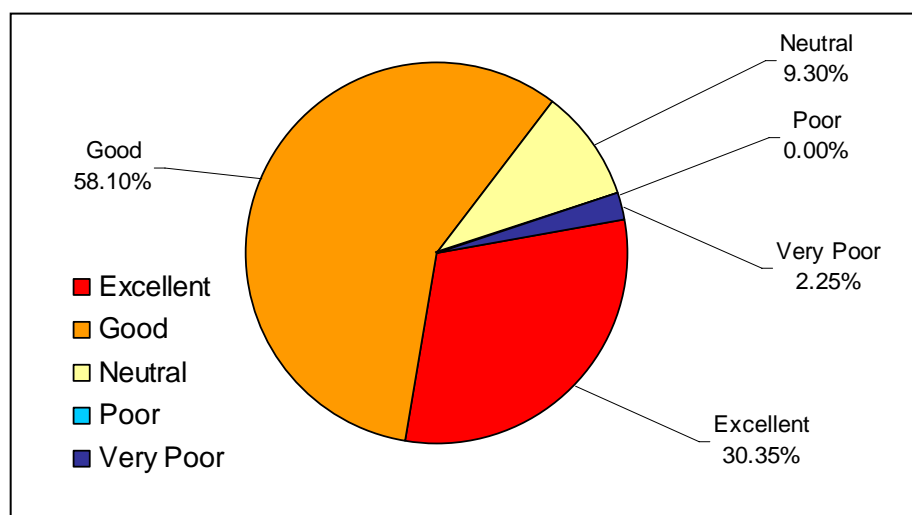


Figure 321: Results of Question 1 from the industrial design and engineering design practitioners



The second question asked respondents about the physical size of the cards which were now developed into a slightly larger ISO B8 size (62mm by 88mm). From the median scores of the industrial design and engineering design practitioners' responses, 8 of them (18.8%) responded excellent, 27 (62.6%) responded good, 7 (16.1%) responded neutral, 1 (2.5%) responded poor and none responded very poor (Figure 322).

Some of the positive comments were that the size was comfortable, easy to carry and could fit into the pocket. Another participant suggested that the size was appropriate at a personal level. But another larger version could be also made for use in groups. The negative comments came from the older participants who were in their early 50s and said that the size was slightly small for senior users. Also, another respondent said that there were too many cards and it was bulky for his pocket.

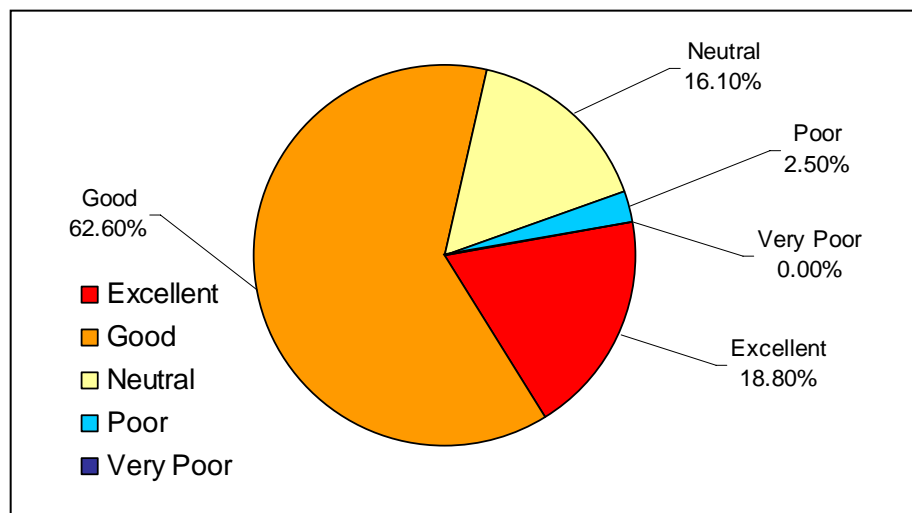


Figure 322: Results of Question 2 from the industrial design and engineering design practitioners

The third question asked the practitioners to rate the clarity and understandability of the textual content and pictorial data. The aim was to find whether the graphic design of the cards was effective and if the information could be easily understood. From the median scores of the industrial design and engineering design practitioners' responses, 7 of them (16.55%) responded excellent, 29 (67.35%) responded good, 6 (13.85%) responded neutral, 1 (2.25%) responded poor and none responded very poor (Figure 323).

Most of the positive comments centred that the cards were generally clear and easy to understand. However, other respondents felt that the numbers on the bar charts were easily misunderstood. They felt that the numbers next to the bar charts should be either removed or merged with the bar charts since both meant the same. They were confused about what the numbers meant.

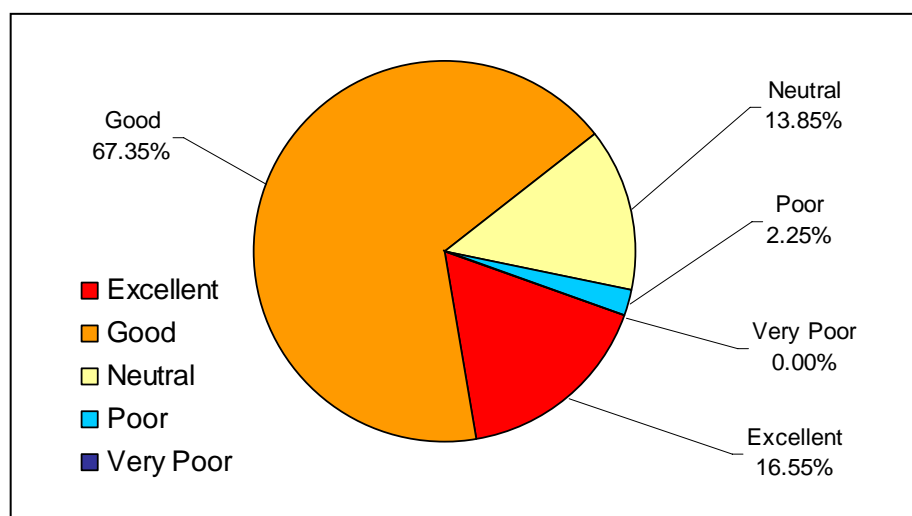


Figure 323: Results of Question 3 from the industrial design and engineering design practitioners

The fourth question asked the practitioners how they would rate the ability of the cards to provide them with an enhanced understanding and clearer definition of design representations. The purpose was to find whether the cards would provide them with a clearer definition and better understanding of the design representations. From the median scores of the industrial design and engineering design practitioners' responses, 13 of them (30.22%) responded excellent, 25 (58.28%) responded good, 5 (11.51%) responded neutral, none responded poor and none responded very poor (Figure 324).

Most respondents felt that the cards provided a good overview and background of the design representations. They felt that it was a good way to standardise terms and providing them with a clear definition. Some respondents felt that more information could be provided. For instance, one of them suggested that the cards could also show the media used for creating a particular sketch.

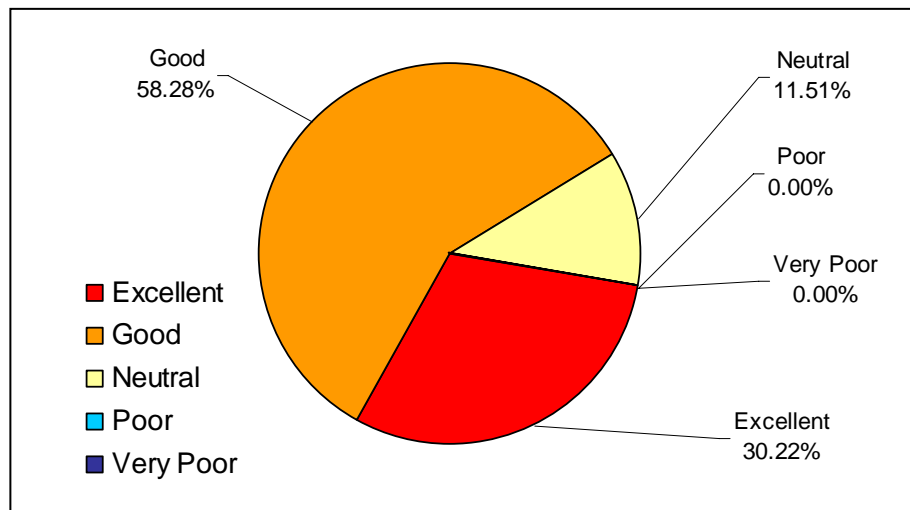


Figure 324: Results of Question 4 from the industrial design and engineering design practitioners

In the fifth question, the practitioners were asked if the cards had provided them with a common understanding of design representations between industrial designers and engineering designers. From the median scores of the industrial design and engineering design practitioners' responses, 11 of them (25.8%) responded excellent, 26 (60.15%) responded good, 4 (9.3%) responded neutral, 2 (4.75%) responded poor and none responded very poor (Figure 325).

Most respondents felt that the combination of pictures and words was a good way to convey the definition of each representation. One respondent felt that it was more effective than using a traditional textbook. Another respondent felt that there should be more images to provide a better understanding instead of just one image.

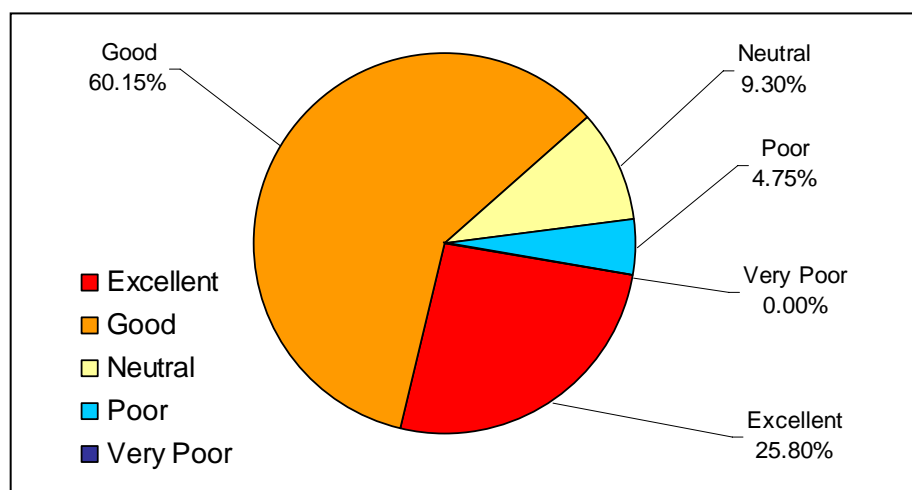


Figure 325: Results of Question 5 from the industrial design and engineering design practitioners

In question 6, the practitioners were asked how they rated the use of bar charts to show key design and technical information. The purpose was to find out whether the bar charts could be easily understood. From the median scores of the industrial design and engineering design practitioners' responses, 12 of them (27.9%) responded excellent, 22 (51%) responded good, 8 (18.8%) responded neutral, 1 (2.3%) responded poor and none responded very poor (Figure 326).

The use of bar charts was seen as a good way of visualising the data. However, a number of participants felt that having both numbers and bars was not necessary and might be confusing. Another respondent felt that more explanation could be provided to explain what the bars and numbers meant.

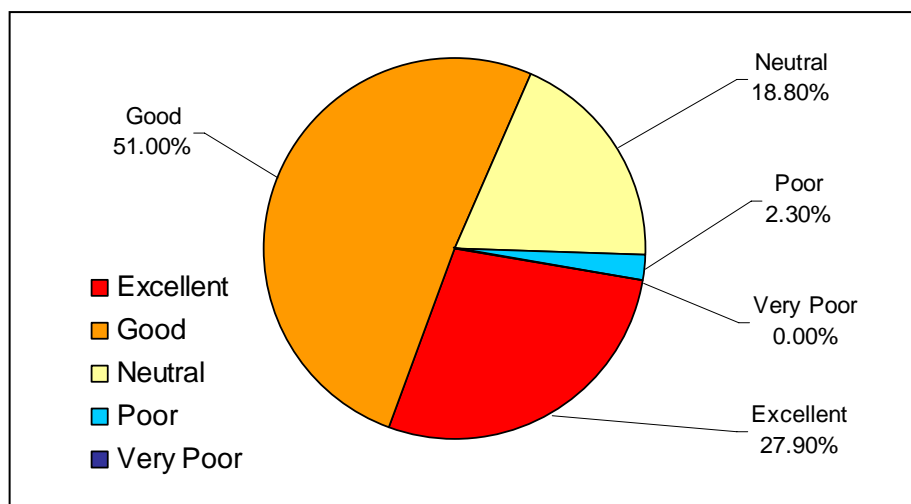


Figure 326: Results of Question 6 from the industrial design and engineering design practitioners

Question 7 asked the practitioners to rate the ability of the cards to help them identify the representation most commonly used during different stages of the design process. From the median scores of the industrial design and engineering design practitioners' responses, 12 of them (28.1%) responded excellent, 26 (60.35%) responded good, 5 (11.55%) responded neutral, none responded poor and none responded very poor (Figure 327).

Most of the respondents did not have problems identifying representations used during the different stages of the design process. Although some of them felt that it would be irrelevant for more experienced users, most of the respondents felt that it would be useful for younger practitioners or other less experienced members of the design team or even students.

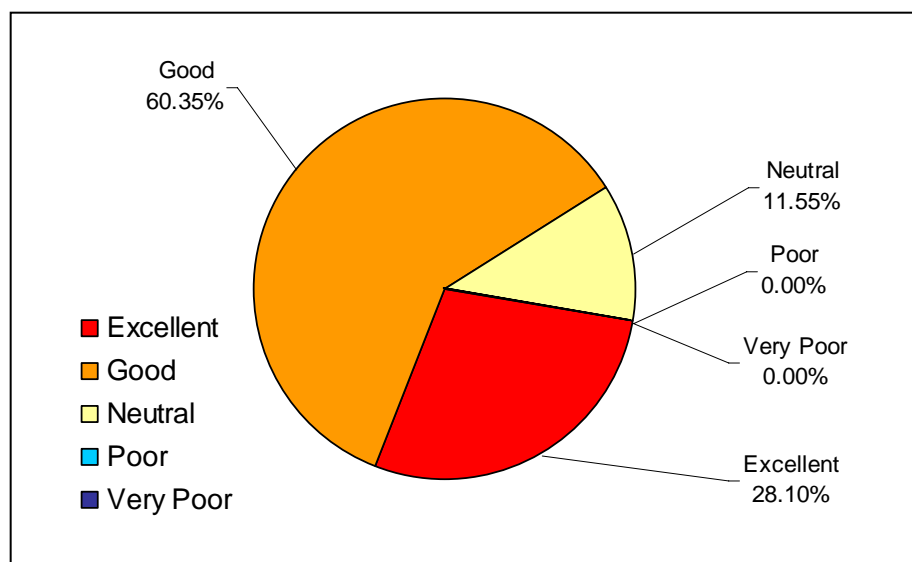


Figure 327: Results of Question 7 from the industrial design and engineering design practitioners

Question 8 asked the practitioners how they felt about the cards to foster enhanced collaboration between industrial designers and engineering designers. From the median scores of the industrial design and engineering design practitioners' responses, 6 of them (14.05%) responded excellent, 23 (53.3%) responded good, 13 (30.4%) responded neutral, 1 (2.25%) responded poor and none responded very poor (Figure 328).

Some of the respondents replied that the cards would help industrial designers and engineering designers to understand their differences and would be especially useful for new members of a design team. One participant found that it would be useful before a project had started so as to foster a common ground among the members early in the process. Another participant mentioned that the cards were too tedious to use by having to find each card individually.

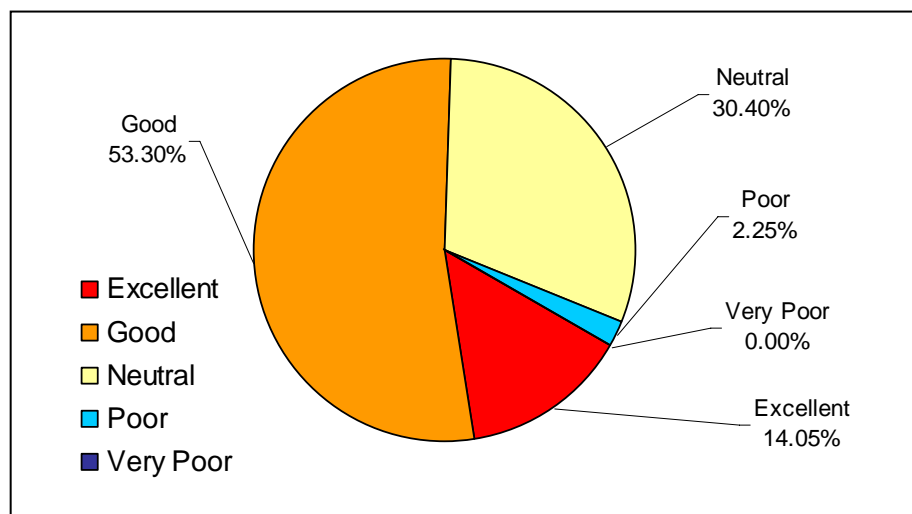


Figure 328: Results of Question 8 from the industrial design and engineering design practitioners

Question 9 asked the practitioners about the ability of the cards to improve design collaboration among themselves and other industrial designers / engineering designers. From the median scores of the industrial design and engineering design practitioners' responses, 7 of them (16.55%) responded excellent, 27 (62.6%) responded good, 8 (18.6%) responded neutral, 1 (2.25%) responded poor and none responded very poor (Figure 329).

Most of the respondents felt that the cards were useful as a communication platform. It would allow clarification, sharing of knowledge and to define one's role and responsibilities. Some respondents who were more experienced in their field, felt that the cards might not be useful as they already had a good knowledge of their work.

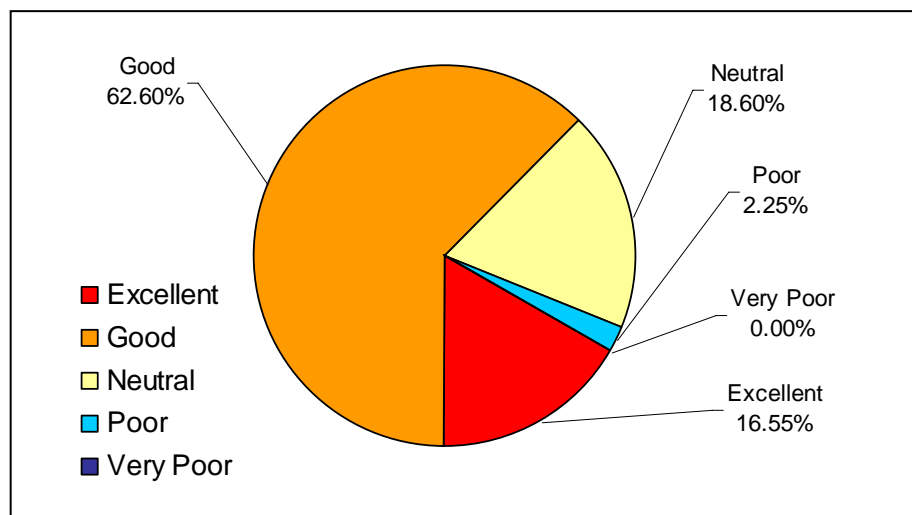


Figure 329: Results of Question 9 from the industrial design and engineering design practitioners

Question 10 asked for a general feedback regarding suggestions or improvements for the cards. One suggestion was to sort the cards into a format that might apply to non-mechanical, electronic, furniture, etc. products. Another respondent felt that there was too much information and the use of colour coding would improve the identification for each card content. The respondent also suggested using key words and bullet points for the



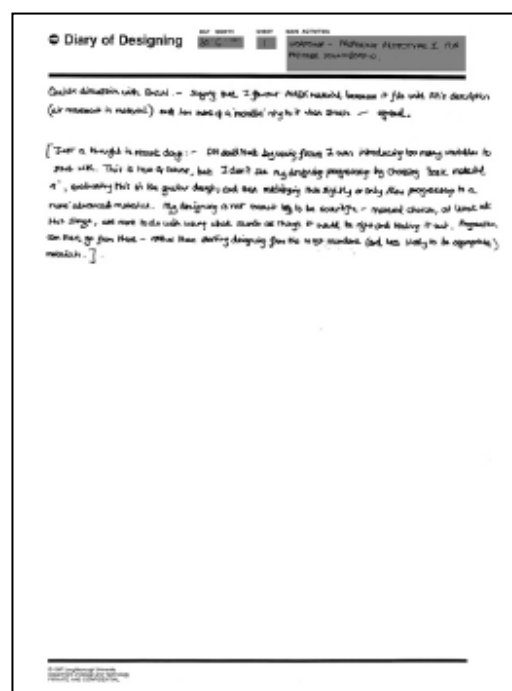
definitions. Another respondent suggested an instruction sheet to show how the cards could be used. Another respondent felt that the cards were interesting and had educational use. However, it might not be useful for those who have work experience. It was argued that the cards would not only be used by senior practitioners but by all levels.

A significant difference between the industrial design and engineering design respondents can be observed in question 5 that asked if the cards had provided both disciplines with a common understanding of design representations. While 13.6% of the industrial designers responded excellent, more than one-third of engineering designers (38%) responded excellent to the question. Another significant difference in responses can be observed in question 9. It asked the practitioners how they felt about the ability of the cards to foster enhanced collaboration between industrial designers and engineering designers. Although only 9.1% of the industrial designers gave an excellent rating, a large percentage of 24% of the engineering designers responded excellent. In summary, the results indicated most practitioners were positive that the CoLab system would provide a common ground in design representations, contributing to enhanced collaboration.

## **10.6 Data Collection with Case Study**

The purpose of the case study was to gain an insight on how CoLab might be used during a real-life situation. The case study also aimed to verify if the system would lead to a standardised understanding of design representations among members of a design project. Case studies have been employed by researchers including Kleinsmann (2006) who investigated how actors in a collaborative design project performed. Patton (1990) and Hamel, *et al.* (1993) also cited that using case studies allowed the researcher to gain a deeper insight into a particular issue. Similarly, Verschuren and Doorewaard (1999) stated that a case study would allow researchers to obtain a profound understanding of the processes involved. According to Yin (1989), a case study is an empirical approach for investigating a phenomenon within its real-

life context when there is little control over the activities that take place. A case study may comprise two sources of evidence by means of direct observation and systematic interviewing. For this case-study, the researcher took on a participant-observation approach that was used during the first round of empirical research (Section 5.4).



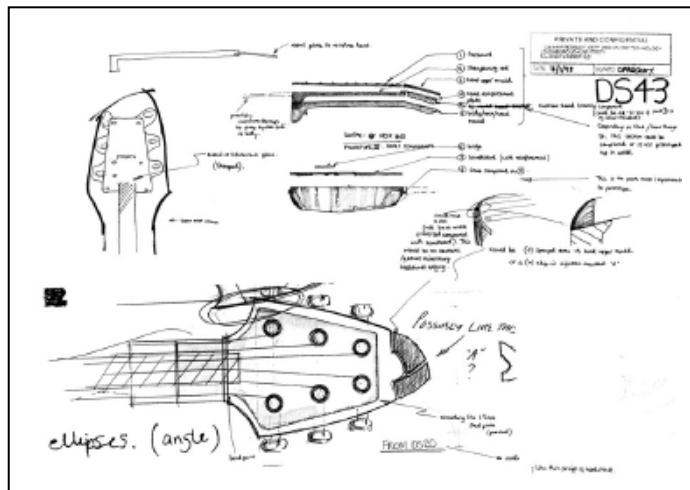


Figure 331: The design diary format by Pedgley (2007)

By comparing both formats, Pedgley found that the retrospective format was less disruptive and more effective. In addition, the activities of a day's work would still remain fresh in the mind. Using diaries as a means to record data has been acknowledged by academics to be a successful research tool and is identical to a self-administered questionnaire in providing an account or a reflection of their experiences (Robson, 1993). The drawback is that such diaries would be ineffective to 'reveal trains of thought' during designing (Ericsson and Simon 1993).

The two-week case-study was used to test the CoLab cards involving an industrial design consultancy that employed 12 staff. The case-study involved the design of a consumer earphone from the concept design to embodiment design phase. To enhance reliability of the findings, the same industrial design consultancy that was observed during the first round of empirical research was approached. This allowed the same project members to have a better grasp of the research and they were more comfortable when discussing issues with the same investigator. This has been cited by Stake (1995) that the selection of participants should include easy and willing subjects so that it maximises what can be learned from a limited amount of time. In this case, the CoLab cards were made available in the design studio and recordings were made through a design diary at the end of the day to minimise disruption.

At the end of each day, the industrial designers, engineering designers and design manager were informally interviewed (refer to Tables 60, 61).

No.		Participant Code	Company	Profession
1.	ID	R7-1	Company 1	Industrial Designer
2.	ID	R7-2	Company 1	Industrial Designer
3.	ED	R7-3	Company 1	Engineering Designer
4.	M	R7-4	Company 1	Project Manager

Table 60: Case study statistics

Details of Case Study R7	
Total number of participants	4
Industrial designers observed	2
Engineering designers observed	1
Project Managers observed	1


	Industrial Designer		Engineering Designer
	Project Manager		

Table 61: Description of case study respondents Interviewed

The design diary (Figure 332) was sectioned into two parts. The first section asked ‘what happened today?’ and the second section asked whether the CoLab cards were used or if there were any interactions, events or actions worth noting (Figure 333). Having blank spaces in the diary allowed for notes or sketches to be made. Entries made on the design diary can be found in Appendix 13.14.



Figure 332: Cover of the design diary

<b>Design Diary</b> <b>End-of-the-Day Diary</b>		 <b>Design Representation Quality Management</b> <small>Eugin Pei Loughborough University Department of Design &amp; Technology</small>
Diary Log No: _____ Date: _____ Location: _____ People involved: _____		
<b>What happened today?</b> Points of day's main activities: <div style="border: 1px solid black; height: 100px; margin-top: 5px;"></div>		
<b>Use of Design Representation cards:</b> Any interactions / events related to the use of cards / feedback? <div style="border: 1px solid black; height: 150px; margin-top: 5px;"></div>		

Figure 333: Layout of the design diary showing the 2 boxed sections

During the observation, it was noted that the cards were well received. They were widely used as a clarification tool during the design process. By the end of the second week, it became clear that both industrial designers and engineering designers were using identical keywords from the cards to minimise misunderstanding. The observations reinforced the interview findings that CoLab could support collaboration in a multi-disciplinary workspace through a common ground and a shared knowledge of design representations. A more detailed chronological observation of the findings shall now be discussed.

#### **10.6.1 Case Study Records**

The following pages summarise events recorded from the design diary.

##### **Day One:**

The design brief was issued by the project manager to the industrial designer and engineering designer. During this time, they looked at the design brief and discussed the technical specifications. Work on the first day centred on clarifying the project deliverables.

##### **Day Two:**

The industrial designers started work on a mood board with simple sketches over a brainstorming session. These marks on paper were recognised as Idea Sketches (Figures 334, 335). It was also observed that the discussions between the industrial designer and engineering designer were mostly related to technical issues concerning the product.

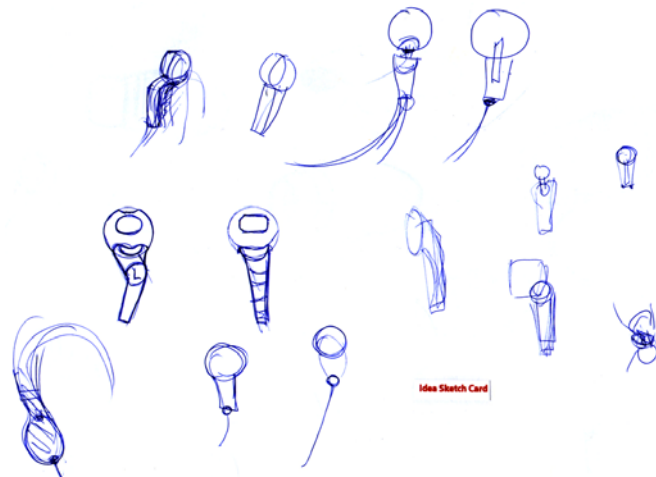


Figure 334: Idea Sketches observed during the case study

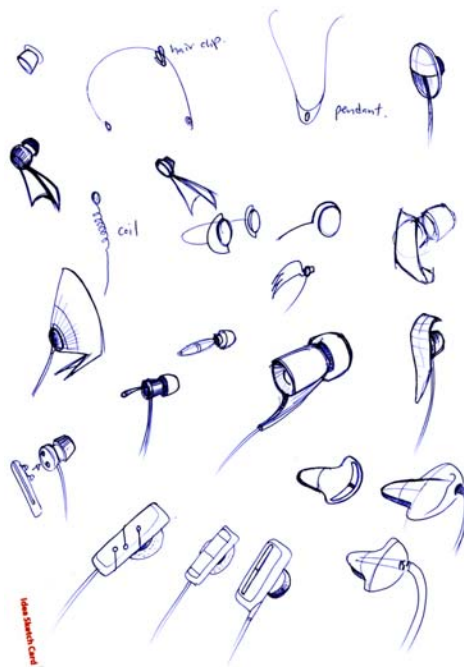


Figure 335: Idea Sketches observed during the case study

### Day Three:

On the third day, the CoLab cards were formally introduced to the design team. They were briefed about the research and observation process and told that the researcher would be involved as an observer-participant.

The engineering designer commented that he did not have a profound knowledge of the industrial design process and the cards seemed to be useful.

However, he said that the cards might get mixed up or misplaced when in use. The industrial designer also commented that the cards system seemed to be useful for reference and he could learn more about the differences of both disciplines. He wished that there would be a digital version available. Work continued and it was observed that Study Sketches (Figures 336 - 341) were used. In one of the sketches, the industrial designer had placed images for reference and they were recognised as Referential Sketches (Figure 342).

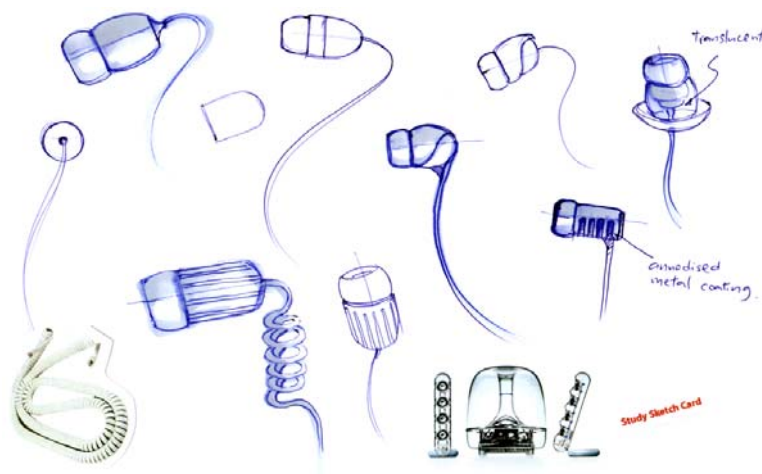


Figure 336: Study Sketches observed during the case study

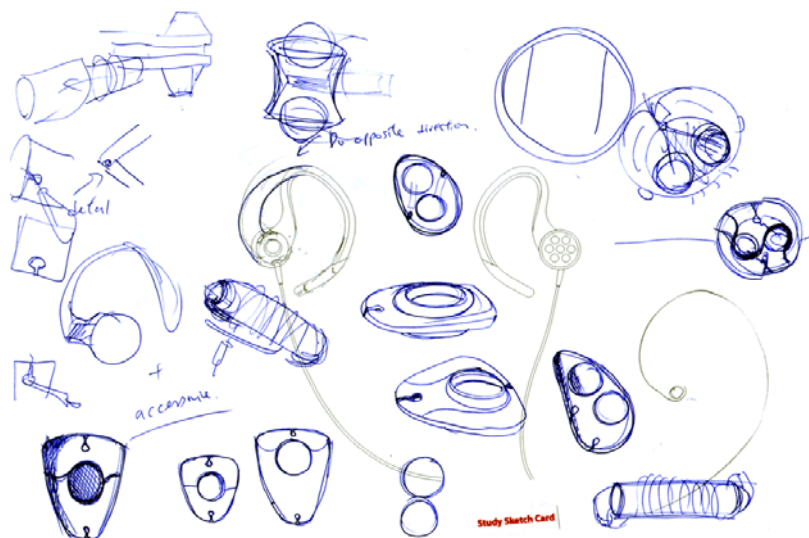


Figure 337: Study Sketches observed during the case study



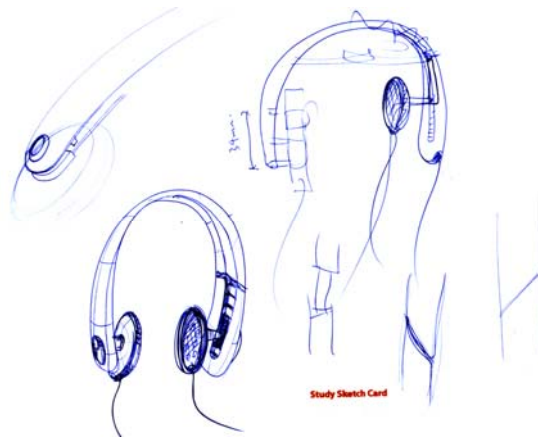


Figure 338: Study Sketches observed during the case study

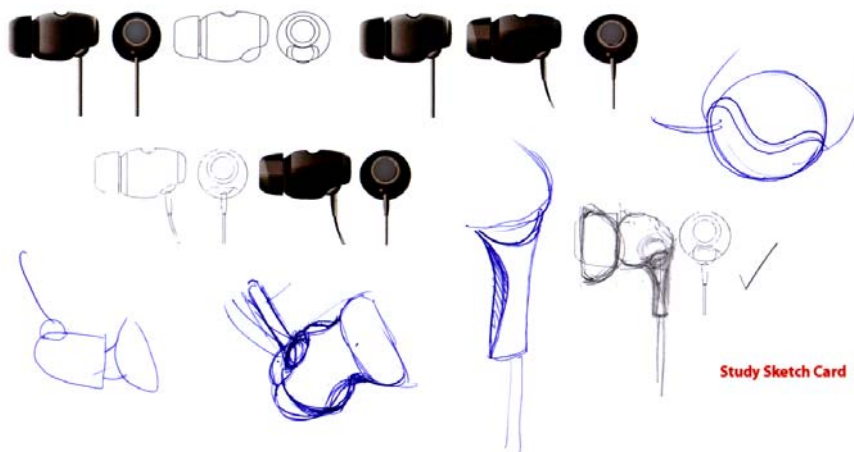


Figure 339: Study Sketches observed during the case study

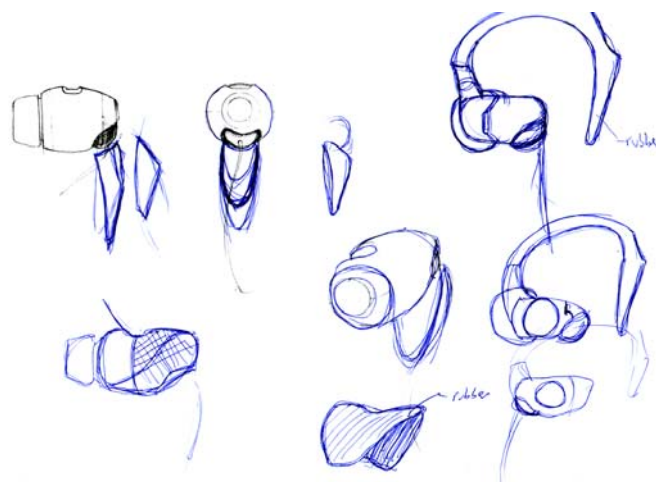


Figure 340: Study Sketches observed during the case study

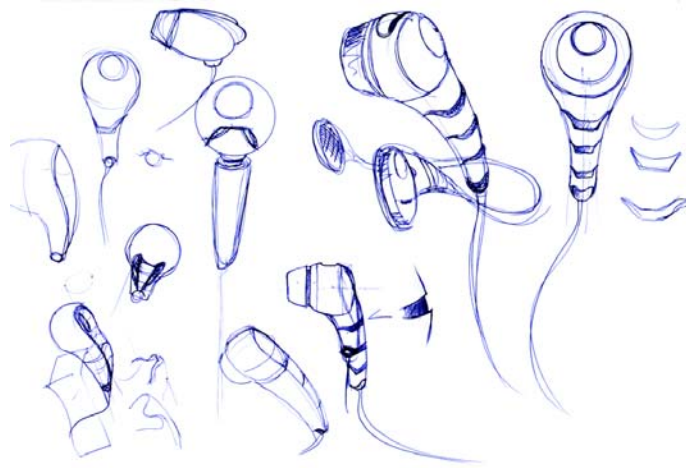


Figure 341: Study Sketches observed during the case study

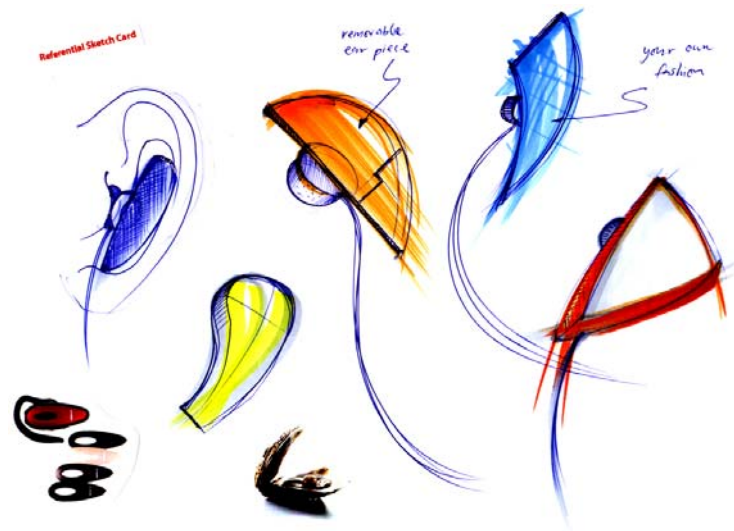


Figure 342: Referential Sketches observed during the case study

#### Day Four:

On the fourth day, the project manager decided that some of the initial concepts were to be developed further. Although the engineering designer was present at the meeting, he did not comment on the technical feasibility of the concepts as it was still in the early stages. The chosen concepts were translated into a more refined sketch with use of markers and text annotations. They were recognised as Information Sketches (Figures 343, 344) that was sent to the client for initial feedback.

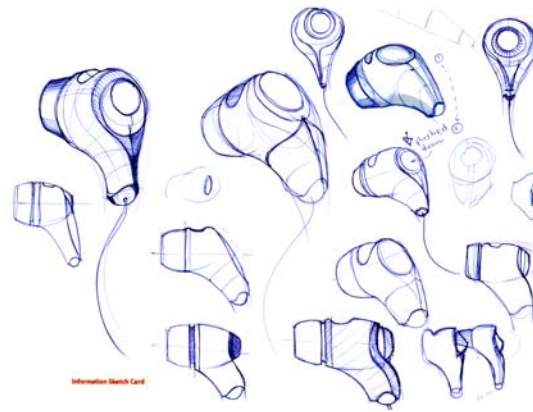


Figure 343: Information Sketches observed during the case study

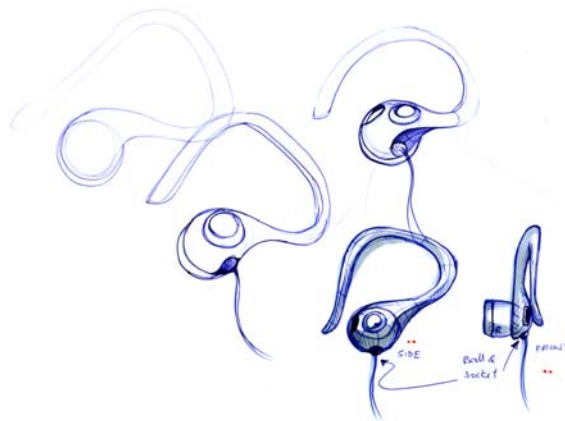


Figure 344: Information Sketches observed during the case study

### Day Five:

The client shortlisted several promising concepts. Improvements were made and they were redrawn more accurately to scale with dimensions. These were recognised as Prescriptive Sketches (Figures 345, 346).

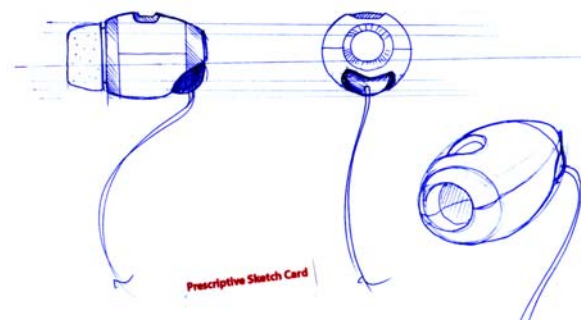


Figure 345: Prescriptive Sketches observed during the case study

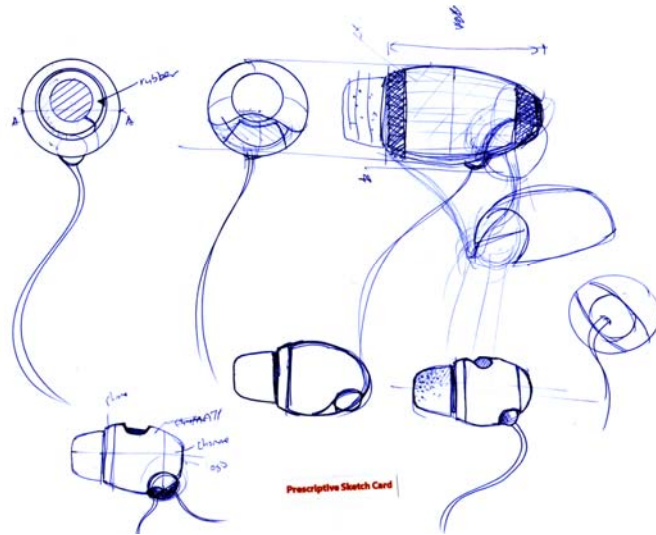


Figure 346: Prescriptive Sketches observed during the case study

### Day Six:

Concept development work continued and there was now more emphasis on the use of markers to show shading, reflections and colour. The industrial designer used the CoLab cards to find out which representations were used during the concept development stage. When looking back at the sketches he had created, the cards confirmed that Idea and Study Sketches were used at the concept design stage, while Information Sketches (Figures 347 - 349) and Prescriptive Sketches were employed during the concept development stage.



Figure 347: Information Sketches observed during the case study



Figure 348: Information Sketches observed during the case study

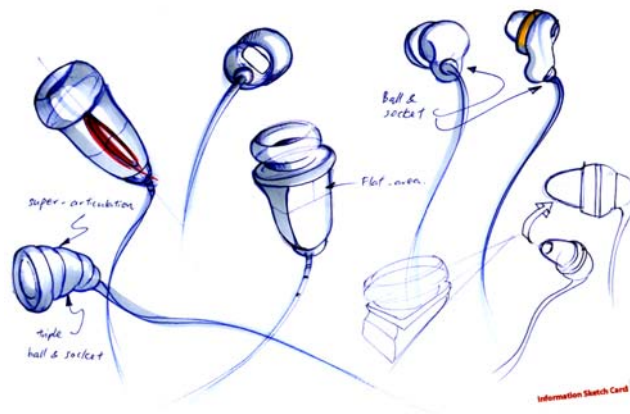


Figure 349: Information Sketches observed during the case study

### Day Seven:

Before the sketches could be handed over to the engineering designer, the industrial designer had to translate his concepts to allow the engineering designer to visualise them clearly. Therefore, the Information Sketches were translated into a more defined sketch – a Prescriptive Sketch. The industrial designer wanted to know which design representation would most appropriately show dimensions. By referring to CoLab, he confirmed that Prescriptive Sketches would be most appropriate. These sketches were converted into a line-art using Adobe Illustrator. They were now recognised as Multi View Drawings (Figure 350), making the transition from sketches to drawings.



Figure 350: Multi View Drawings observed during the case study

### Day Eight:

The use of colour was added to the Multi View Drawings, converting the representations into Concept Drawings. The Concept Drawings emphasised texture, material and finishing of the product (Figure 351). As one of the concepts required more explanation, the industrial designer decided to create a simple rough physical model. This model was recognised as a functional concept model (not shown). Looking at the CoLab cards, it confirmed that the functional concept models were commonly used during the concept development stage of the design process.



Figure 351: Concept Drawings observed during the case study



### Day Nine:

The project manager used the Multi View Drawings as a template to show where the changes should be made to the design (Figures 352, 353). The industrial designer wanted to find out how he could show the mechanism of his concept. By referring to the CoLab cards, it showed Information Sketches would be most appropriate. However, the industrial designer realised that the Information Sketches would be difficult for the engineering designer to visualise. By looking at the CoLab cards, he found Prescriptive Sketches to be the most appropriate choice. At this point in time, the engineering designer confirmed by replying to the industrial designer that he was looking forward to the 'Prescriptive Sketches'. This clearly reflected that both industrial designer and engineering designer now adopted a common language through the use of CoLab cards.

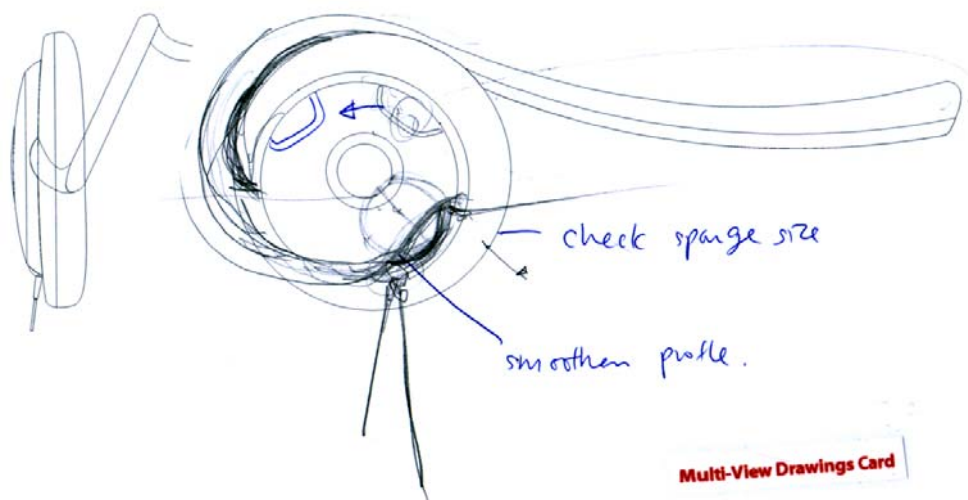


Figure 1: Multi View Drawings observed during the case study

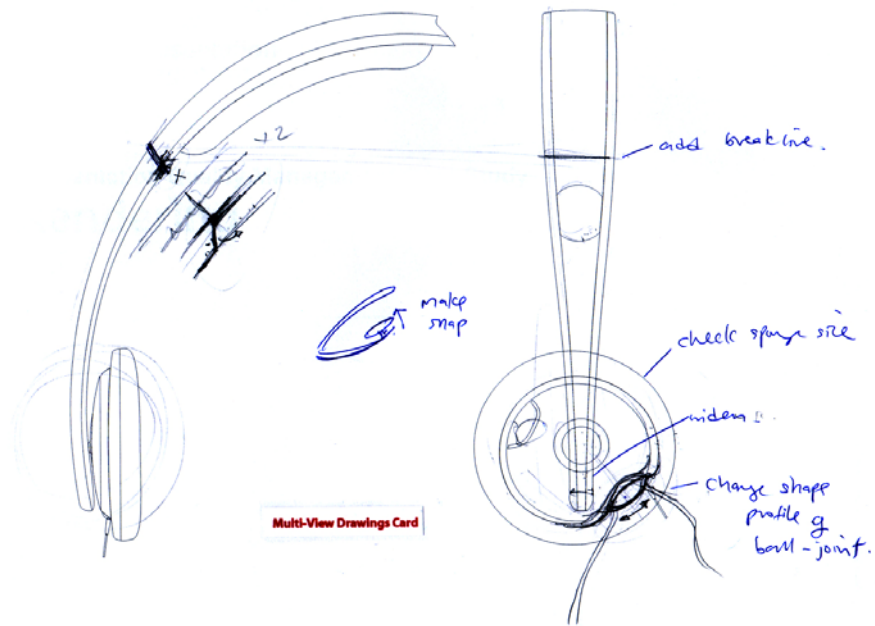


Figure 2: Multi View Drawings observed during the case study



**Day Ten:**

Work continued on the Concept Drawings (Figure 354).

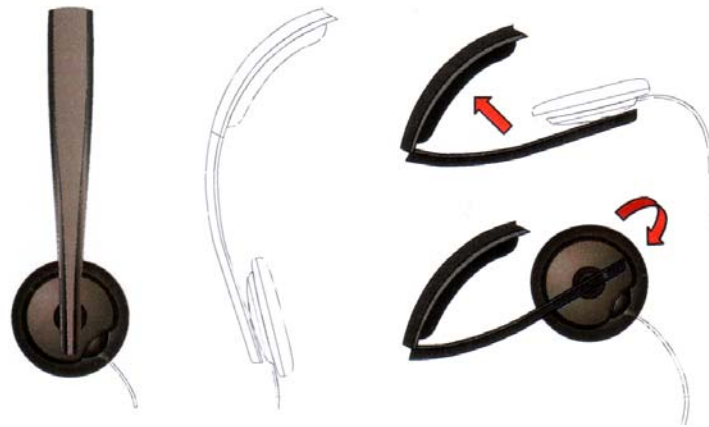


Figure 354: Concept Drawings observed during the case study

**Day Eleven:**

At this point, the Concept Drawings were nearing completion. They showed multi views, form and detail, colour and texture and finishing in the drawings. Referring to the CoLab cards confirmed that all of these elements were present in Concept Drawings. It also showed that the CoLab system could be used as a checklist to ensure that the elements of a design representation would be accurately represented.

**Day Twelve:**

The Concept Drawings were put together as a Presentation Drawing. The final artwork was then printed and ready for the client. The final artwork cannot be shown because of project confidentiality.

**Day Thirteen:**

The client presentation took place and from the initial feedback, the client was generally very pleased with the deliverables and the final decision was subsequently made known.

### **10.6.2 Case Study Discussion**

From the two-weeks of case-study, it became evident that the CoLab system was well received by the participants. The industrial designer and engineering designer gave a positive rating and agreed that the cards had enhanced collaboration among them. The case study confirmed that CoLab fostered a standardised understanding of design representations. Towards the second week, both industrial designers and engineering designers had used the same terms learnt from the cards (e.g. Prescriptive Sketch) which minimised misunderstanding. CoLab was also used as a reference tool and a checklist during the design process. The validation confirmed that the Idea Sketches, Study Sketches were widely used during the initial stages of concept design. Similarly, it also confirmed that Concept Drawings, Information Sketches, Prescriptive Sketches and Presentation Drawings were used during the concept development stages of the design process, and that Functional Concept Models, Concept Drawings, Multi View Drawings and Presentation Drawings were employed during the embodiment design stage.

### **10.7 Final Card Design**

Following pilot study and validation, it was decided that the cards could be improved in several areas. A thinner paper would be used as the current grade (120gsm) was too thick. When put together, a thinner grade (80gsm) would make the pack less bulky. Secondly, to prevent the cards from being mixed up, a decision was made to punch a hole at the top left-hand corner (refer to Figure 355 no. 1) for the cards to be secured together with a ring (Figure 356). Next, because some words were at a 90° orientation that made reading difficult, it was decided to orientate all text at a uniform angle (refer to Figure 355 no. 2). Fourthly, it was found that the numbers next to the bar charts did not have a clear meaning. A decision was made to redesign this (refer to Figure 355 no. 3). Next, the bar chart and its corresponding number would be merged into a single entity. The bar chart would be removed to allow for more text (refer to Figure 355 no. 4).

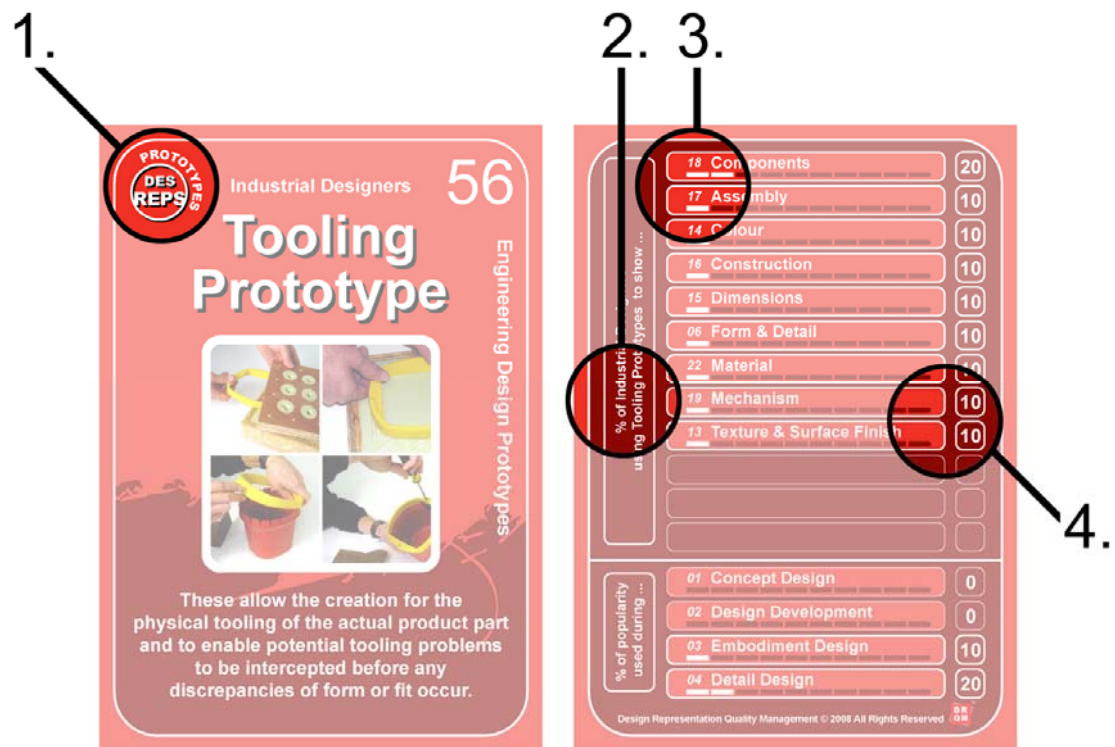


Figure 355: Changes to the card design



Figure 356: The new design allows the cards to be secured together

A decision was made to ensure that the information contained in each card could be easily identified. Colour coding was proposed as a solution (Figures 357, 358). The colour scheme would still be limited to a red hue for industrial designers and a blue hue for engineering designers.

Suggested New Colour Scheme



Figure 357: Suggested colour scheme for cards

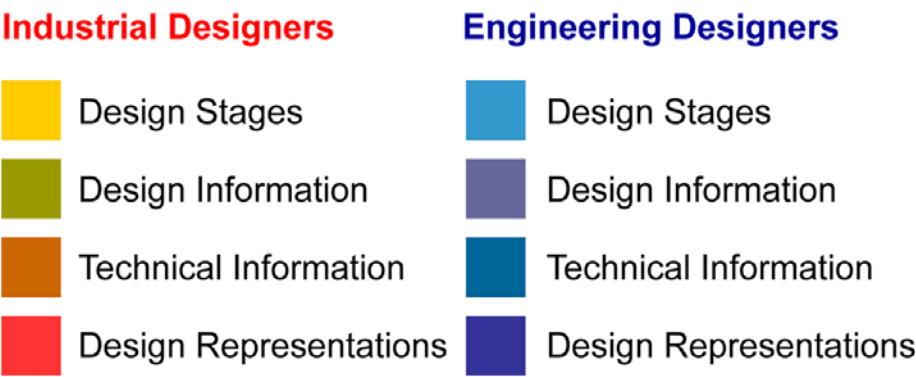


Figure 358: Representative colour scheme for cards

However, it was felt that having eight different colours was confusing and the original two colour (red and blue) scheme was retained. To distinguish the four packs of cards (Design Stages, Design Information, Technical Information, Design Representations), a coloured tab will be located at the bottom of each card, signifying the design stage in orange, design information in green, technical information in grey and design representations in purple (Figures 359, 360). The structure of the coloured tabs is shown in Figures 361 and 362. The overall summary of improvements made to the cards can be seen in Figure 363. An overall view of the card system can be found in Figure 364, while each of the final design of the cards may be found in Appendix 13.15. The breakdown of the CoLab cards is shown below in Table 62.

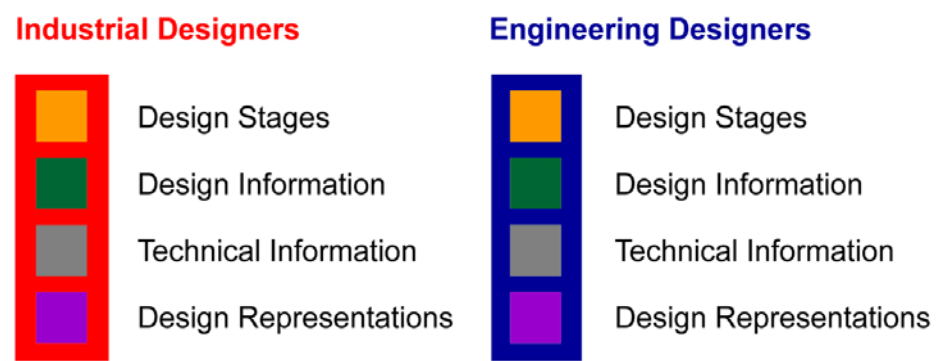


Figure 359: New representative colour scheme for cards

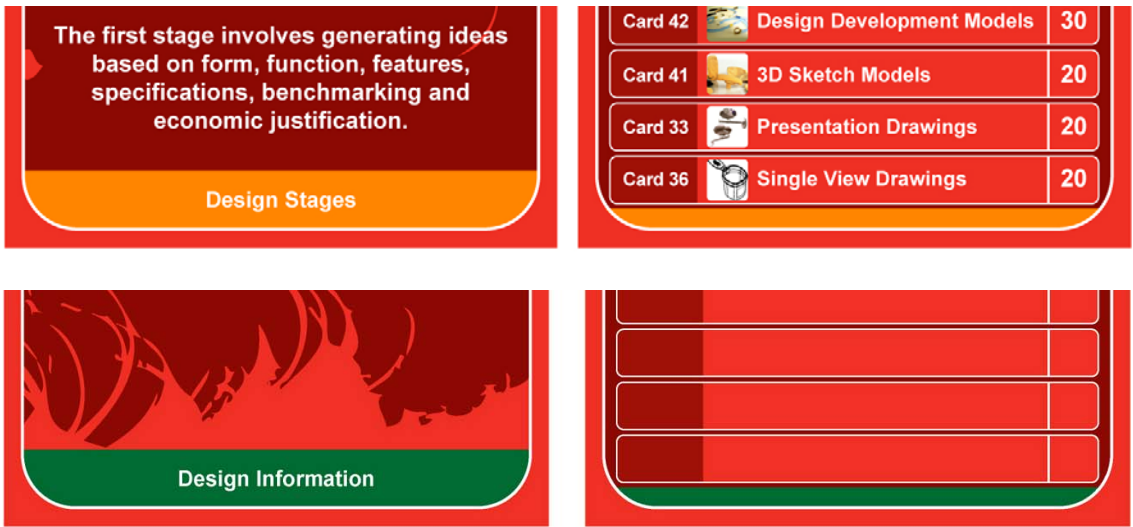


Figure 360: Examples of the coloured tabs



# One Box of CoLab Cards

## Red Set      Blue Set



### 4 Packs of Red Cards

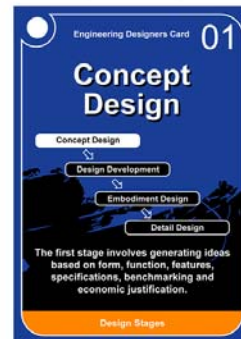
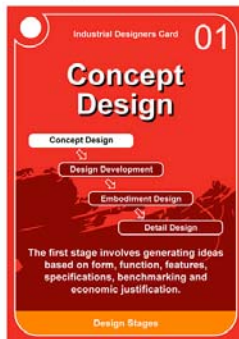
### 4 Packs of Blue Cards

design stages

design information

design stages

design information



technical  
information

design  
representations

technical  
information

design  
representations

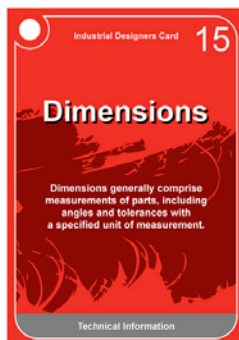


Figure 361: Structure of the coloured tabs for the 4 packs



Figure 362: Final design showing coloured tabs for the 4 packs

Summary of general improvements made to the cards as shown in Figure 415.

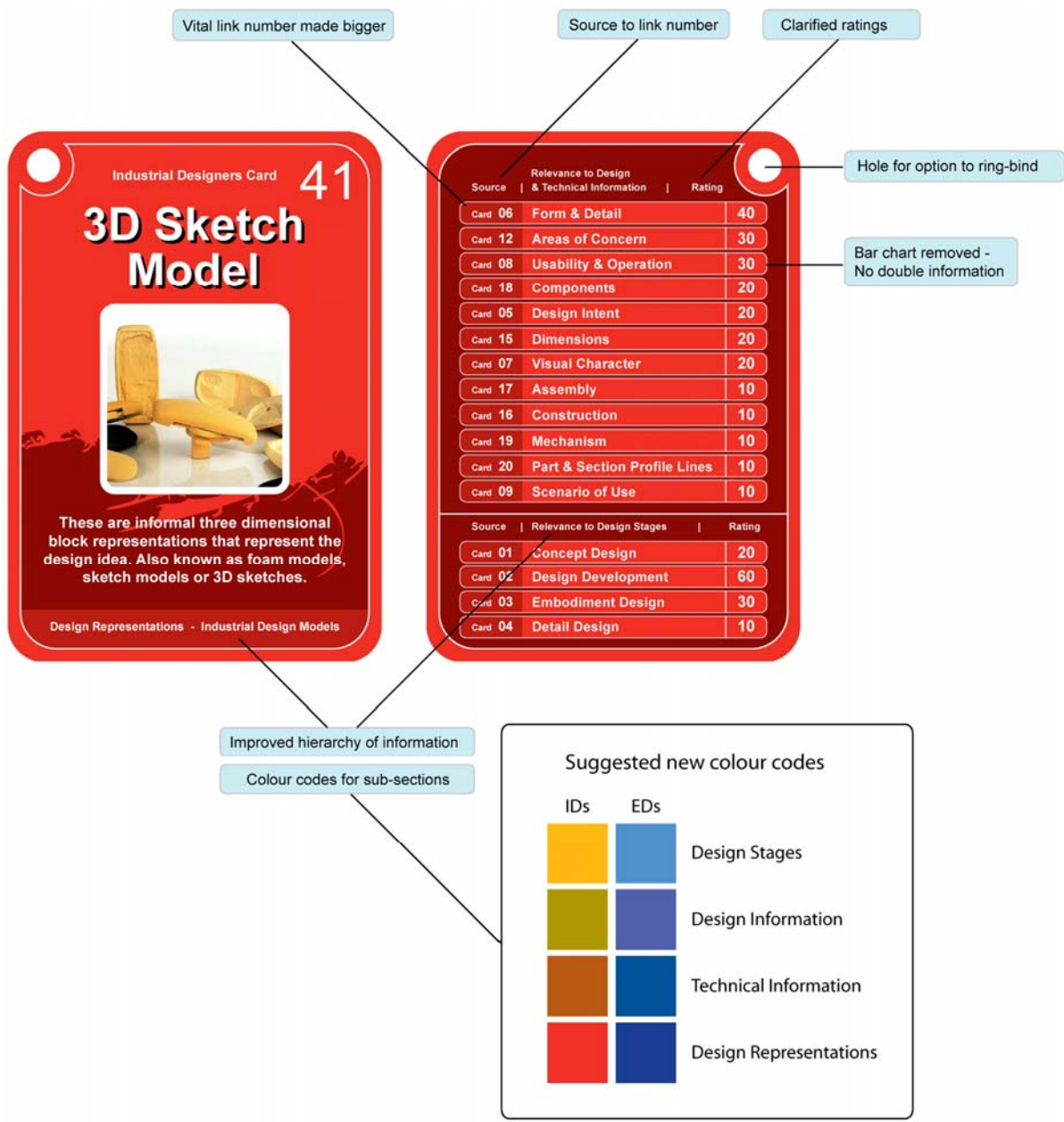


Figure 363: Summary of improvements



## Design Stages



## Design Information



## Technical Information



## Design Representations: Sketches



## Design Representations: Drawings



## Design Representations: Models



## Design Representations: Prototypes



Figure 364: The overall card system

1	<b>Design Stages (Total: 4)</b>	1	Concept Design
		2	Concept Development
		3	Embodiment Design
		4	Detail Design
2	<b>Design Information (Total: 10)</b>	1	Design Intent
		2	Form and Detail
		3	Visual Character
		4	Usability and Operation
		5	Scenario of Use
		6	Single Views
		7	Multi Views
		8	Areas of Concern
		9	Texture and Surface Finish
		10	Colour
3	<b>Technical Information (Total: 8)</b>	1	Dimensions
		2	Construction
		3	Assembly
		4	Components
		5	Mechanism
		6	Part and Section Profile Lines
		7	Exploded Views
		8	Material
4	<b>Sketches (Total: 9)</b>	1	Idea Sketch
		2	Study Sketch
		3	Referential Sketch
		4	Memory Sketch
		5	Coded Sketch
		6	Information Sketch
		7	Renderings
		8	Inspiration Sketch
		9	Prescriptive Sketch
5	<b>Drawings (Total: 9)</b>	1	Concept Drawings
		2	Presentation Drawing
		3	Scenario & Storyboard
		4	Diagram
		5	Single-View Drawing
		6	Multi-View Drawing
		7	General Arrangement Drawing
		8	Technical Drawing
		9	Technical Illustration
6	<b>Models (Total: 8)</b>	1	3D Sketch Model
		2	Design Development Model
		3	Appearance Model
		4	Functional Concept Model
		5	Concept of Operation Model
		6	Production Concept Model
		7	Assembly Concept Model
		8	Service Concept Model
7	<b>Prototypes (Total: 9)</b>	1	Appearance Prototype
		2	Alpha Prototype
		3	Beta Prototype
		4	Pre-Production Prototype
		5	Experimental Prototype
		6	System Prototype
		7	Final Hardware Prototype
		8	Tooling Prototype
		9	Off-Tool Prototype

Table 62: Breakdown of cards

## **10.8 Chapter Summary**

The first section of the chapter described the design refinements that were undertaken by first increasing the size to ISO B8, allowing for larger images and text. Each definition was also rephrased for clarity and the background was improved with a more consistent colour. More importantly, a numerical system was put in place, allowing users to identify each card with a unique number. The 114 cards (57 for industrial designers and 57 for engineering designers) were subjected to a vigorous three-phase validation. The first phase involved interviews with 18 final-year undergraduate students from industrial design and engineering design departments who had worked together on a recent industrial project, while the second phase involved interviews with 43 industrial design and engineering design practitioners and academics. From the interview findings, CoLab received a very positive response. In the third phase, the CoLab cards were validated with an industrial design consultancy involving a real-life project. CoLab was very well received and found to have provided a standardised understanding of design representations to the industrial designers and engineering designers during design practice. The cards were observed to be used as a source of reference and as a checklist. In summary, findings from the interview and case study validation provided evidence to show that CoLab had supported collaboration in a multi-disciplinary workspace by means of forging a common ground and building a shared knowledge of design representations.

Following validation, several final improvements were made. A thinner grade of paper reduced the bulk of the cards, a hole punched on the top-left corner now allowed the cards to be secured, the orientation of the text was made uniform, the bar charts were removed and a coloured tab would now allow the four sets of cards to be easily identified (Figure 365). A summary of the four distinct sets of cards are presented in Figures 366 to 369.

The next chapter shall discuss how the research objectives have been met during the course of research and attempts to answer the research questions.

It also discusses the limitations to the research and states the contributions that have been made, ending with suggestions for future work.



Figure 365: Final design of the CoLab cards



## 1. Design Stages Pack

The design stages pack consists of four industrial design cards and four engineering design cards.

### Design Stages (4 x 2)

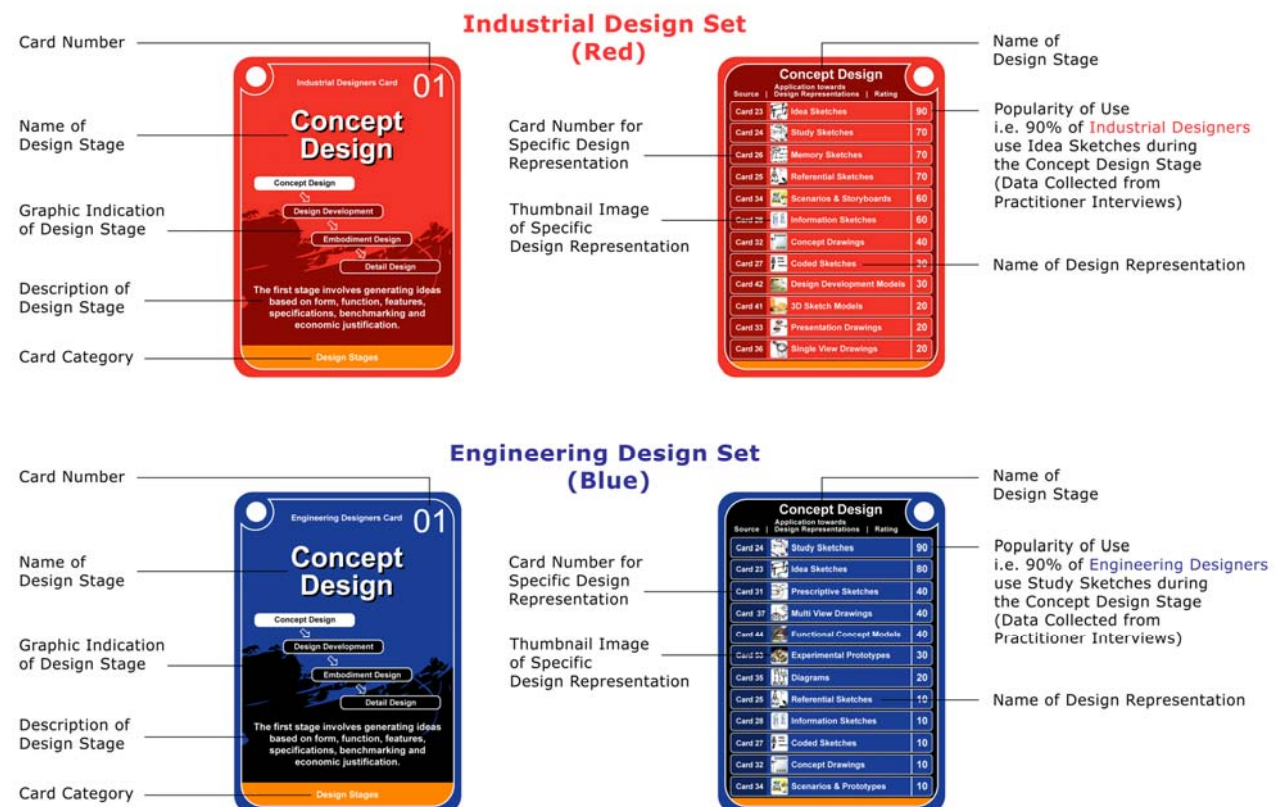


Figure 366: Explanation of the Design Stages pack

## 2. Design Information Pack

The design information pack consists of ten industrial design cards and ten engineering design cards.

### Design Information (10 x 2)



Figure 367: Explanation of the Design Information pack

### 3. Technical Information Pack

The design stages pack consists of eight industrial design cards and eight engineering design cards.

## Technical Information (8 x 2)



Figure 368: Explanation of the Technical Information pack

#### 4. Design Representations Pack

The design stages pack consists of 35 industrial design cards and 35 engineering design cards. Of these, there are nine cards concerning sketches, nine concerning drawings, eight concerning models and nine concerning prototypes.



Figure 369: Explanation of the Design Representations pack



## 11. CONCLUSION

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### ***11.1 Summary of Achievements***

The research has examined past studies concerned with design, industrial design, engineering design, collaborative work and design representations. Undertaking the literature review had two purposes. As well as identifying shortcomings in collaborative design research, the literature provided material for generating a taxonomy and in the production of the CoLab design tool.

From the first phase of empirical research, three problem areas among industrial designers and engineering designers during design practice were identified. There were conflicts in values and principles, differences in the use of design representations, and differences in education. Centring on the issue of design representations, a second phase of empirical research assessed how visual representations were used by the two disciplines during new product development. Using knowledge from the literature and data acquired from empirical studies, the CoLab system was developed to help industrial designers and engineering designers achieve a common vocabulary in design representations, creating shared knowledge and empathy towards their related yet distinct work practices. A pilot study was undertaken with industry practitioners that resulted in several improvements.

A final three-phase validation through interviews with practitioners, students, and an industry case study established the usability and efficacy of the design tool. The results showed that CoLab attained positive results (excellent + good) with 88.45% of the industrial design and engineering design practitioners and 92.2% of the industrial design and engineering design students indicating that the tool had built a common understanding in design representations (Question 4). In addition, when asked if the system would improve collaboration between themselves and other industrial designers / engineering designers (Question 9), a positive result (excellent + good) was obtained from 79.15% of the industrial design and engineering design

practitioners and 76.8% of the industrial design and engineering design students.

The next section discusses the research objectives that were identified at the start of this research and how they have been met. It also outlines the limitations of the research project and draws conclusions by stating new contributions to knowledge that have been made and to identify avenues for further work.

## ***11.2 Meeting the Initial Research Objectives***

The following section describes how the research objectives identified at the start of the research project (Section 1.5) have been addressed by means of the literature review.

1. To define the terms industrial design and engineering design.

Industrial design refers to the professional service of creating and developing concepts and specifications that optimise function, value and appearance of products and systems for the mutual benefit of both user and manufacturer (IDSA 2006). Engineering design refers to the technical activities that establish and define solutions to problems through applying scientific knowledge and ensuring that the product satisfies market needs, design specifications and is produced through optimum manufacture (Hurst 1999).

2. To understand collaboration within the context of new product development.

Collaboration is defined as a process where members from different disciplines work together with a common vision to achieve joint goals (Kahn 1996b; Tseng and Abdalla 2006). This takes place by leveraging the expertise and experience of multi-disciplinary members (Sprow 1992; Rothstein 2002). Collaborative design also requires members to create shared understanding and integrating their knowledge together (Kleinsmann 2006). Members must be focused with cooperation, communication and interaction in place (Persson

and Warell 2003c). In addition, there must be mutual sharing, understanding, having a common vision, seeking collective goals and a willingness to work together (Kahn and McDonough III 1997). Jasawalla and Sashittal (1998) added that the elements of at-stakeness, mindfulness, transparency and synergy are necessary for collaboration and this can be supported by synchronising tasks, effective planning and structuring of activities to build a shared perspective of the project (Chiu 2002; Lang *et al.* 2002; TCT 2004). According to Dougherty (1992b), knowledge creation and integration are the two key pillars of a collaborative process. Knowledge integration requires a shared understanding among members (Kleinsmann and Valkenburg 2005; Kleinsmann and Dong 2007; Kleinsmann *et al.* 2007) and having a common frame of reference when using visual design representations (Visser 2007).

3. To investigate issues and identify factors affecting collaboration between industrial designers and engineering designers in new product development.

With the exception of Persson (2002a), very little work has been done to investigate barriers influencing collaboration between industrial designers and engineering designers during new product development. Therefore, supplemental empirical research by means of semi-structured interviews and observations was undertaken to examine issues occurring between them. A total of 61 issues were identified, of which they were further clustered into three problem areas. More details of this objective has been addressed by answering the first research question (Section 11.3).

4. To determine if a common ground in visual design representations would support collaboration between the two disciplines.

Research by Persson (2002c) identified that design representations employed by industrial designers and engineering designers were different. In line with this research, Persson (*ibid*) verified that industrial designers preferred to use renderings and representative pictures, while engineering designers used verbal models and technical drawings. Acknowledging these differences,

other researchers proposed that having shared representations would enable a common frame of reference and allows multi-disciplinary members to work harmoniously (Ferguson 1992; Johansson *et al.* 2001; Do 2002; Buxton 2007). Logan and Radcliffe (2000) added that when design representations are collectively employed, it would build common reference points. Importantly, Goldschmidt (2007) stressed that design representations allow individual viewpoints to converge and members are able to look at issues on the same wavelength. Therefore, design representations have the potential to act as a mediator among disciplines (Heath and Luff 1991; Perry and Sanderson 1998; Gutwin and Greenberg 2002) and they are the foci for social interaction that supports collaborative work (Lakin 1990; Leonard-Barton 1991; Schrage 1993; Robertson 1996; Perry and Sanderson 1998; Eckert and Boujut 2003; Ulrich and Eppinger 2003; Olofsson and Sjölen 2005; Alisantoso *et al.* 2006). Thus, having a common ground in visual design representations bridges the gap between different perspectives and supports collaboration among multi-disciplinary members (Hack and Canto 1984). Lastly, a recent study by Kim and Kang (2008) confirmed that a unified culture with a common language and common geographic conditions were pillars for successful cross-functional teams.

### **11.3 Answering the Research Questions**

The research questions that were formulated for this project and their answers from the empirical studies are now discussed.

Q1. What factors most greatly affect collaboration between industrial designers and engineering designers in new product development?

Empirical research by means of semi-structured interviews with 31 industrial designers and engineering designers from 17 industrial design consultancies revealed 61 issues (Section 5.3.2). Of these, 19 problem areas were found to have occurred three or more times among the companies. Pattern coding simplified the 19 issues into larger categories and to seek an emergent theme. It was found that there were three key problem areas influencing collaboration

among industrial designers and engineering designers: 1) Conflict in values, principles and aims 2) Differences in design representations 3) Differences in education. The use of observations involving an industrial design consultancy over 2 weeks confirmed these problem areas to be present.

Findings from the empirical research established that engineering designers had a systematic way of doing things and their work was largely based on efficiency or cost. In contrast, industrial designers followed a more flexible and creative approach. These were examples of conflicts in values, principles and aims. The empirical research also identified that different design representations were used by industrial designers and engineering designers. For instance, engineering designers used technical specifications, while the industrial designers used ambiguous sketches and drawings to represent concepts. The dissimilar approach made communication and collaborative work difficult. These were examples of differences in design representations. Lastly, because of their different education backgrounds, both disciplines adopted different work approaches. The industrial designers were less familiar with group work while engineering designers often worked in groups. These were examples stemming from differences in their education background.

Q2. What visual design representations are used by both disciplines in the design process?

From the literature, 35 visual design representations were identified and categorised into four key groups: sketches, models, drawings and prototypes (Table 63). The description for each of the representations can be found in Section 7.3 (Sketches), 7.4 (Drawings), 7.5 (Models) and 7.6 (Prototypes). The information was confirmed by questioning the practitioners and academics by means of semi-structured interviews (Section 8.3).

Group	Sub-group	Visual Design Representation
Sketches	Personal Sketches	Idea Sketch Study Sketch Referential Sketch Memory Sketch
	Shared Sketches	Coded Sketch Information Sketch
	Persuasive Sketches	Renderings Inspiration Sketch
	Handover Sketches	Prescriptive Sketch
Drawings	Industrial Design Drawings	Concept Drawings Presentation Drawing Scenario & Storyboard
	Engineering Design Drawings	Diagram Single-View Drawing Multi-View Drawing General Arrangement Drawing Technical Drawing Technical Illustration
Models	Industrial Design Models	3D Sketch Model Design Development Model Appearance Model
	Engineering Design Models	Functional Concept Model Concept of Operation Model Production Concept Model Assembly Concept Model Service Concept Model
Prototypes	Industrial Design Prototypes	Appearance Prototype Alpha Prototype Beta Prototype Pre-Production Prototype
	Engineering Design Prototypes	Experimental Prototype System Prototype Final Hardware Prototype Tooling Prototype Off-Tool Prototype

Table 63: Visual design representation groups

Q3. Could a common ground in visual design representation support collaboration between industrial designers and engineering designers?

The CoLab card system was developed in order to provide information on the nature, role and significance of design representations (sketches, drawings, models and prototypes) used during new product development. The purpose was to facilitate the use of a common vocabulary when employing design representations, creating shared knowledge and empathy towards the related yet distinct working practices of industrial designers and engineering designers. Results from a pilot study and a rigorous three-phase validation involving 28 industrial designers and 36 engineering designers (practitioners, academics and students) revealed that the design tool was very well received. Having employed the cards, when asked if CoLab had built a common ground in design representations (question 5, Sections 10.4, 10.5), 85.95% of industrial design and engineering design practitioners gave a positive response (excellent + good), while 78.6% of the industrial design and engineering design students gave a positive response. When asked if the CoLab system (that aimed to achieve a common ground in design representations) would foster enhanced collaboration between the two disciplines (question 8, Sections 10.4, 10.5), 67.35% of industrial design and engineering design practitioners gave a positive response (excellent + good), while 92.9% of the industrial design and engineering design students gave a positive response. CoLab was very well received by the survey participants who found that the cards supported collaboration in providing a standardised understanding of design representations during design practice.

### ***11.4 Reliability of Research Results***

The research adopted a qualitative approach using interviews, observations and a qualitative analysis by means of pattern coding provided an understanding and insight into the research context. A quantitative analysis approach was used for tabulating, ranking and sorting the data by occurrence, categorising the information leading to an emergent pattern. Linking both

approaches was beneficial as the qualitative methods investigated the research in-depth while the quantitative approach confirmed the findings. A list of the various methods employed for this research is summarised in Table 64.

Data Collection / Analysis Method	Type	Section Reference	Description / Purpose
Qualitative Data Collection	Semi-structured Interviews	5.3	To identify factors influencing collaborative work between industrial designers and engineering designers
		8.3	To understand the application of design representations employed by industrial designers and engineering designers during new product development
		9.7	Pilot study on use of the CoLab cards
		10.4	Validation of CoLab cards with students
		10.5	Validation of CoLab cards with practitioners
	Participant observation	5.4	To confirm interview results of 5.3 and to obtain new findings.
Qualitative Analysis	Case Study with participant-observation	10.6	To gain an insight on how CoLab might be used during a real-life situation and to verify if the system would lead to a standardised understanding of design representations among members of a design project.
	Pattern Coding	5.3.2	To seek out and identify key problem areas from the interview results of 5.3
	Qualitative Analysis	5.4.2	To confirm interview results of 5.3 and to obtain new findings.
		9.7.1	Analyses findings of 9.7
		10.6.1	Analyses findings of 10.6
Quantitative Analysis	Tabulated Matrix	8.4	Analyses findings of 8.3
		10.4.1	Analyses findings of 10.4
		10.5.1	Analyses findings of 10.5

Table 64: List of qualitative and quantitative methods used for this research



This research project was not without limitations. The source of empirical data involving industrial designers and engineering designers was based mainly in Singapore. Although 80 different industrial design consultancies and organisations based in the United Kingdom were contacted, a very poor response was received perhaps due to the economic downturn. Facilitated by the researcher's own contacts by having several years of work experience with industrial design consultancies in Singapore, a decision was therefore made to undertake the empirical search in that country.

Although it could be argued that undertaking the research in Singapore may have limited the generalisability of the findings, the survey involved a wide sampling of large, medium and small industrial design consultancies. These employed international staff that included Italians, Britons, Germans, as well as local designers working to global design practices. In addition, the respondents were all qualified practitioners with at least 3 years work experience and industrial design work is conducted in an English-speaking environment. Whenever possible, practitioners, project managers, academics and students were surveyed from both disciplines. Viewing project documents, reports and artefacts and noting informal comments provided supporting data. For consistency, only industrial design consultancies involved in consumer electronics design were chosen. All participants had at least 3 years of work experience and each was given a booklet (refer to Appendix 13.3) explaining the research. This allowed them to gain a better understanding and to relay relevant feedback. The CoLab cards were demonstrated to each participant so that they could fully understand and evaluate its use.

Reliability was strengthened by transcribing the interviews and observations on the same day to minimise memory loss. In addition, all interviews and observations were conducted by the same researcher with the same set of questions. Using semi-structured questions allowed leading questions to be avoided, minimising unintentional influences on the responses. In addition, conducting the interviews individually as opposed to a group interview

minimised a vocal participant from influencing other less confident participants. The transcribed records were emailed to the corresponding participant so that their responses could be verified. Another limitation was the respondents' lack of time. Their busy schedules meant that most interviews were limited to 1 hour and current projects could not be discussed because of confidentiality. To overcome this, the interview data was corroborated with information from other sources such as through observations or by looking at project documents. Although the observations involved a small group of participants, the small setting allowed better access and transparency to the design process, enabling first-hand accounts to be recorded. The participant-observation approach was used for the observation studies. Although inadvertent bias might have occurred, this approach allowed flexibility with considerable freedom for the researcher to gather and record information close to the subjects. Lastly, reliability and validity of the research was maintained by presenting the research findings and the CoLab cards at numerous international conferences to gain further feedback. The list of conference papers and presentations are listed in Section 11.8.

Despite achieving positive results from the validation, there are several points that should be considered in light of the study constraints. The validation was limited to 65 respondents (43 practitioners, 18 students, 4 from case studies) and therefore generalisation of the findings should be made with caution. In addition, the tool was tested only within a short time frame. More confidence could be gained if the CoLab system could be tested for a longer duration and involving a wider range of participants.

### ***11.5 Contributions to Knowledge***

This research has contributed towards advances in knowledge and is relevant to industrial design and engineering design practitioners, academics and students, as well as for other professionals involved during new product development. The key original contributions derived from this research are as follows:

1. The research examined barriers occurring among industrial designers and engineering designers and confirmed three problem areas in multi-disciplinary collaboration to be present. They were conflicts in values and principles, differences in design representations and differences in education. The findings from the empirical studies undertaken have gone beyond existing research and are a contribution to knowledge.

2. Despite various attempts by scholars to classify representations used during the design process (Engelbrektsson and Soderman 2004, Johansson et al. 2001, Tovey, 1989; Ferguson, 1992; Veveris, 1994; Goldschmidt, 1992, 1997; Cross, 1999; Do et al. 2000; Ullman, 2003), they have been either incomplete or do not incorporate both industrial design and engineering design representations. This research has identified 35 types of visual design representations employed by industrial designers and engineering designers during new product development. Each of these representations have been clearly defined with visual examples. While the list is not exhaustive and the visual design representations are by no means all the representations that exist for industrial designers and engineering designers, it can be claimed that the most significant ones found in the literature today have been included.

3. A taxonomy of design representations was generated, visually illustrating and linking four categories of sketches, drawings, models and prototypes. The taxonomy identified and hierarchically classified 35 design representations employed by industrial designers and engineering designers during New Product Development.

The taxonomy could be seen as the most important contribution in this research as it is a useful aid in the broader objective of achieving more effective use of design representations. Through understanding the taxonomic relationships, it is hoped that the classification will help industrial designers, engineering designers and other stakeholders involved in new product

development to be more effective in recognising, selecting and employing representations.

4. The CoLab cards provided information on the nature, role and significance of these design representations (sketches, drawings, models and prototypes) used by industrial designers and engineering designers during new product development. It is hoped that the tool will aid understanding in the use of visual design representations by industrial designers and engineering designers, as well as assisting users to decide how to represent various kinds of information.

Additionally, CoLab has an application as a teaching and learning tool for design education. Students using CoLab would be able to have a clearer definition of representations, as well as recognising the limitations of representations when conveying certain design or technical information.

5. The popularity of use for the 35 types of design representations have been identified and are shown on the reverse of the CoLab cards. The statistical information illustrated how commonly each of the representations are employed by industrial designers and engineering designers. In addition, the CoLab cards provided statistical information to show when sketches, drawings, models and prototypes are used by the two disciplines during the four stages of the design process. By comparing the statistics, it allows users to recognise and acknowledge differences between industrial designers and engineering designers when employing design representations.

6. The research identified 18 types of key design and technical information employed by the two disciplines during new product development. By cross-linking with design representations, users gain a holistic and thorough understanding of the design process. For example, 60% of industrial designers use texture and surface finish (design information) in appearance

prototypes; or 50% of industrial designers use prescriptive sketches to show components (technical information).

7. Through the use of CoLab in a case study (Section 10.6), this research confirmed that having a common ground in design representations has led to higher levels of understanding and collaboration between industrial designers and engineering designers in design practice. This is in line with the findings from other researchers (Hack and Canto 1984; Ferguson 1992; Johansson *et al.* 2001; Do 2002; Buxton 2007). In addition, through the use of CoLab, professional practice can be enhanced by standardising vocabulary and facilitating social networks between the partners. By simplifying processes and communication, interfacing becomes easier, operations are quickened and parallel processing achieved. Users are able to eliminate unnecessary design representations, saving time and accelerating NPD.

## 11.6 Reflections from the Research

This research project employed the use of a systematic methodology through a high degree of data collection from industrial design and engineering design practitioners. It resulted in the development of a viable tool that was found to have enhanced collaboration between the two disciplines. A summary of the empirical studies that has been undertaken for this research is shown in Table 65.

Type of Investigation	Initial Investigations			Trial	Validation		
Number	Study 1		Study 2	Study 3	Study 4	Study 5	Study 6
Investigation Code	R1	R2	R3	R4	R5	R6	R7
Thesis Section	Section 5.3	Section 5.4.1	Section 8.2	Section 9.7	Section 10.4	Section 10.5	Section 10.6
Purpose	Examining issues faced by industrial designers and engineering designers		Investigating the use of design representations by industrial designers and engineering designers	Pilot Study	Validation with practitioners	Validation with students	Case-Study Validation with practitioners
Date Conducted	July 2006		June 2007	November 2007	February 2008		
Location	Singapore		Singapore	United Kingdom	Singapore		

(Table 65 continued)

<b>Data Collection Method</b>	Semi-structured interviews	Practitioner-observer based Observations	Semi-structured interviews	Semi-structured interviews	Likert-scale semi-structured interviews	Likert-scale semi-structured interviews	Practitioner-observer Observations
<b>Recording Method</b>	Through interview questions and viewing project documents	Note taking and viewing project documents	Through interview questions and viewing project documents	Through interview questions and viewing project documents	Through interview questions and viewing project documents		Note taking, use of design diary and viewing project documents
<b>Number of Firms</b>	17 industrial design consultancies	1 industrial design consultancy	17 industrial design consultancies	6 industrial design consultancies and academic institutions	15 industrial design consultancies and academic institutions		1 industrial design consultancy
<b>Number of Industrial Design Practitioners</b>	9 industrial designers	1 industrial designer	13 industrial designers	4 industrial designers	22 industrial designers	-	2 industrial designers
<b>Number of Engineering Design Practitioners</b>	6 engineering designers	1 engineering designer	10 engineering designers	4 engineering designers	21 engineering designers	-	1 engineering designer
<b>Number of Academics</b>	-	-	6 academics out of the 27 practitioners	2 academics	12 academics out of the 43 practitioners	-	-
<b>Number of Project Managers</b>	16 project managers	1 project manager	4 project managers	-	4 project managers out of the 43 practitioners	-	1 project manager
<b>Number of Industrial Design Students</b>	-	-	-	-	-	4 industrial design students	-
<b>Number of Engineering Design Students</b>	-	-	-	-	-	14 engineering design students	-
<b>Sub Total</b>	31 practitioners	3 practitioners	27 practitioners and project managers	10 practitioners and academics	43 practitioners, academics and project managers	18 students	4 practitioners
<b>Total Number of Respondents</b>	34 practitioners and project managers		27 practitioners, academics and project managers	10 practitioners and academics	61 practitioners, academics, project managers and students		

Table 1: Details of empirical research

Reflecting on the research programme allows for personal improvement. This research originated from a personal interest. This meant that it was largely self-directed and the initial study covered a wide subject area. The research would have been more efficient if it had been more specific. This would have reduced the time spent on the literature review and allowed earlier investigations. However, lack of current research justified the need for a robust review of the literature and to undertake empirical research.

This empirical research could have been more effective if more participants from each company could have been involved. Conducting interviews with a larger pool of respondents from a company would enable greater consistency. Even more so, more respondents from a similar background would have

made the feedback more reliable. Another suggestion was that the booklet documenting the research could have been emailed to the respondents prior to the actual meeting. This would remove the need for repeated explanations of the research and saved time. It would also have been more satisfying to conduct the empirical research and the validation with industrial design consultancies in the United Kingdom and in other countries. Mention must be made that because of the poor response from industrial design consultancies in the United Kingdom, a decision was therefore made to undertake the empirical research and validations in Singapore. Next, the pilot study could have been more effective if it had engaged with more practitioners and involved more student participants. Having a monetary budget using a reward incentive might have helped to attract the student participants. Lastly, a longer period of case study observations would have allowed a more robust record of CoLab in use. However, given the limited time in Singapore, this was not possible. Despite these reflections, undertaking this PhD programme has been a truly rewarding experience. The timeline illustrating an overview of key activities undertaken for this research is shown in Figure 370.

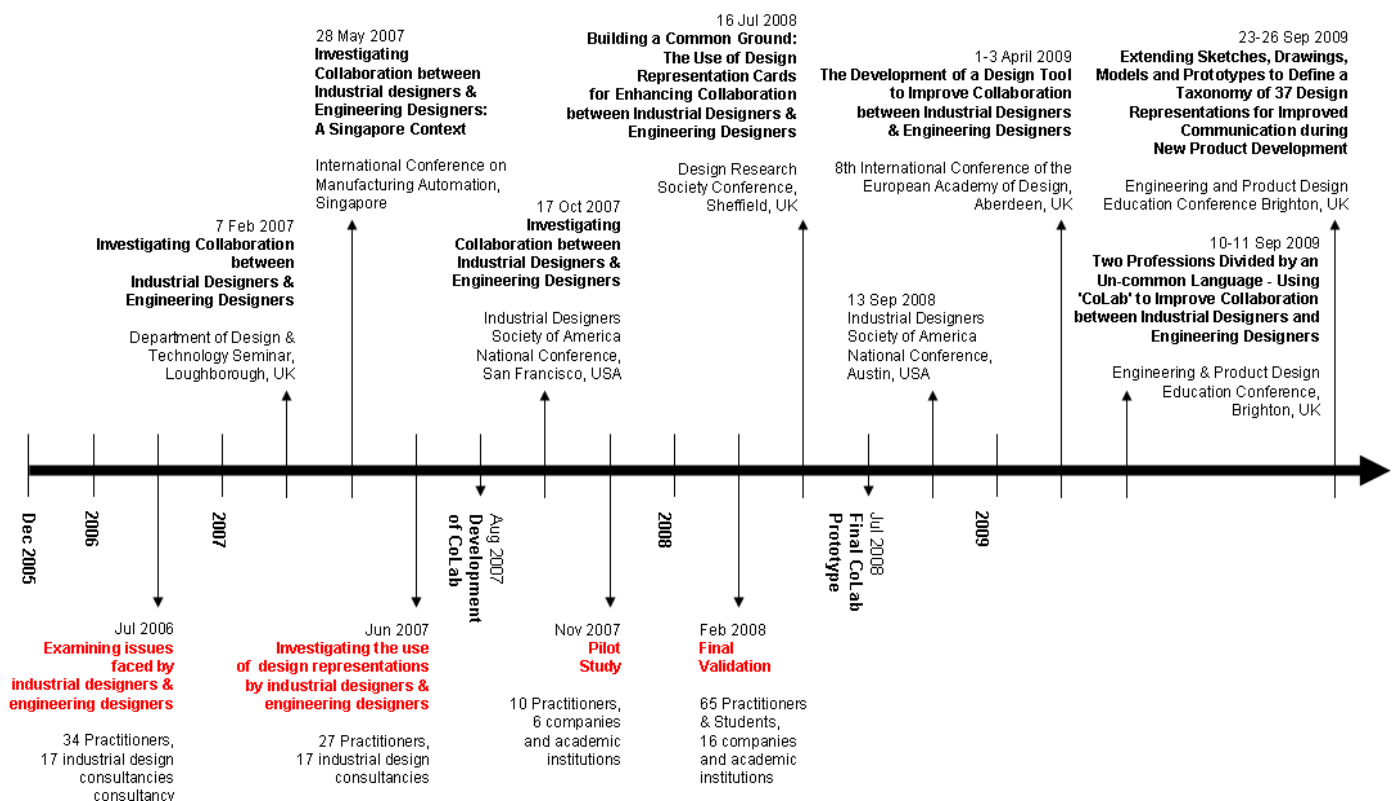


Figure 1: Activity Timeline

### ***11.7 Suggestions for Future Work***

While this project has achieved the research aims and objectives, several recommendations could be implemented to take this project further. Some of the suggestions for future work would include testing the CoLab system for a longer duration and involving a larger sample of participants. It was also suggested that research in other European nations such as in Germany could be conducted. It would help establish a more comprehensive, thorough and global feedback. Another opportunity is to develop an alternative format of the CoLab cards in the form of a web-based interface so that users can magnify text or details on the screen for better readability.

During the course of this research, an industrial design consultancy based in Singapore had shown keen interest in commercialising the CoLab cards. In another occasion at the Industrial Designers Society of America (IDSA), Frank M. Tyneski, the Executive Director of the Industrial Designers Society of America (IDSA) was contacted to discuss the possible commercialisation of the CoLab tool and he expressed very positive interest in working together. In his email, he is quoted as saying, “I think the Design Stages, Information and Representation cards are just brilliant. There's no doubt in my mind that the CoLab cards will be extremely valuable to our IDSA members.” Details of his email can be found in Appendix 13.16.1. At this point of writing, the CoLab cards are being developed for commercialisation with the support of Loughborough University's Department of Design and Technology.

### ***11.8 Summary of Published Papers***

During the course of the research, opportunities were taken to publish the results of ongoing work and this allowed valuable feedback to be obtained. A brief description of the papers is described, regarding the intention and the content.



**Paper A:**

Pei, E., Campbell, R.I. and Evans, M.A., "Investigating Collaboration between Industrial designers and Engineering Designers: A Singapore Context", Proceedings of the 2007 International Conference on Manufacturing Automation, Gibson, I., National University of Singapore, The 2007 International Conference on Manufacturing Automation, Singapore, 2007, 0, ISBN 978 981 05 8089 6, [CD-ROM].

Paper A presented the results from interviews and observations directed to industrial design consultancies in Singapore. The purpose was to investigate the level of collaboration between industrial designers and engineering designers during new product development. The study highlighted the importance of collaboration during new product development. More importantly, it revealed three problem areas between the two disciplines during collaborative activity, namely: conflicts in values and principles; differences in tools and methods used for representation; and differences in education.

**Paper B:**

Pei, E., Evans, M.A. and Campbell, R.I., "Them and Us?: Exploring the Collaboration between Industrial Designers and Engineering Designers", Proceedings of the 2007 Industrial Designers Society of America International Education Symposium, Cullen, C., Connecting, San Francisco, USA, 2007, pp 217-223.

This article was also published by ICSID (International Council of Societies of Industrial Design) on their webpage in August 2008.  
<<http://www.icsid.org/education/education/articles491.htm>>

Paper B discussed the findings of the empirical investigation that was undertaken in Singapore. The paper answered several research questions

that were posed: 1) How and when do industrial designers and engineering designers work together? 2) What leads to successful or poor collaboration? 3) What factors influence collaboration and can they be categorised? 4) Do representation tools affect collaboration? 5) What are the characteristics for a successful tool for effective collaboration between industrial designers and engineering designers?

### **Paper C:**

Pei, E., Evans, M.A. and Campbell, R.I., "Building a Common Ground: The Use of Design Representation Cards for Enhancing Collaboration between Industrial Designers and Engineering Designers", Proceedings of the 2008 Design Research Society Conference, Durling, D. (ed), Sheffield Hallam University, Undisciplined - Design Research Society Conference, Sheffield, UK, 2008, [CD-ROM].

Paper C is a continuation and deepening of the research by introducing the theme of visual design representations. It argued that having a common language in the use of representations would help improve communication and create shared knowledge between industrial designers and engineering designers. A taxonomy was generated to categorise sketches, drawings, models and prototypes, leading to the development of the CoLab system. The tool was validated by means of practitioner and student interviews, followed by a case study. The findings revealed positive feedback, reinforcing the benefits of the tool for successful collaboration in a multi-disciplinary environment.

### **Paper D:**

Evans, M.A., Pei, E. and Campbell, R.I., "The Development of a Design Tool to Improve Collaboration between Industrial Designers and Engineering Designers", Proceedings of the Eighth European Academy of Design International Conference, Malins, J., Robert Gordon University, Design

Connexity, Robert Gordon University, UK, 2009, pp 161-165, ISBN 978 1 901085 97 6.

Paper D presented an overview of the research and its contributions to knowledge. It presented findings concerning differences between industrial designers and engineering designers during new product development. It proposed a design tool that would build a uniform definition of visual design representations to help improve communication and collaboration between the two disciplines. The proposed tool would also show key design and technical information serving as a decision-making guide; as well as identifying representations used during stages of the design process to allow users to be aware of each others' working processes and to facilitate effective planning. Having validated the cards by means of interviews with students and practitioners, the feedback was overwhelmingly positive with a majority of the respondents being certain that the cards would provide better understanding in the use of design representations and improve collaboration between the two disciplines for greater product success.

#### **Paper E:**

Evans, M.A., Pei, E. and Campbell, R.I. "Two Professions Divided by an Un-common Language - Using 'CoLab' to Improve Collaboration between Industrial Designers and Engineering Designers" Engineering and Product Design Education Conference Brighton, UK 10 - 11 September, 2009

Paper E presented the challenges faced during interaction between industrial design and engineering design professions with the aim of producing a tool that would remove or significantly reduce some of these problems. The paper discusses the development of the design tool that comprises two sets of cards divided into three packs. The central feature of the card-based tool is the provision of information on the role and significance of design representations used during NPD. When employed, the tool facilitates the use of a common vocabulary, creating shared knowledge and empathy towards the related yet

distinct working practices of each group. Following a pilot validation, interviews and design diaries were used to assess the significance of the cards. When asked if the system would foster enhanced collaboration, the feedback was overwhelmingly positive, with 68% of industrial designers (27% neutral) and 63% of engineering designers (37% neutral) giving a positive response.

#### **Paper F:**

Evans, M.A., Pei, E. and Campbell, R.I. "Extending Sketches, Drawings, Models and Prototypes to Define a Taxonomy of 37 Design Representations for Improved Communication during New Product Development" International Conference 23 - 26 September 2009, Miami, USA

To avoid costly rework and to reduce development time, effective externalisation of design concepts amongst NPD team members is crucial. The ideas that initially take place in the form of language, graphics or actual objects must be externalised without unnecessary ambiguity if they are to be shared with others. The aim of paper F was to provide a more effective, consistent and clear understanding of design representations. The paper considers the nature of design representations and then explores the development, structure and content of the taxonomy of design representations that are employed by industrial designers and engineering designers during NPD. The taxonomy is finally appraised through a four-way evaluation by means of orthogonality, spanning, precision and usability.

#### **Journal Papers Currently with Editors**

1. Eujin Pei, Dr Ian Campbell, Dr Mark Evans "A Taxonomic Classification of Visual Design Representations Used by Industrial Designers and Engineering Designers" (submitted to The Design Journal)

2. Eujin Pei, Dr Ian Campbell, Dr Mark Evans “Towards a Common Ground – Using CoLab for Enhanced Understanding between Industrial Designers & Engineering Designers” (pending submission to CoDesign journal)

### **Other Presentations**

1. E.Pei, "Investigating Collaboration between Industrial designers and Engineering Designers" Department of Design and Technology Research Seminar, Loughborough University, UK, 2006. (Presented by Eujin Pei)

2. Dr M.A. Evans, E. Pei, Dr R.I. Campbell, “Two Professions Divided by an Uncommon Language: Using “CoLab” to Improve Collaboration between Industrial Designers and Engineering Designers (Collaboration and the design-based PhD)” 2008 Industrial Designers Society of America International Education Symposium Arizona, USA (Presented by Dr M. A. Evans)

- end of report -

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## 12. REFERENCES

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360-DeepDive (2007). Collaborative Workspaces - Insights about collaborative workspaces.

<<http://www.steelcase.com/uk/files/ee3f2d4acc8f45db84735ee5a5fa4794/Full%20version%20of%20this%20story.pdf>> Accessed on 12 January 2007.

Acar, B. S. (1996). "A new model for design processes," Proceedings of the Institution of Mechanical Engineers, Series E No. 210 pp. 135-138. Quoted in: Wright, Ian (1998) "Design Methods in Engineering and Product Design," Berkshire: McGraw Hill Publishing Company.

Adler, P. S. (1995). "Interdepartmental interdependence and coordination: the case of the design manufacturing interface," Organisation Science Vol. 6 No. 2 pp.147-167. Quoted in: Leenders, Mark A. A. M. and Wierenga, Berend (2002) "The Effectiveness of Different Mechanisms for Integrating Marketing and R&D," Journal of Product Innovation Management. Vol. 19 pp. 305-309.

Aiken, M. and J. Hage (1966). "Organisational Alienation," American Sociological Review No. 31 pp. 497-507. Quoted in: Maltz, Elliot and Kohli, Ajay K. (2000) "Reducing Marketing's Conflict with Other Functions: The Differential Effects of Integrating Mechanisms," Journal of the Academy of Marketing Science No. 28 pp. 479.

Alexander, C. (1964). "Notes on the Synthesis of Form," Cambridge, Mass. Quoted in: Bürdek, Erhard E. (2005) "Design - History, theory and practice of product design," Basel: Birkhauser.

Alisantoso, D., L. P. Khoo, *et al.* (2006). "A design representation scheme for collaborative product development." International Journal of Advanced Manufacturing Technology(No. 30).

Ancona, D. G. and D. Caldwell (1992). "Speeding Product Development: Making Teamwork Work." Cambridge, MA: Sloan School of Management. Quoted in: Holland, S., Gaston, K. and Gomes, J. (2000) "Critical success factors for cross-functional teamwork in new product development." International Journal of Management Reviews Vol. 2 No. 3 pp. 231 - 259.

Anderson, J. C. and J. A. Narus (1990). "A Model of Distributor Firm and Manufacturer Firm Working Partnerships," Journal of Marketing No. 54 pp. 42-58. Quoted in: Hillebrand, Bas and Biemans, Wim G. (2004) "Links between Internal and External Cooperation in Product Development: An Exploratory Study," Journal of Product Innovation Management No. 21.

Andreasen, M. M. (1994). "Modelling - The Language of the Designer." Journal of Engineering Design Vol. 5(No. 2).

Andreasen, M. M., S. Kähler, *et al.* (1988). "Design for Assembly" (2nd ed.) London: IFS Publishers. Quoted in: "A Typology of Designs and Designing," International Conference on Engineering Design ICED 03 Stockholm.

Andreasen, M. M. and J. Olesen (1993). "Design for X," In: "Notes from WDK '93 Workshop," Lyngby: Technical University of Denmark, Institute for Engineering Design. Quoted in: Eva Brandt (2005) "How Tangible Mock-Ups Support Design Collaboration," Proceedings of the Nordic Design Research Conference, 'In the Making' Copenhagen, Denmark.

Archer, L. B. (1965). "Systematic Method for Designers," London: The Design Council. Quoted in: Jones, John Chris (1970) "Design Methods (2nd ed.)," New York: John Wiley & Sons, Inc.

Arnheim, R. (1969). Visual Thinking. CA, University of California Press.

Ashford, F. C. (1969a). The Aesthetics of Engineering Design. Quoted in: R. Hague, I. Campbell, P. Dickens, P. Reeves (2002) "Integration of Rapid Manufacturing in Design: Time Compression Technologies," Vol. 10 No. 4 pp. 48.

Ashford, F. C. (1969b). The Aesthetics of Engineering Design. London.

AskOxford (2008). Dictionary resources from Oxford University. <<http://www.askoxford.com/dictionaries/?view=uk>> Accessed on: 19 September 2008.

Austin, S., J. Steele, *et al.* (2001a). "Mapping the conceptual design activity of interdisciplinary teams." Design Studies Vol. 22(No. 3): pp. 211-232.

Austin, S., J. Steele, *et al.* (2001b). "Mapping the conceptual design activity of interdisciplinary teams," Design Studies Vol. 22 No. 3 pp. 211-232. Quoted in: Ostergaard, Karen J. and Summers, Joshua D. (2003) "A Taxonomic Classification on Collaborative Design," International Conference on Engineering Design ICED 03 held in Stockholm August 19-21 2003.

Avrahami, D. and S. E. Hudson (2002). Forming interactivity: A tool for rapid prototyping of physical interactive products. Proceedings of the Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques (DIS'02) pp. 141-146.

Backhouse, C. J. and N. J. Brookes (1996). Concurrent Engineering - What's Working Where. Hampshire, Gower Publishing Limited.

Badke-Schaub, P. and E. Frankenberger (1999). "Analysis of design projects," Design Studies No. 20. Quoted in: Goldschmidt, Gabriela and Porter, William L. (2004) "Design Representation," London: Springer-Verlag.

Baecker, R., G. Glass, *et al.* (1994). "SASSE: the collaborative editor," In: ACM Conference on Human Factors in Computing Systems video tape. In: Nam, Tek-Jin and Wright, David (2001) "The development and evaluation of Syco3D: a real-time collaborative 3D CAD system," Design Studies Vol. 22 No. 6 (2001).  
Bailey, C. A. (2007). A Guide to Qualitative Field Research (2nd ed.). Thousand Oaks, California, Pine Forge Press.

Bairstow, J., R. Barber, *et al.* (1999). Design Modelling - Visualising Ideas in 2D and 3D. London, Hodder & Stoughton.

Barge, R. A. (2008) The Feasibility of Using Virtual Prototyping Technologies for Product Evaluation. Department of Design and Technology. Loughborough, Loughborough University.

Barnett, A. (2006). "Medical Products." New Design(No. 44).

Baskinger, M. (2008). "Pencils Before Pixels: A Primer in Hand-Generated Sketching." Interactions March - April.

Baxter, M. (1995). Product Design: A Practical Guide to Systematic Methods of New Product Development. London, Chapman & Hall.

Beardsley, S. (1994). "The Product Interface: Crossroads of Communication," Design Journal Vol. 5 No. 1 pp. 53-54. Quoted in: Bohemia, Erik (2002) "Designer as Integrator: Reality or Rhetoric?" Design Journal Vol. 5 No. 2.

Beck, A. (1988). "Love is Never Enough," New York: Harper & Row. Quoted in: Gudykunst, William B. (1998) "Bridging Differences - Effective Intergroup Communication," (3rd ed.) California: Sage Publications.

Bermúdez, J. and K. King. (1998). Media Interaction and Design Process: Establishing a Knowledge Base. In: Proceedings of the ACADIA Conference, Digital Design Studios: Do Computers Make A Diference?: 7-25. Quebec: Association for Computer-Aided Design in Architecture. Quoted in: Dorta, T. and E. Pérez (2006). "Hybrid modeling: Revaluating manual action for 3D modeling" in: <<http://www.din.umontreal.ca/documents/dorta/12-ACADIA2006b.pdf>> Accessed on 15 October 2008.

Bertoline, G. R. (2002). Introduction to Graphics Communications for Engineers (2nd ed.). New York, McGraw Hill.

Beskow, C. (1997). "Product Development in Change - Cross-functional Co-operation and PDM Implementations," Licentiate Thesis: Department of Machine Design, Royal Institute of Technology, Stockholm. Quoted in: Persson, Sara and Warell, Anders (2003) "Relational Modes between Industrial Design and Engineering Design - a Conceptual Model for Interdisciplinary Design Work," Proceedings of the 6th Asian Design International Conference, Tsukuba.

Best, K. (2006). Design Management - Managing Design Strategy, Process and Implementation. Switzerland, AVA Publishing SA.

Bilda, Z., J. S. Gero, *et al.* (2006). "To sketch or not to sketch? That is the question." Design Studies Vol. 27(No. 5).

Billings, S. (2006). "Functional Fashion." DesignWeek Vol. 21(No. 37).

Bishop, A. (2001). "Hardware - Marvellous Mechanical Mouse Organ." New Design January February: pp. 71.



Blackwell, A. F. (1997). "Diagrams about Thoughts about Thoughts about Diagrams," In: M. Anderson (1997) "Reasoning with Diagrammatic Representations II", AAAI 1997 Fall Symposium held in Menlo Park, California pp. 77-84. Quoted in: Do, Ellen Yi-Luen; Gross, Mark D. and Zimring, Craig (1999) "Drawing and Design Intentions - An Investigation of Freehand Drawing Conventions in Design," Proceedings Design Thinking Research Symposium held in Cambridge, MA.

Blake, R. R., H. A. Shepard, *et al.* (1964). Managing Intergroup Conflict in Industry. Houston, Texas, Gulf Publishing.

Bly, S. A. (1988a). A Use of Drawing Surfaces in Different Collaborative Settings. Proceedings of Computer Supported Cooperative Work '88, Portland, OR, ACM Press, New York.

Bly, S. A. (1988b). "A use of drawing surfaces in different collaborative settings," In: CSCW '88 held in Portland USA pp 250 - 256. Quoted in: Scrivener, Stephen A. R.; Ball, Linden J. and Woodcock, Andre (2000) "Collaborative Design - Proceedings of CoDesigning 2000," London: Springer-Verlag pp. 339.

Bødker, S. and J. Buur (2002). "The Design Collaboratorium - A Place for Usability Design." ACM Transactions on Computer- Human Interaction Vol. 9(No. 2): pp. 152-169.

Boekholt, J. T. (1985). "The architect as a skilled participant," In: Proceedings of DPC 85 Vol. 2 pp. 249–259. Quoted in: Pugh, Stuart (1986) "Design activity models: worldwide emergence and convergence," Design Studies Vol. 7 No. 3.

Bogdan, R. and S. J. Taylor (1982). Introduction to Qualitative Research Methods. New York, John Wiley.

Bohemia, E. (2002). "Designer as Integrator: Reality or Rhetoric?" Design Journal Vol. 5(No. 2).

Bohemia, E. and Harman, K. (2008) "Globalization and Product Design Education: The Global Studio". Design Management Journal Vol. 3 No. 2

Boisot, M. (1995). "Information Space: A Framework for Learning in Organisations, Institutions, and Culture," London: Routledge. Quoted in: Patrashkova, Ralitza R. and McComb, Sara A. (2004) "Exploring why more communication is not better: Insights from a computational model of cross-functional teams," Journal of Engineering Technology Management No. 21.

Bond, E. U., B. A. Walker, *et al.* (2004). "Reputational Effectiveness in Cross-Functional Working Relationships." Journal of Product Innovation Management(No. 21).

Boote, S. (2006). "Visualization - Visible Benefits." New Design(No. 35): pp. 44.

Boujut, J.-F. and P. Laureillard (2002). "A co-operation framework for product-process integration in engineering design." Design Studies Vol. 23(No. 5).

Boujut, J. F. and P. Laurillard (2002). "A co-operation framework for product process integration in engineering design." Design Studies(No. 23).

Bousbaci, R. (2008). "'Models of Man' in Design Thinking: The 'Bounded Rationality' Episode." Design Issues Vol. 24(No. 4).

Bradshaw, J. L. and N. C. Nettleton (1983). "Human Cerebral Asymmetry," Prentice Hall. Quoted in: Tovey, Michael (1984) "Designing with both halves of the brain," Design Studies Vol. 5 No. 4.

Brandt, E. (2005). How do Tangible Mock-ups Support Design Collaboration? Proceedings of the Nordic Design Research Conference, 'In the Making', Copenhagen, Denmark.

Brandt, E. and J. Messeter (2004). Facilitating Collaboration through Design Games. Proceedings of the eighth conference on Participatory design: Artful integration: interweaving media, materials and practices Vol. 1, Toronto, Ontario, Canada.

Brereton, M. F., D. M. Cannon, *et al.* (1996). "Collaboration in Design Teams: How Social Interaction Shapes the Product," Palo Alto, CA: Stanford University. Quoted in: Cross, Nigel; Christiaans, Henri and Dorst, Kees (1996) "Analysing Design Activity," Chichester: John Wiley & Sons.

Brown, A. G. P. (2003). "Visualization as a common design language: Connecting art and science." Automation in Construction Vol. 12: pp. 703- 713.

Brown, S. L. and K. M. Eisenhardt (1995a). "Product development: Past research, present findings, and future directions." Academy of Management Review(No. 20): 343-378.

Brown, S. L. and K. M. Eisenhardt (1995b). "Product development: past research, present findings, and future directions," Academy of Management Review Vol. 20 No. 2 pp. 343-378. Quoted in: Leenders, Mark A. A. M. and Wierenga, Berend (2002) "The Effectiveness of Different Mechanisms for Integrating Marketing and R&D," Journal of Product Innovation Management. Vol. 19 pp. 305-309.

Bruce, M. and J. Bessant (1995). Design in Business. London, Pearson Education.

Bruce, M., F. Leverick, *et al.* (1995). "Success Factors for Collaborative Product Development: A Study of Suppliers of Information and Communication Technology," R&D Management Vol. 25 No. 1 pp. 33-44. Quoted in: Bstieler, Ludwig (2006) "Trust Formation in Collaborative New Product Development," Journal of Product Innovation Management No. 23.

Bryden, M. P. (1982). "Laterality, functional asymmetry in the intact brain," Academic Press. Quoted in: Tovey, Michael (1984) "Designing with both halves of the brain," Design Studies Vol. 5 No. 4.

Bstieler, L. (2006). "Trust Formation in Collaborative New Product Development." Journal of Product Innovation Management(No. 23).

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

Bucciarelli, L. (1999). Delta design: Seeing, Seeing as. 4th Design Thinking Research Symposium, Design Representation, MIT.

Bucciarelli, L. L. (1984). "Reflective practice in engineering design." Design Studies Vol. 5(No. 3).

Bucciarelli, L. L. (1988). "An Ethnographic Perspective on Engineering Design." Design Studies(No. 9): pp. 159-168.

Bucciarelli, L. L. (2002). "Between thought and object in engineering design." Design Studies Vol. 23(No. 3).

Bucolo, S. (2007). Celebrating a Common and Uncommon Ground - A Case Study. In: Brickwood, Cathy; Ferran, Bronan; Garcia, David and Putnam, Tim (2007) "(Un)Common Ground - Creative Encounters across Sectors and Disciplines," Amsterdam: BIS Publishers.

Budde, R., K. Kautz, *et al.* (1992). "Prototyping: an approach to evolutionary system development," Berlin: Springer. Quoted in: Yang, Maria C. and Daniel, J. (2005) "A study of prototypes, design activity, and design outcome," Design Studies Vol. 26 No. 6.

Buijs, J. and R. Valkenburg (2005). Integrated Product Development, 2005 (3rd Ed.) Uitgeverij Lemma BV: Utrecht (In Dutch: "Integrale Productontwikkeling" Derde, geheel herziene druk, Uitgeverij Lemma BV: Utrecht). Quoted in: Maaïke Kleinsmann, M., Valkenburg, R. and Buijs, J. (2007) "Why do(n't) actors in collaborative design understand each other? An empirical study towards a better understanding of collaborative design" In: CoDesign Vol. 3 No. 1.

Bürdek, E. E. (2005). Design - History, theory and practice of product design. Basel, Switzerland, Birkhauser.

Burghardt, M. D. (1999). Introduction to Engineering Design & Problem Solving. Singapore, McGraw-Hill International.

Burton, M. J. (2005) Design for Rapid Manufacture: Developing an appropriate knowledge transfer tool for industrial designers (PhD thesis). Department of Design and Technology. Loughborough, Loughborough University.

Buur, J. and M. M. Andreasen (1989a). "Design models in mechatronic product development." Design Studies Vol. 10(No. 3): pp. 155- 162.

Buur, J. and M. M. Andreasen (1989b). "Design models in mechatronic product development," Design Studies No. 3 pp 105-162. Quoted in: Andreasen, Mogens Myrup (1994) "Modelling - The Language of the Designer," Journal of Engineering Design Vol. 5, No. 2.

Buxton, B. (2007). Sketching User Experiences - Getting the design right and the right design. San Francisco, Morgan Kaufmann.

C3 (2000). Media Directories International 2000. In: Evans, Mark Andrew (2002) "The Integration of Rapid Prototyping within Industrial Design Practice (Staff Thesis)," Loughborough: Department of Design and Technology Loughborough University.

Cagan, J. and C. M. Vogel (2002). Creating Breakthrough Products - Innovation from Product Planning to Program Approval. NJ, Prentice-Hall.

Cain, R. E. (2005) Involving users in the Design Process: The Role of Product Representations in Co-Designing (PhD Thesis). Department of Design and Technology. Loughborough, Loughborough University.

Campbell, R. I., R. J. Hague, *et al.* (2006). "The Potential for the Bespoke Industrial Designer." The Design Journal Vol. 6(No. 3): pp. 24-26.

Cardella, M. E., C. J. Atman, *et al.* (2006). "Mapping between design activities and external representations for engineering student designers." Design Studies Vol. 27(No. 1).

Carlson, J. R. and R. W. Zmud (1999). "Channel expansion theory and the experiential nature of media richness perceptions," *Academy of Management Journal* Vol. 42 No. 2 pp. 153-170. Quoted in: Patrashkova, Ralitza R. and McComb, Sara A. (2004) "Exploring why more communication is not better: Insights from a computational model of cross-functional teams," *Journal of Engineering Technology Management* No. 21.

Castelvecchi, J. (2002). Design Intent what is it? - Symposium HI-02-20. <[http://tc79.ashraetcs.org/pdf/Castelvecchi\\_SympHI-02-20.pdf](http://tc79.ashraetcs.org/pdf/Castelvecchi_SympHI-02-20.pdf)> Accessed on 12 October 2008.

Castka, P., C. J. Bamber, *et al.* (2001). "Factors Affecting Successful Implementation of High Performance Teams." Team Performance Management: An International Journal Vol. 7(No. 7): pp. 123-134.

Chauhan, T. (2004). "Nokia 7600: Souvenir from the Future." Innovation: Yearbook of Industrial Design Excellence Fall: pp. 97.

Chen, H.-H., M. You, *et al.* (2003). The sketch in industrial design process. Proceedings of the 6th Asian Design Conference: Integration.

Chiu, M.-L. (2002). "An Organisational View of Design Communication in Design Collaboration." Design Studies Vol. 23(No. 2): pp.187-210.

Chung, W. and C.-Y. Wang (2002). "Knowledge-based Design and Decisions: Accommodating Multi-disciplined Product Development Teams." The Design Journal Vol. 7(No. 1).

Clark, H. H. and S. E. Brennan (1991). "Grounding in Communication," In: Baecker, R. M. (ed.) "Readings in Groupware and Computer Supported Cooperative Work: Assisting Human-Human Collaboration," Mountain View, CA: Morgan-Kaufmann Publishers. pp. 222-233. Quoted in: Gutwin, C., Greenberg, S. (2002) "A Descriptive Framework of Workspace Awareness for Real-Time Groupware," *Computer Supported Cooperative Work* No. 11.

Clark, K. B. and T. Fujimoto (1991). "Product Development Performance: Strategy, Organisation, and Management in the World Auto Industry," Boston: Harvard Business School Press. Quoted in: Tessarolo, Paolo (2007) "Is Integration Enough for Fast Product Development? An Empirical Investigation of the Contextual Effects of Product Vision," *Journal of Product Innovation Management* No. 24 pp. 69-82.

Clark, K. B. and S. C. Wheelwright (1992). Managing new product and process development. New York, The Free Press.

Clay, T. (2005). "Rapid Prototyping with 3D Printers - Beyond Traditional Prototyping." Time Compression Technologies Vol. 13 Sep / Oct(No. 5): pp. 46.

Coates, G., R. I. Whitfield, *et al.* (2000). "Coordination approaches and systems (Part II) : An operational perspective," Research in Engineering Design No. 12 pp. 73-89. Quoted in: Maranzana, Nicolas; Gartiser, Nathalie and Caillaud, Emmanuel (2007) "Less Design Resources Thanks to Merging Collaborative Design and Learning Network for Innovative Design," International Conference on Engineering Design ICED 07 held in Cite Des Sciences et de L'industrie, Paris, France 28-31 August 2007.

Cohen, S. G. and D. E. Bailey (1997). "What makes teams work: Group effectiveness research from the shop floor to the executive suite." Journal of Management Vol. 23(No. 3): pp. 239 - 290.

Collins Dictionary of Art Terms and Techniques (1993). R. Mayer (Ed.). Glasgow, Harper Collins Publishers.

Connell, A. (2004). "The Rise and Rise of Virtual Prototyping." Time Compression Technologies Vol. 12 May / June(No. 3): pp. 44.

Cooper, R., M. Bruce, *et al.* (2000). "The Designer as Innovator". Quoted in: Scrivener, Stephen A. R.; Ball, Linden J. and Woodcock, Andre (2000) "Collaborative Design - Proceedings of CoDesigning 2000," London: Springer-Verlag pp. 117.

Cooper, R. G. (1994). "Third generation New Product Processes." Journal of Product Innovation Management(No. 11): pp. 3-14.

Cooper, R. G. and E. J. Kleinschmidt (1995). "Benchmarking the firm's critical success factors in new product development." In: Journal of Product Innovation Management No. 12 pp. 374–391. Quoted in: Ernst, H (2002) "Success factors of new product development: A review of the empirical literature." International Journal of Management Reviews Vol. 4 No. 1 pp. 1 - 40.

Corbet, F. (2009a). "Ministry of Sound." Develop3D - Technology for the Product Lifecycle. X3DMedia, London(March): pp. 22-26.

Corbet, F. (2009b). "Street Machine (Bombardier Recreational Products)." Develop3D - Technology for the Product Lifecycle. X3DMedia, London(January).

Corfield, K. G. (1979). Product Design: A Report by Mr K G Corfield carried out for the National Economic Development Council. London, National Economic Development Council.

Cox, G. (2005) "The Cox Review of Creativity in Business" HM Treasury, London.  
<<http://www.hm-treasury.gov.uk/d/coxreview-chap6preparingfuture.pdf>> Accessed 20 Oct 2009

Crosby, P. B. (1979). "Quality is Free," McGraw-Hill Book Company. Quoted in: Cross, Nigel; Dorst, Kees and Roosenburg, Norbert (1991) "Research in Design Thinking," Proceedings of a workshop meeting held at the Faculty of Industrial Design Engineering, Delft University of Technology, the Netherlands, May 29-31 1991.

Cross, N. (1983). Methods Guide: Control of technology, 3rd level course Unit 8 T361. Milton Keynes, Open University Press.

Cross, N. (1984). Developments in Design Methodology. Chichester, John Wiley and Sons Ltd.

Cross, N. (1996). Creativity in design: Not leaping but bridging. Proceedings of the second international symposium of Creativity and Cognition '96, Loughborough, LUTCHI.

Cross, N. (2000). Engineering Design Methods - Strategies for Product Design (3rd ed.). Chichester, John Wiley and Sons Ltd.

Cross, N. (2007). Designerly Ways of Knowing. Basel, Switzerland, Birkhauser Press.

Cross, N., H. Christiaans, *et al.* (1996). Analysing Design Activity. Chichester, John Wiley & Sons Ltd.

Culverhouse, P. F., L. Ball, *et al.* (1992). "A tool for tracking engineering design in action." Design Studies Vol. 13(No. 1).

Daft, R. L. and R. L. Lengel (1986). "Organisational information requirements, media richness and structural design," *Management Science* Vol. 32 No 5 pp. 554-571. Quoted in: Leenders, Mark A. A. M. and Wierenga, Berend (2002) "The Effectiveness of Different Mechanisms for Integrating Marketing and R&D," *Journal of Product Innovation Management*. Vol. 19 pp. 305-309.

Dai, F. (2003). Creative Design Under Product Lifecycle Constraints - The Future of Product Development. International Conference on Engineering Design ICED '03 August 19 - 21 2003, Stockholm.

Darmanpour, F. (1991). "Organisational innovation: a meta analysis of effects of determinants and moderators," *Acad Management Journal* No. 35 pp. 555-590. Quoted in: Leenders, Mark A. A. M. and Wierenga, Berend (2002) "The Effectiveness of Different Mechanisms for Integrating Marketing and R&D," *Journal of Product Innovation Management*. Vol. 19 pp. 305-309.

Davis, J. G., E. Subrahmanian, *et al.* (2001). "Creating Shared Information Spaces to Support Collaborative Design Work." Information Systems Frontiers Vol. 3(No. 3).

De Bono, E. (1970). "Lateral Thinking: a textbook of creativity," Ward Lock Educational. Quoted in: Cross, Nigel; Dorst, Kees and Roosenburg, Norbert (1991) "Research in Design Thinking," Proceedings of a workshop meeting held at the Faculty of Industrial Design Engineering, Delft University of Technology, the Netherlands, May 29-31 1991.

Denison, D. R., S. L. Hart, *et al.* (1996). "From chimneys to cross-functional teams: Developing and validating a diagnostic model." *Academy of Management Journal* No. 39 pp. 1005–1022. Quoted in: Holland, S., Gaston, K. and Gomes, J. (2000) "Critical success factors for cross-functional teamwork in new product development." *International Journal of Management Reviews* Vol. 2 No. 3 pp. 231 - 259.

Denton, H. (1997). "Multidisciplinary Team-based Project Work: Planning Factors." *Design Studies* Vol. 18(No. 2): pp.155-170.

Detienne, F. (2006). "Collaborative design: Managing task interdependencies and multiple perspectives." *Interacting with Computers*(No. 18): pp. 1-20.

Détienne, F., G. Martin, *et al.* (2005). "Viewpoints in co-design: a field study in concurrent engineering." *Design Studies* Vol. 26(No. 3): pp. 215-241.

*Dictionary of 20th Century Design*, (1990). J. Pile (Ed.). New York, Facts on File, Inc.

*Dictionary of Architecture and Construction* (3rd Edition) (2000). C. M. Harris (Ed.). New York, McGraw Hill.

*Dictionary of Art Terms* (2003). *Thames and Hudson World of Art*. E. Lucie-Smith (Ed.). London, Thames and Hudson.

Digman, J. (1990). "Personality Structure: Emergence of the Five-Factor Model", In: Rosenweig, M.R., Porter, L.W. (eds.) (1990) "Annual Review of Psychology," Palo Alto, CA, pp. 417-440. Quoted in: Ostergaard, Karen J. and Summers, Joshua D. (2003) "A Taxonomic Classification on Collaborative Design," International Conference on Engineering Design ICED 03 held in Stockholm August 19-21 2003.

Do, E. Y.-L. (2002). "Drawing marks, acts, and reacts: Toward a computational sketching interface for architectural design." *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*(No. 16): pp. 149-171.

Do, E. Y.-L. (2005). "Design sketches and sketch design tools." *Knowledge-Based Systems*(No. 18): pp. 383-405.

Do, E. Y.-L., M. D. Gross, *et al.* (2000). "Intentions in and relations among design drawings." *Design Studies* Vol. 21(No. 5).

Dominick, P. G., J. T. Demel, *et al.* (2001). *Tools and Tactics of Design*. New York, John Wiley & Sons, Inc.

Dorta, T. (2005). *Hybrid Modeling: Manual and digital media in the first steps of the design process*. <<http://www.din.umontreal.ca/documents/dorta/9-eCAADe2005.pdf>> Accessed on 12 October 2008.

Dorta, T. (2008). *Design Flow and Ideation*. <<http://www.din.umontreal.ca/documents/dorta/22-IJAC.pdf>> Accessed on 12 October 2008.

Dorta, T. and E. Pérez (2006). *Hybrid modeling: Revaluing manual action for 3D modeling*. <<http://www.din.umontreal.ca/documents/dorta/12-ACADIA2006b.pdf>> Accessed on 15 October 2008.

Dorta, T., E. Perez, *et al.* (2008). "The ideation gap: hybrid tools, design flow and practice." Design Studies Vol. 29(No. 2).

Dougherty, D. (1992a). "Interpretive Barriers to Successful Product Innovation in Large Firms," Organisation Science Vol. 3 No. 2 pp. 179-202.

Dougherty, D. (1992b). "Interpretive barriers to successful product innovation in large firms," Organisation Science Vol. 3 No. 2 pp 179-202. Quoted in: Leenders, Mark A. A. M. and Wierenga, Berend (2002) "The Effectiveness of Different Mechanisms for Integrating Marketing and R&D," Journal of Product Innovation Management. Vol. 19 pp. 305-309.

DTI (1992). Managing Product Design Projects. London, Department for Trade and Industry.

Duffy, A. H. B., M. M. Andreasen, *et al.* (1993). "Design Coordination for Concurrent Engineering." Journal of Engineering Design Vol. 4(No. 4).

Dummet, M. (1993). The Seas of Language. New York, Oxford University Press.

Durling, D., Cross, N., & Johnson, J. (1996) "Personality and learning preferences of students in design and design-related disciplines". In: J. S. Smith (Ed.) Proceedings of IDATER 96 (International Conference on Design and Technology Educational Research), 2-4 September, Loughborough University, 88-94.

<<http://magpie.lboro.ac.uk:8080/dspace-jspui/bitstream/2134/1477/3/durling96.pdf>>  
Accessed 18 Oct 2009

Dyer, W. G. (1995). Team Building - Current Issues and New Alternatives (3rd ed.). Reading, Massachusetts, Addison-Wesley Publishing Company.

Dym, C. L. and P. Little (2003). Engineering Design - A Project-based Introduction (2nd ed.). New Jersey, John Wiley & Sons Inc.

Eckert, C. and J.-F. Boujut (2003). "The Role of Objects in Design Co-Operation: Communication through Physical or Virtual Objects." Computer Supported Cooperative Work(No. 12): pp. 145-151.

Eckert, C. M. (2001). "The Communication Bottleneck in Knitwear Design: Analysis and Computing Solutions," Computer Supported Cooperative Work Vol. 10 pp. 29-74. Quoted in: Eckert, Claudia and Boujut, Jean-Francois (2003) "The Role of Objects in Design Co-Operation: Communication through Physical or Virtual Objects," Computer Supported Cooperative Work No. 12 pp. 145-151.

Eckert, C. M. and M. K. Stacey (2000). "Sources of Inspiration: a Language of Design." Design Studies Vol. 21: pp. 523-538.

Eckert, C. M., M. K. Stacey, *et al.* (2003). Ambiguity is a double-edged sword: Similarity references in communication. 14th International Conference of Engineering Design (ICED '03), Stockholm, Sweden.

Eekels, J. (1994). "The Engineer as Designer and as a Morally Responsible Individual." Journal of Engineering Design Vol. 5(No. 1).



Ehn, P. and M. Kyng (1991). "Cardboard Computers: Mocking it-up or Hands-on the Future," In: Greenbaum, Joan and Kyng, Morten (1992) "Design at work: cooperative design of computer systems," Mahwah, NJ: Lawrence Erlbaum pp. 169 - 195. Quoted in: Eva Brandt (2005) "How Tangible Mock-Ups Support Design Collaboration," Proceedings of the Nordic Design Research Conference, 'In the Making' Copenhagen, Denmark.

Ehrlenspiel, K. and N. Dylla (1993). "Experimental Investigation of Designers' Thinking Methods and Design Procedures." Journal of Engineering Design Vol. 4(No. 3).

Eisenhardt, K. M. and B. N. Tabrizi (1995). "Accelerating Adaptive Processes-Product Innovation in the Global Computer Industry," Administrative Science Quarterly Vol. 40 No. 1 pp. 84-110. Quoted in: Tassarolo, Paolo (2007) "Is Integration Enough for Fast Product Development? An Empirical Investigation of the Contextual Effects of Product Vision," Journal of Product Innovation Management No. 24 pp. 69-82.

Eissen, K. and R. Steur (2008). Sketching: Drawing Techniques for Product Designers. Singapore, Bis Publishers / Page One Publishing.

Emori, R. I. (1977). "Scale Models in Engineering," London: Pergamon Press In: Engineering Designer (January 1999) Wiltshire: Institution of Engineering Designers. In: Evans, Mark Andrew (2002) "The Integration of Rapid Prototyping within Industrial Design Practice (Staff Thesis)," Loughborough: Department of Design and Technology Loughborough University.

Engelbrektsson, P. and M. Soderman (2004). "The use and perception of methods and product representations in product development: a survey of Swedish industry." Journal of Engineering Design Vol. 15(No. 2).

Erhorn, C. and J. Stark (1994). Competing by Design - Creating Value and Market Advantage in New Product Development. Vermont, Oliver Wight Publications, Inc.

Ericsson, K. and H. Simon (1993). Protocol Analysis - Verbal Reports as Data (2nd Ed.). Cambridge, MIT Press.

Erlhoff, M. (1987). "Kopf über zu Füßen. Prolog für Animatoren," In: documenta 8, Vol. 1 Kassel. Quoted in: Bürdek, Erhard E. (2005) "Design - History, theory and practice of product design," Basel: Birkhauser.

Ernst, H. (2002). "Success factors of new product development: A review of the empirical literature." International Journal of Management Reviews Vol. 4(No. 1): pp. 1 - 40.

Evans, M. (1992). Model or prototype which, when and why? IDATER 1992 Conference, Loughborough University (Design and Technology).

Evans, M. and P. Wormald (1993). The future role of virtual and physical modelling in industrial design. IDATER 1993 Conference, Loughborough University (Design and Technology).

Evans, M. A. (200) The Integration of Rapid Prototyping within Industrial Design Practice (Staff Thesis). Department of Design and Technology. Loughborough, Loughborough University.

Evans, M. A. and R. I. Campbell (2003). "A comparative evaluation of industrial design models produced using rapid prototyping and workshop-based fabrication techniques." Rapid Prototyping Journal Vol. 9(No. 5).

Falzon, P. (1994). "Dialogues fonctionnels et activité collective (Functional dialogs and collective activity)," Le Travail Humain Vol. 57 No. 4 pp. 299-312. Quoted in: Maier, Anja M.; Hepperle, Clemens; Kreimeyer, Matthias; Eckert, Claudia; Lindemann, Udo and Clarkson, P. John (2007) "Associations between Factors Influencing Engineering Design Communication," International Conference on Engineering Design, ICED '07 held in Cite Des Sciences Et De L'Industrie, Paris, France 28 - 31 August 2007.

Feierabend, P. and M. Erhoff (2004). Product Design. Berlin, Feierabend Verlag OHG.

Ferguson, E. S. (1992). Engineering and the mind's eye. Cambridge, Massachusetts, MIT Press.

Fielden, G. B. R. (1963). Engineering design: Her Majesty's Stationery Office. Quoted in: Tovey, Michael (1989) "Drawing and CAD in industrial design," Design Studies Vol. 10 No. 1.

Fiell, C. and P. Fiell (2003a). Design for the 21st Century. Köln, Taschen GmbH.

Fiell, C. and P. Fiell (2003b). Industrial Design A-Z. Cologne, Taschen GmbH.

Finger, S., D. Gelman, *et al.* (2006). "Supporting collaborative learning in engineering design." Expert Systems with Applications(No. 31).

Finn, A. (1985). "A theory of the consumer evaluation process for new product concepts," Research in Consumer Behaviour Vol. 1 pp. 35-65. Quoted in: Söderman, Mikael (2002) "Comparing Desktop Virtual Reality with handmade sketches and real products: Exploring key aspects for end-users' understanding of proposed products," Journal of Design Research Vol. 2 No. 1.

Fischer, G., K. Nakakoji, *et al.* (1995). "Supporting the Evolution of Design Artifacts with Representations of Context and Intent." Proceedings of the Conference on Designing Interactive Systems, Processes, Practices, Methods and Techniques, DIS 95, ACM Press.

Fish, J. and S. Scrivener (1990). "Amplifying the mind's eye: Sketching and visual cognition." Leonardo Vol. 23(No. 1): pp. 117-126.

Fish, J. C. (1996). "How Sketches Work-A Cognitive Theory for Improved System Design," PhD dissertation: Loughborough University of Technology. Quoted in: Do, Ellen Yi-Luen; Gross, Mark D.; Neiman, Bennett and Zimring, Craig (2000) "Intentions in and relations among design drawings," Design Studies Vol. 21 No. 5.

Fleischer, M. and J. K. Liker (1997). Concurrent Engineering Effectiveness - Integrating Product Development Across Organisations. Cincinnati, OH, Hanser Gardner Publications.

Fraser, I. and R. Henmi (1994). "Envisioning Architecture-An Analysis of Drawing," New York: Van Nostrand Reinhold. Quoted in: Lawson, Bryan (1997) "How Designers Think - The Design Process Demystified," Oxford: Architectural Press.

- French, M. J. (1985). Conceptual Design for Engineers. Berlin, Springer Verlag.
- Frishberg, N. (2006). "Prototyping with Junk." Interactions(January February).
- Frost, R. B. (1999). "Why does Industry ignore Design Science?" Journal of Engineering Design(No. 10): pp. 301-304.
- Gadsden, R. (2006) Questionnaire Design. Professional Development, Loughborough University.
- Gantz, C. M. (2005). "What a Difference 50 Years Makes!" Innovation: The Quarterly Journal of the Industrial Designers Society of America Vol. 24(No. 1): pp. 20-21.
- Garner, S. (1999) Drawing and Designing: An analysis of sketching and its outputs as displayed by individuals and pairs when engaged in design tasks (unpublished PhD thesis). Loughborough, Loughborough University.
- Garner, S. (2004). T211 Design and Designing - An Introduction to Design & Designing. Milton Keynes, The Open University.
- Garner, S. (2006). Modelling Workbook 1: T211 Design and Designing Workbook 1 Technology Level 2 (2nd ed.). Milton Keynes, The Open University.
- Gemsera, G. and M. A. A. M. Leenders (2001). "How integrating industrial design in the product development process impacts on company performance." Journal of Product Innovation Management(No. 18).
- Giannini, F., M. Monti, *et al.* (2006). "Aesthetic-driven tools for industrial design." Journal of Engineering Design Vol. 17(No. 3): pp. 193-215.
- Girard, P. and V. Robin (2006). "Analysis of collaboration for project design management." Computers in Industry(No. 57).
- Gisi, M. A. and C. Sacchi (1994). "Co-CAD: A collaborative mechanical CAD system," In: Presence Vol. 3 pp. 341-350. Quoted in: Nam, Tek-Jin and Wright, David (2001) "The development and evaluation of Syco3D: a real-time collaborative 3D CAD system," Design Studies Vol. 22 No. 6 (2001).
- Goel, V. (1995). Sketches of thought. Cambridge MA, MIT Press.
- Goldschmidt, G. (1989). "Problem representation versus domain of solution in architectural design teaching," Journal of Architectural and Planning Research Vol. 6 No. 3 pp. 204-215. Quoted In: Purcell, A. T. and Gero, J. S. (1998) "Drawings and the design process," Design Studies Vol. 19 No. 4.
- Goldschmidt, G. (1991a). "The dialectics of sketching." Creativity Research Journal Vol. 4(No. 2): pp. 123-143.
- Goldschmidt, G. (1991b). "The dialectics of sketching," Design Studies Vol. 4 pp 123-143. Quoted In: Purcell, A. T. and Gero, J. S. (1998) "Drawings and the design process," Design Studies Vol. 19 No. 4.

Goldschmidt, G. (1992). "Serial sketching: Visual problem solving in designing," *Cybernetics and Systems* Vol. 23 pp 191-219. Quoted In: Cardella, Monica E.; Atman, Cynthia J. and Adams, Robin S. (2006) "Mapping between design activities and external representations for engineering student designers," *Design Studies* Vol. 27 No. 1.

Goldschmidt, G. (1994). "On visual design thinking: the vis kids of architecture," *Design Studies* Vol. 15 pp. 158-174. Quoted In: Purcell, A. T. and Gero, J. S. (1998) "Drawings and the design process," *Design Studies* Vol. 19 No. 4.

Goldschmidt, G. (1995a). "The Designer as a Team of One." *Design Studies* Vol. 16(No. 2).

Goldschmidt, G. (1995b). "Visual displays for design: imagery, analogy and databases of visual images," In: Koutamanis, A., Timmermans, H., Vermeulen, I. (eds.) "Visual databases in architecture: recent advances in design and decision-making," Averbury, Aldershot pp 53-76. Quoted In: Purcell, A. T. and Gero, J. S. (1998) "Drawings and the design process," *Design Studies* Vol. 19 No. 4.

Goldschmidt, G. (2007). "To see eye to eye: the role of visual representations in building shared mental models in design teams." *CoDesign* Vol. 3(No. 1): pp. 43 - 50.

Goldschmidt, G. and W. L. Porter (2004). *Design Representation*. London, Springer-Verlag.

Goodman, P. S., E. C. Ravlin, *et al.* (1986). "Current thinking about groups: setting the stage for new ideas," In: Goodman, P.S. (ed.) "Designing Effective Work Groups" CA: Jossey-Bass. Quoted in: Patrashkova, Ralitza R. and McComb, Sara A. (2004) "Exploring why more communication is not better: Insights from a computational model of cross-functional teams," *Journal of Engineering Technology Management* No. 21.

Gorb, P. (1986). "The Business of Design Management." *Design Studies* Vol. 7(No. 2).

Gorner, R. (1994). "Zur psychologischen Anayse von Konsteukteur - und Entwurfstatigkeiten," In: "Die Handlungsregulationstheorie: Von der Praxis einer Theorie," Bergmann, B. and Ritchter, P. (eds.) Gottingen: Hogrege pp. 233-241. Quoted in: Goldschmidt, Gabriela and Porter, William L. (2004) "Design Representation," London: Springer-Verlag.

Gouvinhas, R. P. and J. Corbett (1999). "The Development of a Design Method for Production Machinery Companies." *Journal of Engineering Design* Vol. 10(No. 4).

Graves, M. (1977). "The necessity for drawing: Tangible speculation," *Architectural Design* No. 6 pp. 384-394. Quoted in: Do, Ellen Yi-Luen (2002) "Drawing marks, acts, and reacts: Toward a computational sketching interface for architectural design," *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* No.16 pp. 149-171.

Greenberf, S., M. Roseman, *et al.* (1995). "Human and technical factors of distributed group drawing tools," In: Greenberg, S., Hayne, S. and Rada, R. (eds.) (1995) "Groupware for Real-Time Drawing: A Designer's Guide," McGraw-Hill Book Company pp. 737-762. Quoted in: Nam, Tek-Jin and Wright, David (2001) "The development and evaluation of Syco3D: a real-time collaborative 3D CAD system," *Design Studies* Vol. 22 No. 6 (2001).

Greene, J. C., V. J. Caracelli, *et al.* (1989). "Toward a Conceptual Framework for Mixed-Method Evaluation Designs." *Educational Evaluation and Policy Analysis* Vol. 11 No. 2, pp 255 - 274. Quoted in: Miles, M. B. and A. M. Huberman (1994). "Qualitative Data Analysis" (2nd Edition). Thousand Oaks, California, Sage Publications.

Griffin, A. and J. R. Hauser (1993). "The voice of the customer." Marketing Science(No. 12): pp. 1-27.

Griffin, A. and J. R. Hauser (1996a). "Integrating R&D and Marketing: A Review and Analysis of the Literature." Journal of Product Innovation Management(No. 13): pp. 191-215.

Griffin, A. and J. R. Hauser (1996b). "Integrating R&D, and marketing: a review, and analysis of the literature," *Journal of Product Innovation Management* No. 13 pp. 191 -215. Quoted in: Leenders, Mark A. A. M. and Wierenga, Berend (2002) "The Effectiveness of Different Mechanisms for Integrating Marketing and R&D," *Journal of Product Innovation Management*. Vol. 19 pp. 305-309.

Gudykunst, W. B. (1998). Bridging Differences - Effective Intergroup Communication (3rd ed.). California, Sage Publications.

Gudykunst, W. B. and M. R. Hammer (1988). "Strangers and Hosts," In: Kim, Y. and Gudykunst, W (eds.) "Cross-cultural Adaptation," Newbury Park, CA: Sage. Quoted in: Gudykunst, William B. (1998) "Bridging Differences - Effective Intergroup Communication," (3rd ed.) California: Sage Publications.

Gupta, V. and P. N. Murthy (1980). An Introduction to Engineering Design Method. New Delhi, Tata McGraw Hill Publishing Company Ltd.

Gutwin, C. and S. Greenberg (2002). "A Descriptive Framework of Workspace Awareness for Real-Time Groupware." Computer Supported Cooperative Work(No. 11).

Habraken, H. J. and M. D. Gross (1987). "Concept design Games (Book 1 and 2)," A report submitted to the National Science Foundation Engineering Directorate, Design Methodology Program. Cambridge, Massachusetts: Department of Architecture, MIT. Quoted in: Brandt, Eva and Messeter, Jörn (2004) "Facilitating Collaboration through Design Games," *Proceedings of the eighth conference on Participatory design: Artful integration: interweaving media, materials and practices - Vol. 1* held in Toronto, Canada.

Hack, G. and M. Canto (1984). "Collaboration and context in urban design." Design Studies Vol. 5(No. 3).

Hague, R., I. Campbell, *et al.* (2002). "Integration of Rapid Manufacturing in Design." Time Compression Technologies Vol. 10 Aug(No. 4): pp. 48.

Haller, L. and C. D. Cullen (2006). Design Secrets Products 2 : 50 real-life projects uncovered. Gloucester, Mass., Rockport Publishers.

Hamel, J., S. Dufour, *et al.* (1993). Case Study Methods. Newbury Park, CA, Sage Publications.

Hands, D., S. Edge, *et al.* (2004). "Design as an Integrated Process: Haley Sharpe Associates - Ten Years On." Design Journal Vol. 7(No. 1).

Hanington, B. M. (2006). "Interface in Form: Paper and Product Prototyping for Feedback and Fun." Interactions January February.

Hannah, B. (2004). Becoming a Product Designer. New Jersey, John Wiley & Sons.

Hardin, C. and E. T. Higgins (1996). "Shared Reality: How Social Verification Makes the Subjective Objective," In: Sorrentino, R. M. and Higgins, E. T. (eds.) "Handbook of Motivation and Cognition: Foundation of Social Behavior" New York: Guilford pp. 28-84. Quoted in: Leinonen, Piritta; Ja Rvela, Sanna and Hakkinen, Paivi (2005) "Conceptualizing the Awareness of Collaboration: A Qualitative Study of a Global Virtual Team," Computer Supported Cooperative Work No. 14 pp. 301-322.

Harrison, S. and S. Minneman (1991). "A Bike in Hand; A Study of 3D Objects in Design," Palo Alto, CA: Xerox PARC. Quoted in: Cross, Nigel; Christiaans, Henri and Dorst, Kees (1996) "Analysing Design Activity," Chichester: John Wiley & Sons.

Haskell, B. (2004). Portable Electronics - Product Design & Development. New York, McGraw Hill.

Hauptman, O. and K. K. Hirji (1999). "Managing integration and co-ordination in cross-functional teams: An international study of Concurrent Engineering in product development." R&D Management Vol. 29 No. 2 pp. 179 - 191. Quoted in: Holland, S., Gaston, K. and Gomes, J. (2000) "Critical success factors for cross-functional teamwork in new product development." International Journal of Management Reviews Vol. 2 No. 3 pp. 231 - 259.

Hawkes, B. and R. Abinett (1985). The Engineering Design Process. London, Pitman Publishing Limited.

Heath, C. and P. Luff (1991). "Collaborative activity and technological design: task coordination in London Underground control rooms," Proceedings of ECSCW '91, Amsterdam pp. 65-80. Quoted in: Perry, Mark and Sanderson, Duncan (1998) "Coordinating joint design work: the role of communication and artifacts," Design Studies Vol. 19 No. 3.

Hein, L. (1994). "Design Methodology in Practice." Journal of Engineering Design Vol. 5(No. 2).

Hendry, D. G. (2004). Communication Functions and the Adaptation of Design Representations in Interdisciplinary Teams. Symposium on Designing Interactive Systems: Proceedings of 2004 conference on Designing interactive systems processes practices methods & techniques.

Herbert, D. M. (1993). "Architectural Study Drawings," New York: Van Nostrand Reinhold. Quoted in: Do, Ellen Yi-Luen (2002) "Drawing marks, acts, and reacts: Toward a computational sketching interface for architectural design," Artificial Intelligence for Engineering Design, Analysis and Manufacturing No.16 pp. 149-171.

Herbruck, D. and S. Umbach (1997). "Design management and new product development: Linking people and process." Design Management Journal Vol. 8(No. 2).

Heskett, J. (1980). Industrial Design. London, Thames and Hudson Ltd.

Hewlett-Packard (2000). "Virtual Prototyping: the future arrives in the form of a Showcase Automobile". Quoted in: Nam, Tek-Jin and Wright, David (2001) "The development and evaluation of Syco3D: a real-time collaborative 3D CAD system," Design Studies Vol. 22 No. 6 (2001).

Hill, A., S. Song, *et al.* (2001). "Identifying Shared Understanding in Design Using Document Analysis" Proceedings of DETC '01, Pittsburgh, PA. Quoted in: Persson, Sara and Warell, Anders (2003) "Relational Modes between Industrial Design and Engineering Design - a Conceptual Model for Interdisciplinary Design Work," Proceedings of the 6th Asian Design International Conference, Tsukuba.

Hirdina, H. (1998). "Voraussetzungen postmodern Designs," In: Flierl, Bruno and Hirdona, Heinz (1995) "Postmoderne und Funktionalismus" Berlin: Sechs Vorträge. Quoted in: Bürdek, Ernhard E. (2005) "Design - History, theory and practice of product design," Basel: Birkhauser.

Hoegl, M., K. Weinkauf, *et al.* (2004). "Interteam coordination, project commitment and teamwork in multiteam R&D projects: A longitudinal study." In: Organisational Science Vol. 15 No. 1 pp. 38 – 55. Quoted in: Maaïke Kleinsmann, M., Valkenburg, R. and Buijs, J. (2007) "Why do(n't) actors in collaborative design understand each other? An empirical study towards a better understanding of collaborative design" In: CoDesign Vol. 3 No. 1.

Holbrook, M. B. and W. L. Moore (1981). "Feature interactions in consumer judgements of verbal versus pictorial presentations," Journal of Consumer Research No. 8 pp. 103-113. Quoted in: Söderman, Mikael (2002) "Comparing Desktop Virtual Reality with handmade sketches and real products: Exploring key aspects for end-users' understanding of proposed products," Journal of Design Research Vol. 2 No. 1.

Holland, S., K. Gaston, *et al.* (2000). "Critical success factors for cross-functional teamwork in new product development." International Journal of Management Reviews Vol. 2(No. 3): pp. 231 - 259.

Holme, G. (1934). Industrial Design and the Future - A Challenge to the Producer. London, The Studio Limited.

Holmes, W. P., M. A. Azam, *et al.* (1995). A Preliminary Study of the Relationship between industrial Design and Engineering Design. Symposium on Designing Interactive Systems.

Holmquist, L. E. (2005). "Prototyping: Generating ideas or cargo cult designs?" Interactions Vol. 12(No. 2): pp. 48-54.

Holt, J. E., D. F. Radcliffe, *et al.* (1985). "Design or problem solving a critical choice for the engineering profession." Design Studies Vol. 6(No. 2).

Huang, G. Q. (1996). Design for X: Concurrent Engineering Imperatives. London, Chapman & Hall.

Huang, G. Q. and K. L. Mak (1999). "Web-based collaborative conceptual design." Journal of Engineering Design Vol. 10(No. 2): pp. 183-194.

Hubka, V. (1983). "Design tactics = methods + working principles for design engineers." Design Studies Vol. 4(No. 3).

Hurst, K. (1999). Engineering Design Principles. New York, Arnold Publishers.

Hutchins, E. (1995). "Cognition in the wild," Bradford: MIT Press. Quoted in: Perry, Mark and Sanderson, Duncan (1998) "Coordinating joint design work: the role of communication and artifacts," Design Studies Vol. 19 No. 3.

Iansiti, M., (1993) "Real Word R&D: Jumping the Product Generation Gap, Harvard Business Review", Vol. 71 (3) pp. 138-147.

IDSA (2006). Industrial Designers Society of America (IDSA): About Industrial Design. <<http://www.idsa.org/webmodules/articles/anmviewer.asp?a=89&z=23>> Accessed on 2 Feb 2006.

IDSA (2003). Design Secrets: Products: 50 Real-Life Projects Uncovered. Gloucester, Mass., Rockport Hove RotoVision.

IMData (2000). CoCreate Software Open-Space: A Collaborative Design Infrastructure - IMData Product Review. Quoted in: Nam, Tek-Jin and Wright, David (2001) "The development and evaluation of Syco3D: a real-time collaborative 3D CAD system," Design Studies Vol. 22 No. 6 (2001).

James, L. R. and A. P. Jones (1976). "Organisational Structure: A Review of Structural Dimensions and Their Conceptual Relationships With Individual Attitudes and Behavior." Organisational Behavior and Human Performance No. 16 (June) pp. 74-113. Quoted in: Menon, A., Jaworski, B. J., Kohli, A. K. (1997) "Product Quality: Impact of Interdepartmental Interactions." Journal of the Academy of Marketing Science Vol. 25 No. 3 pp. 187-200.

Janhager, J., S. Persson, *et al.* (2002). "Survey on Product Development Methods, Design Competencies and Communication in Swedish Industry," Proceedings of TMCE: Tools and Methods of Competitive Engineering held in Wuhan, China. Quoted in: Persson, Sara (2002) "Industrial Design - Engineering Design Interaction: Studies of Influencing Factors in Swedish Product Developing Industry," Thesis for the degree of Licentiate of Engineering, Product and Production Department, Chalmers University of Technology, Göteborg, Sweden.

Jassawalla, A. R. and H. C. Sashittal (1998). "An Examination of Collaboration in High-Technology New Product Development Processes." Journal of Product Innovation Management Vol. 15(No.3): pp. 237 - 254.



Johansson, P., S. Persson, *et al.* (2001). "The Use of Product Representations in Industry - A Survey Dealing with Product Development in Sweden," Proceedings of SKFC'01, The 3rd International Workshop on Strategic Knowledge and Concept Formation held in Sydney, Australia. Quoted in: Persson, Sara (2002) "Industrial Design - Engineering Design Interaction - Studies of Influencing Factors in Swedish Product Developing Industry," Thesis for the degree of Licentiate of Engineering, Chalmers University of Technology, Göteborg, Sweden.

Johnson, D. W. (1975). "Cooperativeness and Social Perspective Taking," Journal of Personality and Social Psychology No. 31 pp. 241 - 244. Quoted in: Pinto, Mary Beth and Pinto, Jeffrey K. (1990) "Project Team Communication and Cross-Functional Cooperation in New Program Development," Journal of Product Innovation Management Vol. 7 No. 4.

Johnson, S. (1998). "What's in a representation, why do we care, and what does it mean? Examining evidence from psychology." Automation in Construction(No. 8): pp. 15-24.  
Jonas, W. (1993). "Design as problem-solving? or: here is the solution - what was the problem?" Design Studies Vol. 14(No. 2).

Jones, C. J. (1969). "Design Methods in Architecture," London. Quoted in: Bürdek, Erhard E. (2005) "Design - History, theory and practice of product design," Basel: Birkhauser.

Jones, C. J. (1992). Design Methods (2nd Ed.). New York, John Wiley & Sons.

Jones, J. C. (1974). "The need for new methods". Quoted in: Cross, Nigel; Elliot, David and Roy, Robin (1974) "Man-made Futures: Readings in Society, Technology and Design," London: Hutchinson & Co. Publishers Ltd.

Joseph, S. (1996). "Design Systems and Paradigms." Design Studies(No. 17).

Joshi, A., G. Labianca, *et al.* (2002). "Getting along long distance: understanding conflict in a multinational team through network analysis." Journal of World Business Vol. 37(No. 4): pp. 277-284.

Judson, H. F. (1980). "The Search for Solutions," London: Hutchison. Quoted in: Evans, Mark (1992) "Model or prototype which, when and why?" Idater 1992, Department of Design and Technology, Loughborough University of Technology.

Junginger, S. (2008). "Product Development as a Vehicle for Organisational Change." Design Issues Vol. 24(No. 1).

Kahn, K. B. (1996a). "Interdepartmental Integration: A Definition with Implications for Product Development Performance." Journal of product Innovation Management(No. 13): pp. 137-151.

Kahn, K. B. (1996b). "Interdepartmental Integration: A definition with Implications for Product Development Performance," Journal of Product Innovation Management No. 13 pp.137-151. Quoted in: Persson, Sara and Warell, Anders (2003) "Relational Modes between Industrial Design and Engineering Design - a Conceptual Model for Interdisciplinary Design Work," Proceedings of the 6th Asian Design International Conference, Tsukuba.

Kahn, K. B. and E. F. McDonough III (1997). "An Empirical Study of the Relationships among Co-location, Integration, Performance and Satisfaction." Journal of Product Innovation Management(No. 14).

Kahn, K. B. and J. T. Mentzer (1998). "Marketing's Integration with Other Departments," Journal of Business Research Vol. 42 No. 1 pp. 53 - 62. Quoted in: Bond, Edward U. III; Walker, Beth A.; Hutt, Michael D. and Reingen, Peter H. (2004) "Reputational Effectiveness in Cross-Functional Working Relationships," Journal of Product Innovation Management No. 21.

Kai, C. C. and L. K. Fai (1997). "Rapid Prototyping," Singapore: John Wiley. In: Evans, Mark Andrew (2002) "The Integration of Rapid Prototyping within Industrial Design Practice (Staff Thesis)," Loughborough: Department of Design and Technology Loughborough University.

Kalay, Y. (2004). Architecture's New Media. Cambridge, MIT Press.

Kalay, Y. E. (2002). "Enhancing multi-disciplinary collaboration through semantically rich representation." Automation in Construction(No. 10).

Kaplan, R. and S. Kaplan (1982). Cognition and Environment: Functioning in an uncertain world. New York, Praeger Publishers.

Karjalainen, T-M., Koria, M., Salimäki M. (2009) "Educating T-shaped Design, Business and Engineering Professionals". Proceedings of the 19th CIRP Design Conference – Competitive Design, Cranfield University, 30-31 March 2009, pp 555. Accessed 20 Oct 2009

<[https://dspace.lib.cranfield.ac.uk/bitstream/1826/3645/3/Educating\\_T-shaped\\_Design\\_Business\\_and\\_Engineering\\_Professionals-2009.pdf](https://dspace.lib.cranfield.ac.uk/bitstream/1826/3645/3/Educating_T-shaped_Design_Business_and_Engineering_Professionals-2009.pdf)>

Kavakli, M., A. R. Stephen, *et al.* (1998). "Structure in idea sketching behaviour." Design Studies Vol. 19: pp. 485-517.

Kelley, T. (2001). "Prototyping is the Shorthand of Innovation." Design Management Journal Vol. 12(No. 3).

Kelly, T. and J. Littman (2001). The Art of Innovation - Lessons in Creativity from IDEO, America's Leading Design Firm. London, Harper Collins Business.

Kiefer, S., L. Silverberg, *et al.* (2004). "A case study of prototyping methods and design for manufacture: Electrostatic window blinds." Journal of Engineering Design Vol. 15(No. 1): pp. 91-106.

Kim, B.-Y. and B.-K. Kang (2008). "Cross-Functional Cooperation with Design Teams in New Product Development." International Journal of Design Vol. 2(No. 3).

Kim, S. (1990). "Interdisciplinary collaboration," In: Laurel, B. (ed.), (1990) "The art of Human Computer interface design," pp. 31-44. Quoted in: Bekker, Mathilde M. (1993) "Representational Issues Related to Communication in Design Teams" INTERACT '93 and CHI '93 conference companion on Human factors in computing systems CHI '93 ACM Press.

Kim, Y. S., M. Philpott, *et al.* (2006). Interdisciplinary Research: Integrated Engineering and Industrial Design.

<[http://www.engr.uiuc.edu/communications/engineering\\_research/1996/gen1/gen1-9.html](http://www.engr.uiuc.edu/communications/engineering_research/1996/gen1/gen1-9.html)> Accessed on 16 May 2006.

Kimura, F. (1997). "Issues in Styling and Engineering Design." CIRP Annuals - Manufacturing Technology Vol. 46(No. 2): pp. 527-534.

Klein, M., H. Sayama, *et al.* (2003). "The Dynamics of Collaborative design: Insights from Complex Systems and Negotiation Research." Concurrent Engineering Vol. 11(No. 3): pp. 201-209.

Kleinsmann, M (2006) Understanding collaborative design (PhD thesis). Delft, University of Technology, Delft.

Kleinsmann, M., J. Buijs, *et al.* (2005). Managing Shared Understanding in Collaborative Design Projects. International Conference of Engineering Design ICED '05, Melbourne August 15-18 2005.

Kleinsmann, M. and A. Dong (2007). Investigating the Affective Force on Creating Shared Understanding. ASME 2007 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2007, Las Vegas, Nevada, USA 4-7 September 2007.

Kleinsmann, M. and R. Valkenburg (2003). Barriers to Shared Understanding in Collaborative Design Projects. International Conference on Engineering Design ICED '03, August 19 - 21 2003, Stockholm.

Kleinsmann, M. and R. Valkenburg (2005). "Learning from collaborative new product development projects." Journal of Workplace Learning Vol. 17(No. 3): pp. 146-156.

Kleinsmann, M. and R. Valkenburg (2008). "Barriers and enablers for creating shared understanding in co-design projects." Design Studies Vol. 29(No. 4).

Kleinsmann, M., R. Valkenburg, *et al.* (2007). "Why do(n't) actors in collaborative design understand each other? An empirical study towards a better understanding of collaborative design." CoDesign Vol. 3(No. 1): pp. 59-73.

Knoben, J. and L. A. G. Oerlemans (2006). "Proximity and inter-organisational collaboration: A literature review." International Journal of Management Reviews Vol. 8(No. 2).

Knoblaugh, R. R. (1958). "Modelmaking for Industrial Design," New York: McGraw-Hill. In: Evans, Mark Andrew (2002) "The Integration of Rapid Prototyping within Industrial Design Practice (Staff Thesis)," Loughborough: Department of Design and Technology Loughborough University.

Kohli, A. K. and B. J. Jaworski (1990). "Market Orientation: The Construct, Research Propositions, and Managerial Implications." In: *Journal of Marketing* 54 pp. 1-189. Quoted in: Menon, A., Jaworski, B.J., Kohli, A. K. (1997) "Product Quality: Impact of Interdepartmental Interactions" *Journal of the Academy of Marketing Science* Vol. 25 No. 3.

Kojima, T., S. Matsuda, *et al.* (1991). "Models and Prototypes," Tokyo: Graphic-Sha Publishing. In: Evans, Mark Andrew (2002) "The Integration of Rapid Prototyping within Industrial Design Practice (Staff Thesis)," Loughborough: Department of Design and Technology Loughborough University.

Kolodner, J. L. and L. M. Wills (1996). "Powers of observation in creative design," *Design Studies* Vol. 17 No. 4 pp. 385-416. Quoted in: Yang, Maria C. and Daniel, J. (2005) "A study of prototypes, design activity, and design outcome," *Design Studies* Vol. 26 No. 6.

Kosslyn, S. (1994). Image and Brain: The Resolution of the Imagery Debate. Cambridge, MA, MIT Press.

Kotler, P. and G. Armstrong (2003). Principles of Marketing (10th Ed.). Englewood Cliffs, NJ, Prentice Hall.

Koutamanis, A. (1993). "The future of visual design representations in architecture." Automation in Construction(No. 2): pp. 47-56.

Kristensen, T. (1995). A Contribution of Design to Business: A Competence-based Perspective. Design Interfaces, Vol. 4 Design Management Proceedings of the European Academy of Design: 11-13 Apr 1995, University of Salford.

Kurvinen, E., I. Koskinen, *et al.* (2008). "Prototyping Social Interaction." Design Issues Vol. 24(No. 3).

Kvan, T. (2000). "Collaborative design : What is it?" Automation in Construction Vol. 9(No. 4): pp. 409-415.

Kvan, T. and R. Thilakaratne (2003). Models in the design conversation:Architecture vs engineering. Proceedings of the AASA Conference, Melbourne: Association of Architecture Schools of Australasia.

Lakin, F. (1990). "Visual languages for cooperation: a performing medium approach to systems for cooperative work," In: Gategher, J.; Kraut, R. E. and Egidio, C. (eds)(1990) "Intellectual/ Teamwork: Social and technological Foundations of Cooperative Work," Lawrence Edbaum Associates pp. 453-488. Quoted in: Peng, Chengzhi (1994) "Exploring communication in collaborative design: co-operative architectural modelling," *Design Studies* Vol. 15 No. 1.

Lang, S. Y. T., J. Dickinson, *et al.* (2002). "Cognitive factors in distributed design," *Computers in Industry* No. 48 pp. 89-98. Quoted in: Tseng, K. C. and Abdalla, H. (2006) "A novel approach to collaborative product design and development environment," *Proc. IMechE* Vol. 220 Part B: J. Engineering Manufacture.

Larkin, J. H. and H. A. Simon (1987). "Why a Diagram is (sometimes) Worth Ten Thousand Words." Cognitive Science Journal(No. 11): pp. 65-99.

Lawrence, P. R. and J. W. Lorsch (1976). "Differentiation and Integration in Complex Organisations," *Administrative Science Quarterly* No. 12 pp.1-47. Quoted in: Moenaert, Rudy K. and Souder, William E. (1990) "An Information Transfer Model for Integrating Marketing and R&D Personnel in New Product Development Projects," *Journal of Product Innovation Management* No. 7.

Lawson, B. (1984). "Cognitive strategies in architectural design," In: Cross, N. (ed.) (1984) "Developments in Design Methodology," Chichester: Wiley. Quoted in: Roozenburg, N. F. M. and Cross, N. G. (1991) "Models of the design process: integrating across the disciplines," *Design Studies* Vol. 12 No. 4.

Lawson, B. (1994). "Design in Mind," Oxford: Butterworth Architecture. Quoted in: McGown, Alistair; Green, Graham and Rodgers, Paul A. (1998) "Visible ideas: information patterns of conceptual sketch activity," *Design Studies* Vol. 19 No. 4.

Lawson, B. (1997). "How Designers Think - the Design Process Demystified," Oxford: Architectural Press. Quoted in: Persson, Sara and Warell, Anders (2003) "Relational Modes between Industrial Design and Engineering Design - a Conceptual Model for Interdisciplinary Design Work," *Proceedings of the 6th Asian Design International Conference*, Tsukuba.

Lawson, B., K. J. Petersen, *et al.* (2009). "Knowledge Sharing in Interorganisational Product Development Teams: The Effect of Formal and Informal Socialization Mechanisms." *Journal of Product Innovation Management* (No. 26): pp. 156-172.

Ledsome, C. (2006). "Design Education - Boundaries in Our Thinking: Engineering and Product Design." *Engineering Designer - The Journal of the Institution of Engineering Designers* Vol. 32(No. 2).

Lee, K. S. (2008) ME2103 Engineering Visualization and Modelling: Lecture Notes, Semester 1, 2007 / 2008. Singapore, Department of Mechanical Engineering, Faculty of Engineering, National University of Singapore.

Leenders, M. A. A. M. and B. Wierenga (2002). "The Effectiveness of Different Mechanisms for Integrating Marketing and R&D." *Journal of Product Innovation Management* Vol. 19: pp. 305-309.

Leinonen, P., S. Ja Rvela, *et al.* (2005). "Conceptualizing the Awareness of Collaboration: A Qualitative Study of a Global Virtual Team." *Computer Supported Cooperative Work* (No. 14): pp. 301-322.

Leonard-Barton, D. (1991). "Inanimate integrators: a block of wood speaks," *Design Management Journal* Summer 1991 pp. 61-67. Quoted in: Söderman, Mikael (2002) "Comparing Desktop Virtual Reality with handmade sketches and real products: Exploring key aspects for end-users' understanding of proposed products," *Journal of Design Research* Vol. 2 No. 1.

Levitt, T. (1969). "The Marketing Mode." New York: McGraw-Hill. Quoted in: Menon, A., Jaworski, B. J., Kohli, A. K. (1997) "Product Quality: Impact of Interdepartmental Interactions." *Journal of the Academy of Marketing Science* Vol. 25 No. 3 pp. 187-200.

Lévy, P. and A. Guénand (2003). *Including Interdisciplinarity to Industrial Design*. International Conference on Engineering Design ICED '03, August 19 - 21 2003, Stockholm.

Li, W. and Y. Ma (2009). "Special issue on: Collaborative and Multi-disciplinary Product Design." *Concurrent Engineering: Research and Applications* Vol. 17(No. 2): pp. 101 - 102.

Ling, B. (2006a). Design Sojourn - Do I have to be able to draw well to be a good designer? <<http://www.designsojourn.com/index.php/2006/12/06/do-i-have-to-be-able-to-draw-well-to-be-a-good-designer/>> Accessed on 17 June 2007.

Ling, B. (2006b). Tips on how to improve your drawing ability. <<http://www.designsojourn.com/2006/12/08/tips-on-how-to-improve-your-drawing-ability/>> Accessed on 14 December 2006.

Lipson, H. and M. Shpitalni (2000). "Conceptual design and analysis by sketching." Artificial Intelligence for Engineering Design, Analysis and Manufacturing(No. 14): pp. 391-401.

Lofthouse, V. A. and T. A. Bhamra (2000). "Ecodesign Integration: Putting the Co into Ecodesign". Quoted in: Scrivener, Stephen A. R.; Ball, Linden J. and Woodcock, Andre (2000) "Collaborative Design - Proceedings of CoDesigning 2000," London: Springer-Verlag pp. 117.

Loftland, J. (1971). Analyzing Social Settings: A Guide to Qualitative Observation and Analysis. Belmont, California, Wadsworth.

Logan, G. D. and D. F. Radcliffe (2000). "Videoconferencing to Support Designing at a Distance". Quoted in: Scrivener, Stephen A. R.; Ball, Linden J. and Woodcock, Andre (2000) "Collaborative Design - Proceedings of CoDesigning 2000," London: Springer-Verlag pp. 364.

Longman Dictionary of Contemporary English, (2005). D. S. (Ed.). Essex, Pearson Education Limited.

Lorenz, C. (1986). "The Design Dimension: Product Strategy and the Challenge of Global Marketing," Oxford: Blackwell. Quoted in: Paashuis, Victor (1997) "The Organisation of Integrated Product Development," Berlin: Springer-Verlag.

Löwgren, J. (2004). "Animated Use Sketches as Design Representations." Interactions(Nov - Dec).

Löwgren, J. and E. Stolterman (1999). "Design methodology and design practice." Interactions Vol. 6(No. 1): pp. 13-20.

Lucci, R. and P. Oirlandini (1989). "Product Design Models," New York: Van Nostrand Reinhold. In: Evans, Mark Andrew (2002) "The Integration of Rapid Prototyping within Industrial Design Practice (Staff Thesis)," Loughborough: Department of Design and Technology Loughborough University.

Lueptow, R. M. (2000). Graphics Concepts. New Jersey, Prentice Hall.

Lutters, E., E. T. Brinke, *et al.* (2000). "Information management and design & engineering processes." International Journal of Production Research Vol. 38(No. 17).

Luzadder, W. J. (1975). "Innovative Design," London: Prentice-Hall. In: Evans, Mark Andrew (2002) "The Integration of Rapid Prototyping within Industrial Design Practice (Staff Thesis)," Loughborough: Department of Design and Technology Loughborough University.

Maddux, G. A. and W. E. Souder (1993). "Overcoming barriers to the implementation of Concurrent Engineering," In: Parsaei, H.R. and Sullivan, W.G. (eds.) "Concurrent Engineering: contemporary issues and modern design tools," London: Chapman and Hall pp. 68. Quoted in: Paashuis, Victor (1997) "The Organisation of Integrated Product Development," Berlin: Springer-Verlag.

Maffin, D. (1998). "Engineering Design Models: context, theory and practice." Journal of Engineering Design Vol. 9(No. 4).

Maier, A. M., C. Hepperle, *et al.* (2007). Associations between Factors Influencing Engineering Design Communication. International Conference on Engineering Design ICED '07 28-31 August 2007, Cite Des Sciences Et De L'Industrie, Paris, France.

Maltz, E. and A. K. Kohli (2000). "Reducing Marketing's Conflict with Other Functions: The Differential Effects of Integrating Mechanisms." Journal of the Academy of Academy of Marketing Science(No. 28): pp. 479.

Maranzana, N., N. Gartiser, *et al.* (2007). Less Design Resources Thanks to Merging Collaborative Design and Learning Network for Innovative Design. International Conference on Engineering Design ICED 07 28-31 August 2007, Cite Des Sciences et de L'industrie, Paris, France.

March, J. G. and H. A. Simon (1958). "Organisations," New York: Wiley. Quoted in: Moenaert, Rudy K. and Souder, William E. (1990) "An Information Transfer Model for Integrating Marketing and R&D Personnel in New Product Development Projects," Journal of Product Innovation Management No. 7.

Martin, J. (1989). "Technical Illustration," London: McDonald & Co. In: Evans, Mark Andrew (2002) "The Integration of Rapid Prototyping within Industrial Design Practice (Staff Thesis)," Loughborough: Department of Design and Technology Loughborough University.

Mathew, B. S. J. (1997). "Are traditional management tools sufficient for diverse teams?" Team Performance Management Vol. 3(No. 1): pp. 3-11.

Mayall, W. (1983). "Problems... problems," In: Engineering Designer Nov / Dec pp. 3. Quoted in: Holt, J. E., Radcliffe, D. F. and Schoorl, D. (1985) "Design or problem solving a critical choice for the engineering profession," Design Studies Vol. 6 No. 2.

McDonagh, D. and I. Storer (2006). "Mood Boards as a Catalyst and Resource: Researching an Under-Researched Area." Design Journal Vol. 7(No. 3).

McGown, A., G. Green, *et al.* (1998). "Visible ideas: information patterns of conceptual sketch activity." Design Studies Vol. 19(No. 4).

McGuffin, L. and G. Olson (1992). "ShrEdit, a Shared Electronic Workspace," Cognitive Science and Machine Intelligence Laboratory, University of Michigan. In: Nam, Tek-Jin and Wright, David (2001) "The development and evaluation of Syco3D: a real-time collaborative 3D CAD system," Design Studies Vol. 22 No. 6 (2001).

McKim, R. H. (1980). Experiences in Visual Thinking. Boston, PWS Publishers.

McKoy, F. L., N. Vargas-Hernández, *et al.* (2001). Influence of Design Representation on Effectiveness of Idea Generation. Proceedings of DETC'01: ASME 2001 Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Pittsburgh, Pennsylvania, September 9-12, 2001.

Menon, A., S. G. Bharadwaj, *et al.* (1996). "The quality and effectiveness of marketing strategy: effects of functional and dysfunctional conflict in intraorganisational relationships." *Journal of the Academy of Marketing Science*, Vol. 24 No. 4 pp. 299 - 313. Quoted in: Holland, S., Gaston, K. and Gomes, J. (2000) "Critical success factors for cross-functional teamwork in new product development." *International Journal of Management Reviews* Vol. 2 No. 3 pp. 231 - 259.

Menon, A., B. J. Jaworski, *et al.* (1997). "Product Quality: Impact of Interdepartmental Interactions." *Journal of the Academy of Marketing Science* Vol. 25(No. 3).

The Merriam-Webster Dictionary, (1994). F. C. Mish (Ed.). Massachusetts, USA, Merriam-Webster.

Miles, M. B. and A. M. Huberman (1985). Qualitative Data Analysis - A sourcebook for new methods. London, Sage Publications.

Miles, M. B. and A. M. Huberman (1994). Qualitative Data Analysis (2nd Edition). Thousand Oaks, California, Sage Publications.

Miller, L. C. G. (1993). Concurrent Engineering Design - Integrating the Best Practices for Process Improvement. Michigan, Society of Manufacturing Engineers.

Minneman, S. L. and S. R. Harrison (1997). "Space, timestreams and architecture," In: Maher L. M. Gero JS, Sudweeks F (Eds.) "Formal aspects of collaborative CAD," Australia: University of Sydney pp 12-25. Quoted in: Scrivener, Stephen A. R.; Ball, Linden J. and Woodcock, Andre (2000) "Collaborative Design - Proceedings of CoDesigning 2000," London: Springer-Verlag pp. 339.

Moenaert, R. K. and F. Caeldries (1996). "Architectural Redesign, Interpersonal Communication and learning in R&D." *Journal of Product Innovation Management*(No. 13).

Moenaert, R. K., F. Caeldries, *et al.* (2000). "Communication Flows in International Product Innovation Teams." *Journal of Product Innovation Management*(No. 17).

Moenaert, R. K. and W. E. Souder (1990). "An Information Transfer Model for Integrating Marketing and R&D personnel in New Product Development Projects." *Journal of Product Innovation Management*(No. 7): pp. 91-107.

Moenaert, R. K., W. E. Souder, *et al.* (1994a). "R&D-marketing integrating mechanisms, communication flows, and innovation success," *Journal of Product Innovation Management* Vol. 11 No. 1 pp. 31-45. Quoted in: Leenders, Mark A. A. M. and Wierenga, Berend (2002) "The Effectiveness of Different Mechanisms for Integrating Marketing and R&D," *Journal of Product Innovation Management*. Vol. 19 pp. 305-309.

Moenaert, R. K., W. E. Souder, *et al.* (1994b). R&D-marketing integrating mechanisms, communication flows, and innovation success: *Journal of Product Innovation Management*



11(1): 31-45. . In: The Effectiveness of Different Mechanisms for Integrating Marketing and R&D. M. Leenders, A. A. M. and B. Wierenga.

Mohr, J. and R. Spekman (1994). "Characteristics of Partnership Success: Partnership Attributes, Communication Behavior, and Conflict Resolution Techniques." Strategic Management Journal Vol. 15(No. 2): pp. 135-152.

Monahan, P. and D. Powell (1987). "Advanced Marker Techniques," London: MacDonald & Co. In: Evans, Mark Andrew (2002) "The Integration of Rapid Prototyping within Industrial Design Practice (Staff Thesis)," Loughborough: Department of Design and Technology Loughborough University.

Montoya, M. M., A. P. Massey, *et al.* (2009). "Can You Hear Me Now? Communication in Virtual Product Development Teams." Journal of Product Innovation Management(No. 26): pp. 139-155.

Morrison, J. (1990). Jasper Morrison - Designs, Projects and Drawings 1981-1989. London, Architecture Design and Technology Press.

Moyer, D. (2007). Napkin Sketches 101  
<<http://www.steelcase.com/uk/files/3d025ccaa4924ac6b67e7d20a89b35b3/Full%20version%20of%20this%20story.pdf>> Accessed on 3 February 2007.

Muller, W. (2001). "Order and Meaning in Design," Utrecht: Lemma Publishers. Quoted in: Persson, Sara and Warell, Anders (2003) "Relational Modes between Industrial Design and Engineering Design - a Conceptual Model for Interdisciplinary Design Work," Proceedings of the 6th Asian Design International Conference, Tsukuba.

Myers, I.B. & McCaulley, M.H. (1985) "A guide to the development and use of the Myers-Briggs Type Indicator". Consulting Psychologists Press, Palo Alto, California.

Nam, T.-J. and D. Wright (2001). "The development and evaluation of Syco3D: a real-time collaborative 3D CAD system." Design Studies Vol. 22(No. 6).

Naylor, M. and R. Ball (2005). Form Follows Idea - An Introduction to Design Poetics. London, Black Dog Publishing Ltd.

Nihtila, J. (1999). "R&D-Production integration in the early Phases of new product development projects." Journal of Engineering Technology Management(No. 16).

Nilsson, B. and A. K. Waldemarson (1990). "Kommunikation - samspel mellan människor," Studentlitteratur: Lund. Quoted in: Persson, Sara and Warell, Anders (2003) "Relational Modes between Industrial Design and Engineering Design - a Conceptual Model for Interdisciplinary Design Work," Proceedings of the 6th Asian Design International Conference, Tsukuba.

Norrgrén, F. (1992). "New challenges for management of product development", Proceedings of the international product development management conference on new approaches to development and engineering held in Brussels May 18-19, pp. 444-445. Quoted in: Paashuis, Victor (1997) "The Organisation of Integrated Product Development," Berlin: Springer-Verlag.

Oakley, M. (1990). Design Management: A Handbook of Issues and Methods. Oxford, Basil Blackwell Ltd.

Olofsson, E. and K. Sjölin (2005). Design Sketching. Sundsvall, Sweden, Keeos Design Books AB.

Olson, G. M., J. S. Olson, *et al.* (1992). "Small group design meetings: an analysis of collaboration." *Human - Computer Interaction* No. 7 pp. 347 – 374. Quoted in: Maaikle Kleinsmann, M., Valkenburg, R. and Buijs, J. (2007) "Why do(n't) actors in collaborative design understand each other? An empirical study towards a better understanding of collaborative design" In: *CoDesign* Vol. 3 No. 1.

Ostergaard, K. J. and J. D. Summers (2003). A Taxonomic Classification on Collaborative Design. International Conference on Engineering Design (ICED 03), Stockholm August 19-21 2003.

Ostergaard, K. J. and J. D. Summers (2009). "Development of a systematic classification and taxonomy of collaborative design activities." Journal of Engineering Design Vol. 21(No. 1): pp. 57 - 81.

Ostwald, J. (1995). Supporting Collaborative Design with Representations for Mutual Understanding. Conference on the Companion on Human Factors in Computing Systems - Mosaic of Creativity CHI '95 May 7-11, 1995, ACM Press.

Otto, K. and K. Wood (2001). Product Design - Techniques in Reverse Engineering and new Product Development. New Jersey, Prentice Hall.

Paashuis, V. (1988). The Organisation of Integrated Product Development. London, Springer Verlag.

Paashuis, V. (1997). The Organisation of Integrated Product Development. Berlin, Springer-Verlag.

Pacull, F., A. Sandoz, *et al.* (1994). "Duplex: a distributed collaborative editing environment in large scale," In: *Proceedings of the Conference on Computer-Supported Cooperative Work CSCW '94* ACM Press, New York pp. 165-173. Quoted in: Nam, Tek-Jin and Wright, David (2001) "The development and evaluation of Syco3D: a real-time collaborative 3D CAD system," *Design Studies* Vol. 22 No. 6 (2001).

Pahl, G. and W. Beitz (1996). Engineering Design - A Systematic Approach (2nd ed.). New York, Springer-Verlag.

Palmer, D. (2006). "Combining Product Design with Engineering is Key." Eureka - Innovative Engineering, Design & Applications Vol. 18(No. 1).

Palmer, S. E. (1987). "Fundamental Aspects of Cognitive Representation," In: Roch, E. and Lloyds, B. B. (eds.) (1987) "Cognition and Categorization," Hillsdale, NJ: Lawrence Erlbaum Associates. Quoted in: Johnson, S. "What's in a representation, why do we care, and what does it mean? Examining evidence from psychology", *Automation in Construction* 8 (1998) 15-24

Pang, A. and C. Wittenbrink (1997). "Collaborative 3D visualization with Cspray," In: IEEE Computer Graphics and Applications Vol. 17 No. 2 pp. 32-41. Quoted in: Nam, Tek-Jin and Wright, David (2001) "The development and evaluation of Syco3D: a real-time collaborative 3D CAD system," Design Studies Vol. 22 No. 6 (2001).

Park, H. (1996). "Digital and Manual Media in Design", in: Education and Practice, Proceedings of 14th European Conference on Education in Computer Aided Architectural Design in Europe eCAADe 1996, Lund, pp. 325–334. Quoted in: Kim, B.-Y. and B.-K. Kang (2008) "Cross-Functional Cooperation with Design Teams in New Product Development." International Journal of Design Vol. 2 (No. 3).

Parry, M. and X. M. Song (1993). "Determinants of R&D-Marketing Interface in hi-tech Japanese Firms." Journal of Product Innovation Management(No. 10): pp. 4-22.

Patton, M. Q. (1990). Qualitative Evaluation and Research Methods. (2nd Ed.). New York, Sage Publishers.

Pavel, N. (2005). The Industrial Designer's Guide to Sketching. Trondheim, Tapir Academic Press.

Pawar, K. S., B. Haque, *et al.* (1999). "Establishing Concordance within Concurrent Engineering Teams." Concurrent Engineering Vol. 7(No. 3).

Pedgley, O. (2007). "Capturing and analysing own design activity." Design Studies Vol. 28(No. 5).

Pedgley, O. and P. Wormald (2007). "Integration of Design Projects within a Ph.D." Design Issues Vol. 23(No. 3).

Peng, C. (1994). "Exploring communication in collaborative design: Co-operative architectural modelling." Design Studies Vol. 15(No. 1).

Perez, D. (2008). What is Design Intent?  
<<http://www2.ivcc.edu/perez/Design%20Intent.htm>> Accessed on 17 December 2008.

Perks, H., R. Cooper, *et al.* (2005). "Characterizing the role of design in new product development: An empirically derived taxonomy." Journal of Product Innovation Management Vol. 22(No. 2).

Perry, M. and D. Sanderson (1998). "Coordinating joint design work: The role of communication and artifacts." Design Studies Vol. 19(No. 3).

Persson, S. (2002a). "Identifying Factors Influencing Industrial Design and Engineering Design Interaction: A Study of Opinions in an Industrial Product Development Setting," Proceedings of the 11th International Forum on Design Management Research and Education Strategies, Resources and Tools for Design Management Leadership, held in Boston, MA. Quoted in: Persson, Sara (2005) "Toward Enhanced Interaction between Engineering Design and Industrial Design," PhD Thesis, Chalmers University of Technology, Goteborg, Sweden.

Persson, S. (2002b). "Industrial Design and Engineering Design Interaction: Studies of Influencing Factors in Swedish Product Developing Industry," Licentiate Thesis: Department of Product and Production Development, Chalmers University of Technology, Göteborg. Quoted in: Persson, Sara and Warell, Anders (2003) "Relational Modes between Industrial Design and Engineering Design - a Conceptual Model for Interdisciplinary Design Work," Proceedings of the 6th Asian Design International Conference, Tsukuba.

Persson, S. (2002c) Industrial Design and Engineering Design Interaction: Studies of Influencing Factors in Swedish Product Developing Industry: Licentiate Thesis. Department of Product and Production Development, Göteborg, Chalmers University of Technology.

Persson, S. (2005a). Toward Enhanced Interaction between Engineering Design and Industrial Design. Goteborg, Sweden, Chalmers University of Technology.

Persson, S. (2005b). Toward Enhanced Interaction between Engineering Design and Industrial Design: Phd Thesis. Goteborg, Sweden, Chalmers University of Technology.

Persson, S. and C. Räisänen (2005). "Interdisciplinary design work through an Activity Theory Lens: Toward a collaborative workspace". Quoted in: Persson, Sara (2005) "Toward Enhanced Interaction between Engineering Design and Industrial Design," PhD Thesis, Chalmers University of Technology, Goteborg, Sweden.

Persson, S., C. Räisänen, *et al.* (2005). "A collaborative workspace: toward a new perspective on interdisciplinary engineering and industrial design work," submitted to DesignStudies In: Persson, S. and Räisänen, C. (2005) "Interdisciplinary design work through an Activity Theory Lens: Toward a collaborative workspace". Quoted in: Persson, Sara (2005) "Toward Enhanced Interaction between Engineering Design and Industrial Design," PhD Thesis, Chalmers University of Technology, Goteborg, Sweden.

Persson, S. and A. Warell (2003a). Relational Modes between Industrial Design and Engineering Design - a Conceptual Model for Interdisciplinary Design Work. 6th Asian Design International Conference, Tsukuba, Chalmers University.

Persson, S. and A. Warell (2003b). Relational Modes between Industrial Design and Engineering Design - a Conceptual Model for Interdisciplinary Design Work. Proceedings of the 6th Asian Design International Conference (ADC'03) held in Tsukuba, Tsukuba.

Persson, S. and A. Warell (2003c). "Relational Modes between Industrial Design and Engineering Design - a Conceptual Model for Interdisciplinary Design Work". Proceedings of the 6th Asian Design International Conference, Tsukuba, Product and Production Development, Chalmers University, Sweden.

Phelps, E. D. (1977). "Improving the Product Development Process," Industrial Marketing Management No. 6 pp. 47-52. Quoted in: Moenaert, Rudy K. and Souder, William E. (1990) "An Information Transfer Model for Integrating Marketing and R&D Personnel in New Product Development Projects," Journal of Product Innovation Management No. 7.

Pinto, M. B. and J. K. Pinto (1990). "Project team communication and cross-functional cooperation in new program development," *Journal of Product Innovation Management* No. 7 pp. 200-212. Quoted in: Leenders, Mark A. A. M. and Wierenga, Berend (2002) "The Effectiveness of Different Mechanisms for Integrating Marketing and R&D," *Journal of Product Innovation Management*. Vol. 19 pp. 305-309.

Pinto, M. B. and J. K. Pinto (1990). "Project Team Communication and Cross-Functional Cooperation in New Program Development." *Journal of Product Innovation Management* Vol. 7.

Pipes, A. (1990). *Drawing for 3-Dimensional Design: concepts, illustration, presentation.* London, Thames and Hudson.

Pipes, A. (2007). *Drawing for Designers.* London, Laurence King Publishing.

Pisano, G. P. (1997). "The development factory: unlocking the potential of process innovation," Boston, MA: Harvard Business Press. Quoted in: Leenders, Mark A. A. M. and Wierenga, Berend (2002) "The Effectiveness of Different Mechanisms for Integrating Marketing and R&D," *Journal of Product Innovation Management*. Vol. 19 pp. 305-309.

Pitts, G. (1973). *Techniques in Engineering Design.* London, Butterworth & Co. Publishers.

Porras, J. I. and P. J. Robertson (1992). "Handbook of Industrial and Organisational Psychology," Palo Alto, California: Consulting Psychology Press Inc. In: Persson, S. (2002) "Identifying Factors Influencing Industrial Design and Engineering Design Interaction: A Study of Opinions in an Industrial Product Development Setting," *Proceedings of the 11th International Forum on Design Management Research and Education Strategies, Resources and Tools for Design Management Leadership*, held in Boston, MA. Quoted in: Persson, Sara (2005) "Toward Enhanced Interaction between Engineering Design and Industrial Design," PhD Thesis, Chalmers University of Technology, Goteborg, Sweden.

Potter, C. (2000). "The CAID Connection," *Computer Graphics World* Vol. 23 No. 3 pp. 21 - 28. In: Evans, Mark Andrew (2002) "The Integration of Rapid Prototyping within Industrial Design Practice (Staff Thesis)," Loughborough: Department of Design and Technology Loughborough University.

Powell, D. (1990). *Presentation Techniques.* London, Macdonald.

Preece, J., Y. Rogers, *et al.* (2002). *Interaction Design - beyond human-computer interaction.* New York, John Wiley & Sons.

Pugh, S. (1991). *Total Design - Integrated Methods for Successful Product Engineering.* Essex, UK, Pearson Education Limited / Addison-Wesley Publishers Ltd.

Purcell, A. T. and J. S. Gero (1998). "Drawings and the design process." *Design Studies* Vol. 19(No. 4).

Purcell, T., J. Gero, *et al.* (1996). "The Data in Design Protocols: The Issue of Data Coding, Data Analysis in the Development of models of the Design Process," Sydney: University of Sydney. Quoted in: Cross, Nigel; Christiaans, Henri and Dorst, Kees (1996) "Analysing Design Activity," Chichester: John Wiley & Sons.

Purcell, T. and J. S. Gero (1996). "Design and other types of fixation," *Design Studies* No. 17 pp. 363-383. Quoted in: Persson, Sara and Warell, Anders (2003) "Relational Modes between Industrial Design and Engineering Design - a Conceptual Model for Interdisciplinary Design Work," *Proceedings of the 6th Asian Design International Conference*, Tsukuba.

QFD Institute (2008). QFD : Quality Function Deployment. <<http://www.qfdi.org/>> Accessed on 02 May 2008.

Rahim, M. A. (1992). Managing Conflict in Organisations. New York, Praeger Publishers.

Raudebaugh, R. A. and J. Newcomer (1999). Visualization, Sketching and Freehand Drawing for Engineering Design. Mission, Kansas, Schroff Development Corporation.

Reddy, Y. V. R., K. Srinivas, *et al.* (1993). "Computer Support for Concurrent Engineering," *IEEE Computer* Vol. 27 No. 1 pp. 12-16. Quoted in: Miao, Yongwu and Haake, Jörg M. (1999) "Supporting Concurrent Design in SCOPE," *Concurrent Engineering* Vol. 7 No. 1.

Rettig, M. (1994). "Prototyping for tiny fingers." Communications of the ACM Vol. 37(No. 4).

Richards, L. (2005). Handling Qualitative Data- A Practical Guide. London, Sage Publications.

Robbins, E. (1994). "Why Architects Draw," Cambridge, MA: MIT Press. Quoted in: Do, Ellen Yi-Luen (2002) "Drawing marks, acts, and reacts: Toward a computational sketching interface for architectural design," *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* No.16 pp. 149-171.

Robertson, T. (1996). "Embodied actions in time and place: the cooperative design of a multimedia educational computer game" *CSCW* Vol. 5 No. 4 pp. 341-367. Quoted in: Perry, Mark and Sanderson, Duncan (1998) "Coordinating joint design work: the role of communication and artifacts," *Design Studies* Vol. 19 No. 3.

Robson, C. (1993). Real World Research - A Resource for Social Scientists and Practitioner-Researchers. Oxford, Blackwell Publishers.

Rodriguez, W. (1992). The Modelling of Design Ideas - Graphics and Visualization Techniques for Engineers. Singapore, McGraw-Hill Book Company.

Roller, D., O. Eck, *et al.* (2002). "Advanced database approach for cooperative product design." Journal of Engineering Design Vol. 13(No. 1).

Romer, A., M. Pache, *et al.* (2001). "Effort-saving product representations in design-results of a questionnaire survey." Design Studies Vol. 22(No. 6): pp. 473-491.

Roozenburg, N. F. M. and N. G. Cross (1991). "Models of the design process: integrating across the disciplines." Design Studies Vol. 12(No. 4).

Roozenburg, N. F. M. and J. Eekels (1995). Product Design: Fundamentals and Methods. Chichester, John Wiley and Sons Ltd.

Rosenberg, D. (2006). "Revisiting Tangible Speculation: 20 Years of UI Prototyping." Interactions(January February).

Rosenthal, S. R. (1992). Effective Product Design and Development - How to cut lead time and increase customer satisfaction. Homewood, IL, Business One Irwin.

Rossmann, G. B. and B. L. Wilson (1984). "Numbers and Words: Combining Quantitative and Qualitative Methods in a Single Large-scale Evaluation Study" *Evaluation Review* Vol. 9 No. 5 pp. 627 - 643. Quoted in: Miles, M. B. and A. M. Huberman (1994). "Qualitative Data Analysis" (2nd Edition). Thousand Oaks, California, Sage Publications.

Rothstein, P. (2002). "When Worlds Collide: Integrated Development with Business and Design Students." Design Management Journal Summer: pp. 62-67.

Rothwell, R. (1992). "Successful industrial innovation: Critical factors for the 1990s," *R&D Management* Vol. 22 No. 3 pp. 221-239. Quoted in: Song, X. Michael; Montoya-Weiss, Mitzi M. and Schmidt, Jeffrey B. (1997) "Antecedents and Consequences of Cross-Functional Cooperation: A Comparison of R&D, Manufacturing and Marketing Perspectives," *Journal of Product Innovation Management* No. 14.

Rouibah, K. and K. Caskey (2003). "A workflow system for the management of inter-company collaborative engineering processes." Journal of Engineering Design Vol. 14(No. 3): pp. 273-293.

Saddler, H. J. (2001). "Understanding Design Representations." Interactions July - August.

Schachinger, P. (2002). "Supporting form Synthesis - Modelling Product Structure and Behaviour in a Computerized Environment," Ph.D. thesis: Product and Production Development, Chalmers University of Technology, Gothenburg. Quoted in: Persson, Sara (2002) "Industrial Design - Engineering Design Interaction: Studies of Influencing Factors in Swedish Product Developing Industry," Thesis for the degree of Licentiate of Engineering, Product and Production Department, Chalmers University of Technology, Göteborg, Sweden.

Schmidt, K. (1998). "Cooperative design : prospects for CSCW in design." Design Sciences and Technology Vol. 6(No. 2): pp. 5-18.

Schmidt, K. and I. Wagner (2002). "Coordinative artifacts in architectural practice," In: Blay-Fornarino, M.; Pinna-Dery, A.M.; Schmidt, K. and Zaraté, P. (eds.) "Cooperative systems design: A challenge of the mobility age" *Proceedings of the Fifth International Conference on the Design of Cooperative Systems, COOP 2002*, pp. 257-274. Quoted in: Visser, Willemien (2007) "Collaborative Designers' Different Representations," *International Conference on Engineering Design (ICED '07)* held in Cite Des Sciences Et De L'Industrie, Paris, France 28 - 31 August 2007.

Schmidt, K. and I. Wagner (2004). "Ordering Systems: Coordinative Practices and Artifacts in Architectural Design and Planning." Computer Supported Cooperative Work(No. 13).

Schön, D. (1963). "Displacement of concepts," London: Tavistock Publications. Quoted in: Bucciarelli, Louis L. (2002) "Between thought and object in engineering design," *Design Studies* Vol 23 No. 3.

Schön, D. A. (1983). The Reflective Practitioner: How professionals think in action. London, Temple Smith.

Schön, D. A. and G. Wiggins (1992). "Kinds of seeing and their functions in designing." Design Studies Vol. 13.

Schrage, M. (1990). "Shared Minds: The New Technologies of Collaboration," New York: Random House. Quoted in: Persson, Sara and Warell, Anders (2003) "Relational Modes between Industrial Design and Engineering Design - a Conceptual Model for Interdisciplinary Design Work," Proceedings of the 6th Asian Design International Conference, Tsukuba.

Schrage, M. (1993). "The Cultures of Prototyping." Design Management Journal Winter 1993: pp. 55-65.

Schweikardt, E. and M. D. Gross (2000). "Digital clay: deriving digital models from freehand sketches." Automation in Construction(No. 9).

Scrivener, S., D. Harris, *et al.* (1993). "Designing at a distance via real-time designer-to-designer interaction," Design Studies Vol. 14 No. 3 pp. 261-282. Quoted in: Nam, Tek-Jin and Wright, David (2001) "The development and evaluation of Syco3D: a real-time collaborative 3D CAD system," Design Studies Vol. 22 No. 6 (2001).

Scrivener, S. A. R., L. J. Ball, *et al.* (2000). Collaborative Design - Proceedings of CoDesigning 2000. London, Springer-Verlag.

Scrivener, S. A. R. and S. M. Clark (1994). "Sketching in collaborative design," In MacDonald, L. and Vince, J. (eds.) "Interacting with virtual environments," Chichester: Wiley. Quoted in: Van der Lugt, Remko (2005) "How sketching can affect the idea generation process in design group meetings," Design Studies Vol. 26 No. 2.

Searle, J. (1969). "Speech acts: an essay in the philosophy of language," Cambridge: Cambridge University Press. Quoted in: Bucciarelli, Louis L. (2002) "Between thought and object in engineering design," Design Studies Vol. 23 No. 3.

Sebastian, R. (2005). "The Interface between Design & Management." Design Issues Vol. 2(No. 1).

Seitamaa-Hakkarainen, P. and K. Hakkarainen (2000). "Visualization and Sketching in the Design Process." Design Journal Vol. 3(No. 1).

Sharrock, W. and B. Anderson (1996). "Organisational innovation and the articulation of the design space," In: Moran TP, Carroll JM, (eds.) (1996) "Design Rationale: Concepts, Techniques, and Use," Marwah, NJ: Lawrence Erlbaum, pp. 429-451. Quoted by: Davis, Joseph G.; Subrahmanian, E.; Konda, Suresh; Granger, Helen; Collins, Michael; Westerberg, Arthur W. (2001) "Creating Shared Information Spaces to Support Collaborative Design Work," Information Systems Frontiers Vol. 3 No. 3 pp. 377-392.

Sherman, J. D., W. E. Souder, *et al.* (2000). "Differential Effects of the Primary Forms of Cross Functional Integration on Product Development Cycle Time." Journal of Product Innovation Management(No. 17).



Shetty, D. (2002). Design for Product Success. Dearborn, Michigan, Society of Manufacturing Engineers (SME).

Shigley, J. and C. Mischke (1989). Mechanical Engineering Design (5th ed.). New York, McGraw-Hill, Inc.

Shyamsundar, N. and R. Gadh (2002). "Collaborative virtual prototyping of product assemblies over the Internet," *Computer Aided Design* No. 34 pp. 755-768. Quoted in: Tsai, Chieh-Yuan; Sun, Te-Hsiu; Huang, Jun-Xian (2006) "A web-based XML information sharing system for collaborative product development," *International Journal of Production Research* Vol. 44, No.15.

Sicotte, H. and A. Langley (2000). "Integration mechanisms and R&D project Performance." Journal of Engineering Technology Management (No. 17).

Singh, K. (2007). Quantitative Social Research Methods. New Delhi, Sage Publications.

Siu, N. W. C. and C. Dilnot (2001). "The challenge of the codification of tacit knowledge in designing and making: A case study of CAD systems in the Hong Kong jewellery industry." Automation in Construction(No. 10).

Smith, G. and T. W. A. Whitfield (2005). "The Professional Status of Designers: A National Survey of How Designers are Perceived." Design Journal Vol. 8(No. 1).

Smith, M. B. J. (1997). "Are traditional management tools sufficient for diverse teams?" Team Performance Management Vol. 3(No. 1): pp. 3-11.

Smyth, M. (1998). "The tools designers use: what do they reveal about design thinking?" Idater 98 Loughborough University.

Snyder, C. (2003). Paper Prototyping: The Fast and Easy Way to Design and Refine User Interfaces. New York, Morgan Kaufmann.

Söderman, M. (2002). "Comparing Desktop Virtual Reality with handmade sketches and real products: Exploring key aspects for end-users' understanding of proposed products." Journal of Design Research Vol. 2(No. 1).

Sommerville, I. (1995). "Software engineering, Wokingham," England: Addison-Wesley. Quoted in: Yang, Maria C. and Daniel, J. (2005) "A study of prototypes, design activity, and design outcome," *Design Studies* Vol. 26 No. 6.

Song, S. and A. S. Agogino (2004). "Insights on designers' sketching activities in product design teams," In: ASME Design Engineering Technical Conference '04 held in Salt Lake City, Utah. Quoted in: Yang, Maria C. and Daniel, J. (2005) "A study of prototypes, design activity, and design outcome," *Design Studies* Vol. 26 No. 6.

Song, S., A. Dong, *et al.* (2003). "Time variation of design 'story telling' in engineering design teams" In: Proceedings of International Conference on Engineering Design ICED03, Stockholm, Sweden. Quoted in: Kleinsmann, M. and Valkenburg, R. (2008) "Barriers and enablers for creating shared understanding in co-design projects," *Design Studies* Vol. 29 No. 4.

Song, X. M., M. M. Montoya-Weiss, *et al.* (1997). "Antecedents and Consequences of Cross-Functional Cooperation: A Comparison of R&D, Manufacturing and Marketing Perspectives." Journal of Product Innovation Management(No. 14).

Song, X. M., R. J. Thieme, *et al.* (1998). "The Impact of Cross Functional Joint Involvement Across Product Development Stages: An Exploratory Study." Journal of Product Innovation Management(No. 15).

Souder, W. E. (1987). "Managing New Product Innovations," Lexington, MA: Lexington Books. Quoted in: Griffin, Abbie and Hauser, John R. (1996) "Integrating R&D and Marketing: A Review and Analysis of the Literature," Journal of Product Innovation Management No. 13.

Sparke, P. (1983). Consultant Design: The History and Practice of the Designer in History (Pembroke History of Design Series). London, Pembroke Press.

Sparke, P. (1996). "An Introduction to Design & Culture in the 20th Century," London: Allen & Unwin Publishers. Quoted in: R. Hague, I. Campbell, P. Dickens, P. Reeves (2002) "Integration of Rapid Manufacturing in Design: Time Compression Technologies," Vol. 10 No. 4 pp. 48.

Sprow, E. (1992). "Chrysler's concurrent engineering challenge," Manufacturing Engineering Vol. 108 No. 4 pp. 35-42. Quoted in: Wang, Lihui; Shen, Weiming; Xie, Helen; Neelamkavil, Joseph and Pardasani, Ajit (2002) "Collaborative Conceptual Design - State of the Art and Future Trends," Computer Aided Design No. 34.

Stacey, M. and C. Eckert (2003). "Against Ambiguity." Computer Supported Cooperative Work (No. 12): pp. 153-183.

Stake, R. E. (1995). The Art of Case Research. Thousand Oaks, CA, Sage Publications.

Star, S. L. (1989). "The structure of ill-structured solutions: boundary objects and heterogeneous distributed problem solving" In: Distributed artificial intelligence, Gasser and Huhns (eds) Vol 2, Pitman, London pp 37-54. Quoted in: Eckert, Claudia and Boujut, Jean-Francois (2003) "The Role of Objects in Design Co-Operation: Communication through Physical or Virtual Objects," Computer Supported Cooperative Work No. 12 pp. 145-151.

Stauffer, L. A., M. Diteiman, *et al.* (1991). "Eliciting and Analysing Subjective Data about Engineering Design." Journal of Engineering Design Vol. 2(No. 4).

Stempfle, J. and P. Badke-Schaub (2002). "Thinking in design teams - An analysis of team communication." Design Studies Vol. 23(No. 5).

Strauss, A. and J. Corbin (1990). Basics of qualitative research: grounded theory procedures and techniques. London, Sage Publications.

Subrahmanian, E., I. Monarch, *et al.* (2003). "Boundary Objects and Prototypes at the Interfaces of Engineering Design." Computer Supported Cooperative Work No. 12: pp. 185-203.

Suri, J. F. (2003). "The Experience of Evolution: Developments in Design Practice." Design Journal Vol. 6(No. 2).

Suwa, M., J. S. Gero, *et al.* (2000). "Unexpected discoveries and s-inventions of design requirements: Important vehicles for a design process." Design Studies Vol. 21: pp. 539-567.

Suwa, M. and B. Tversky (1996). "What Architects See in Their Sketches: A Protocol Analysis." Artificial Intelligence in Design '96, Stanford University.

Suwa, M. and B. Tversky (1997). "What do architects and students perceive in their design sketches? A protocol analysis." Design Studies Vol. 18(No. 4): pp. 385–403.

Svengren, L. (1995). "Industriell design som strategisk resurs - en studie av designprocessens metoder och synsätt som del i företagets strategiska utveckling," Ph.D. thesis: The institute of Economic Research, Lund University Press, Lund. Quoted in: Persson, Sara (2002) "Industrial Design - Engineering Design Interaction: Studies of Influencing Factors in Swedish Product Developing Industry," Thesis for the degree of Licentiate of Engineering, Product and Production Department, Chalmers University of Technology, Göteborg, Sweden.

Swink, M. L., J. C. Sandvig, *et al.* (1996). "Customizing Concurrent Engineering Processes: Five Case Studies." Journal of Product Innovation Management(No. 13).

Syan, C. S. and U. Menon (1994). Concurrent Engineering - Concepts, Implementation and Practice. London, Chapman & Hall.

Tang, J. (1989). "Listing, Drawing, and Gesturing in Design: A Study of the Use of Shared Workspaces by Design Teams," Ph.D. thesis: Stanford University, Stanford, CA. Quoted in: Eckert, Claudia and Boujut, Jean-Francois (2003) "The Role of Objects in Design Co-Operation: Communication through Physical or Virtual Objects," Computer Supported Cooperative Work No. 12 pp. 145-151.

Tang, J. (1991a). "Findings from Observational Studies of Collaborative Work," International Journal of Man-Machine Studies Vol. 34 No. 2 pp. 143-160. Quoted in: Gutwin, C., Greenberg, S. (2002) "A Descriptive Framework of Workspace Awareness for Real-Time Groupware," Computer Supported Cooperative Work No. 11.

Tang, J. C. (1991b). "Findings from observational studies of collaborative work," International Journal of Man-Machine Studies Vol. 34 pp. 143-160. Quoted in: Scrivener, Stephen A. R.; Ball, Linden J. and Woodcock, Andre (2000) "Collaborative Design - Proceedings of CoDesigning 2000," London: Springer-Verlag pp. 339.

Tannenbaum, R. and W. Schmidt (1973). "How to Choose a Leadership," Harvard Business Review May-June 1973. Quoted in: Girard, Philippe and Robin, Vincent (2006) "Analysis of collaboration for project design management," Computers in Industry No. 57.

Tatar, D., G. Foster, *et al.* (1991). "Design for Conversation: Lessons from Cognoter," International Journal of Man-Machine Studies Vol. 34 No. 2 pp. 185-210. Quoted in: Gutwin, C., Greenberg, S. (2002) "A Descriptive Framework of Workspace Awareness for Real-Time Groupware," Computer Supported Cooperative Work No. 11.

Tavcar, J., R. Zavbi, *et al.* (2005). "Skills for Effective Communication and Work in Global Product Development Teams." Journal of Engineering Design Vol. 16(No. 6).

TCT (2000). "Rapid Prototyping & Tooling - Concept Modelling: The Key to Fast Product Development?" Time Compression Technologies Vol. 8(No. 4).

Te Duits, T. (2003). The Origins of Things - Sketches, Models, Prototypes. Rotterdam, Museum Boijmans Van Beuningen Rotterdam / NAI Publishers.

Tellis, W. (1997). Introduction to Case Study, cited in "The Qualitative Report", Vol. 3, No. 2. <<http://www.nova.edu/ssss/QR/QR3-2/tellis1.html>> Accessed on 12 November 2007.

Temple, S. (1994). "Thought made visible: the value of sketching." Co-Design Vol. 1: pp. 16-25.

Tessarolo, P. (2007). "Is Integration Enough for Fast Product Development? An Empirical Investigation of the Contextual Effects of Product Vision." Journal of Product Innovation Management(No. 24): pp. 69-82.

Thamhain, H. J. (1990). "Managing Technologically Innovative Team Efforts Toward New Product Success." Journal of Product Innovation Management(No. 7).

Tjalve, E. (1979). A Short Course in Industrial Design. London, Butterworth & Co.

Tjalve, E., M. M. Anderessen, *et al.* (1979a). Engineering Graphic Modelling: A Practical Guide to Drawing and Design. London, Newnes-Butterworth.

Tjalve, E., M. M. Andreasen, *et al.* (1979b). Engineering Graphic Modelling - A Workbook for Design Engineers. London, Butterworth & Co.

Tjosvold, D. (1990). "Power in Cooperative and Competitive Organisational Contexts." In: Journal of Social Psychology Vol. 130 No. 2: pp. 249-258. Quoted in: Menon, A., Jaworski, B.J., Kohli, A. K. (1997) "Product Quality: Impact of Interdepartmental Interactions" Journal of the Academy of Marketing Science Vol. 25 No. 3.

Tohidi, M., W. Buxton, *et al.* (2006). User sketches: A quick, inexpensive, and effective way to elicit more reflective user feedback. Proceedings of NordiCHI, The Nordic Conference on Human-Computer Interaction pp. 105-114.

Tovey, M. (1984). "Designing with both halves of the brain." Design Studies Vol. 5(No. 4).

Tovey, M. (1989). "Drawing and CAD in industrial design." Design Studies Vol. 10(No. 1): pp. 24-39.

Tovey, M. (1991). "Automotive Stylists Design Thinking: Visual Creativity and CAD". Quoted in: Cross, Nigel; Dorst, Kees and Roosenburg, Norbert (1991) "Research in Design Thinking," Proceedings of a workshop meeting held at the Faculty of Industrial Design Engineering, Delft University of Technology, the Netherlands, May 29-31 1991.  
Tovey, M. (1997). "Styling and design: intuition and analysis in industrial design." Design Studies Vol. 18(No. 1).

Tovey, M. and J. Owen (2000). "Sketching and direct CAD modelling in automotive design." Design Studies Vol. 21(No. 6).

Tovey, M., S. Porter, *et al.* (2003). "Sketching, concept development and automotive design." Design Studies Vol. 24(No. 2): pp. 135-153.

Trueman, M. (1998). "Competing Through Design," *Journal of Long Range Planning* Vol. 31 No. 4 pp. 594. Quoted in: Hands, David; Edge, Stephen and Jerrard, Bob (2004) "Design as an Integrated Process: Haley Sharpe Associates - Ten Years On," *Design Journal* Vol. 7 No. 1.

Trygg, L. (1993a). "Concurrent engineering practices in selected Swedish companies: A movement of an activity of the few?" Journal of Product Innovation Management(No. 10): pp. 403-415.

Trygg, L. (1993b). "Concurrent Engineering Practices in Selected Swedish Companies: A Movement or an Activity of the Few?" Journal of Product Innovation Management(No. 10).

Tseng, K. C. and H. Abdalla (2006). "A novel approach to collaborative product design and development environment." Proceedings of the IMechE Vol. 220 Part B: Journal of Engineering Manufacture.

Turner, R. (2000). "Design and business: Who calls the shots?" Design and Management Journal Vol. 11(No. 3).

Ullman, D. G. and T. G. Dietterich (1987). "Toward expert CAD," *Computers in Mechanical Engineering* Vol. 6 No. 3 pp. 56-70. Quoted in: Ullman, David G.; Wood, Stephen and Craig, David (1990) "The Importance of Drawing in the Mechanical Design Process," *Computer & Graphics* Vol. 14 No. 2 pp, 203-274.

Ullman, D. G. (2003). The Mechanical Design Process (3rd ed.). New York, McGraw-Hill.

Ullman, D. G., S. Wood, *et al.* (1990). "The Importance of Drawing in the Mechanical Design Process." Computer & Graphics Vol. 14(No. 2).

Ulrich, K. T. and S. D. Eppinger (2003). Product Design and Development (3rd ed.). New York, McGraw-Hill.

Ulusoy, Z. (1999). "To design versus to understand design: the role of graphic representations and verbal expressions." Design Studies Vol. 20(No. 2): pp. 123-130.

Urban, G. L. and J. R. Hauser (1993). "Design and Marketing of New Products (2nd Ed.)," Englewood Cliffs, NJ: Prentice Hall. Quoted in: Song, X. Michael; Montoya-Weiss, Mitzi M. and Schmidt, Jeffrey B. (1997) "Antecedents and Consequences of Cross-Functional Cooperation: A Comparison of R&D, Manufacturing and Marketing Perspectives," *Journal of Product Innovation Management* No. 14.

Utterback, J., B.-A. Vedin, *et al.* (2006). Design Inspired Innovation. Singapore, World Scientific Publishing.

Vajna, S. and C. Burchardt (1998). "Dynamic Development Structures of Integrated Product Development." Journal of Engineering Design Vol. 9(No. 1).

Valkenburg, R. and K. Dorst (1998). "The reflective practice of design teams." Design Studies Vol. 19(No. 3): pp. 249-694.

Valkenburg, R. C. (1998). "Shared understanding as a condition for team design." Automation in Construction(No. 7).

Van de Ven, A. H., A. L. Delbecq, *et al.* (1976). "Determinants of coordination modes within Organisations," *American Sociological Review* No. 41 pp. 322-338. Quoted in: Pinto, Mary Beth and Pinto, Jeffrey K. (1990) "Project Team Communication and Cross-Functional Cooperation in New Program Development," *Journal of Product Innovation Management* Vol. 7.

Van der Lugt, R. (2002). Functions of Sketching in Design Idea Generation Meetings. Proceedings of the 4th conference on Creativity & cognition C&C '02, ACM Press.

Van der Lugt, R. (2005). "How sketching can affect the idea generation process in design group meetings." Design Studies Vol. 26(No. 2).

Van Welie, M. and G. C. Van der Veer (2000). "Structured Methods and Creativity: A Happy Dutch Marriage". Quoted in: Scrivener, Stephen A. R.; Ball, Linden J. and Woodcock, Andre (2000) "Collaborative Design - Proceedings of CoDesigning 2000," London: Springer-Verlag pp. 117.

Verschuren, P. and H. Doorewaard (1999). Designing a Research Project. Utrecht, Uitgeverij Lemma BV.

Verstijnen, I. M., J. M. Hennessey, *et al.* (1998). "Sketching and creative discovery." Design Studies Vol. 19(No. 4).

Veveris, M. (1994). The importance of the use of physical engineering models in design. IDATER 1994 Conference, Loughborough University (Design and Technology).

Vinck, D. and A. Jeantet (1995). "Mediating and Commissioning Objects in the Sociotechnical Process of Product Design: A Conceptual Approach," In: MacLean, D.; Saviotti, P. and Vinck, D. (eds.) "Management and New Technology: Design, Networks and Strategy," Brussels: COST Social Science Series. Quoted in: Eckert, Claudia and Boujut, Jean-Francois (2003) "The Role of Objects in Design Co-Operation: Communication through Physical or Virtual Objects," *Computer Supported Cooperative Work* No. 12 pp. 145-151.

Virzi, R. A., J. L. Sokolov, *et al.* (1996). Usability Problem Identification Using Both Low and High Fidelity Prototypes. Proceedings of CHI '96 pp. 236-43.

Visser, W. (2006). "Designing as construction of representations: A dynamic viewpoint in cognitive design research." Human-Computer Interaction, Special Issue "Foundations of Design in HCI" Vol. 21(No. 1): pp. 103-152.

Visser, W. (2007). Collaborative Designers' Different Representations. International Conference on Engineering Design (ICED '07) 28 - 31 August 2007, Cite Des Sciences Et De L'Industrie, Paris, France.

Vroom, V. and A. Jago (1978). "On the Validity of the Vroom-Yetton Model," *Journal of Applied Psychology* Vol. 63 No. 2 pp.151-162. Quoted in: Ostergaard, Karen J. and Summers, Joshua D. (2003) "A Taxonomic Classification on Collaborative Design,"

International Conference on Engineering Design ICED '03 held in Stockholm August 19-21 2003.

Wall, S. and R. Lepsinger (1994). "Cross-functional obstacles," in: Training Vol. 5 No. 2. Quoted in: Kim, B.-Y. and B.-K. Kang (2008) "Cross-Functional Cooperation with Design Teams in New Product Development." International Journal of Design Vol. 2(No. 3).

Walsh, V. and R. Roy (1985). "The Designers as Gatekeepers in manufacturing Industry." Design Studies Vol. 6(No. 3): pp. 127.

Walsh, V., R. Roy, *et al.* (1992). "Winning by Design," Oxford: Basil Blackwell Ltd. Quoted in: Persson, Sara (2005) "Toward Enhanced Interaction between Engineering Design and Industrial Design," PhD Thesis: Goteborg, Sweden: Chalmers University of Technology.

Wang, L., W. Shen, *et al.* (2002). "Collaborative Conceptual Design - State of the Art and Future Trends." Computer Aided Design(No. 34).

Warell, A. (2001). "Design syntactics: A functional approach to visual product form," PhD Thesis: Department of Product and Production Development, Chalmers University of Technology, Göteborg. Quoted in: Persson, Sara and Warell, Anders (2003) "Relational Modes between Industrial Design and Engineering Design - a Conceptual Model for Interdisciplinary Design Work," Proceedings of the 6th Asian Design International Conference, Tsukuba.

Weaver, T. (2006). "One Stop Shop." Engineering - For Innovators in Technology, Manufacturing and Management Vol. 247(No. 2).

Wenger, E. (1998). "Communities of Practice - Learning, Meaning, and Identity," New York: Cambridge University Press. Quoted in: Maier, Anja M.; Hepperle, Clemens; Kreimeyer, Matthias; Eckert, Claudia; Lindemann, Udo and Clarkson, P. John (2007) "Associations between Factors Influencing Engineering Design Communication," International Conference on Engineering Design, ICED '07 held in Cite Des Sciences Et De L'Industrie, Paris, France 28 - 31 August 2007.

Wiendahl, H. P. (1981). "Five years experience with VDI 2222 guideline in a large capital equipment enterprise." Design Studies Vol. 2(No. 3).

Wiio, O. (1973). "Kommunikation - vad är det?" Bokförlaget Natur och Kultur, Stockholm. Quoted in: Persson, Sara and Warell, Anders (2003) "Relational Modes between Industrial Design and Engineering Design - a Conceptual Model for Interdisciplinary Design Work," Proceedings of the 6th Asian Design International Conference, Tsukuba.

Wikström, L. (2001). "Produktens budskap - metoder för värdering av produktens sematiska funktioner ur ett användarperspektiv", Ph.D. thesis: Product and Production Development, Chalmers University of Technology, Gothenburg. Quoted in: Persson, Sara (2002) "Industrial Design - Engineering Design Interaction: Studies of Influencing Factors in Swedish Product Developing Industry," Thesis for the degree of Licentiate of Engineering, Chalmers University of Technology Göteborg, Sweden.

Wilson, B. (1995). "Wscrawl 2.0: A shared whiteboard based on X Windows," In: Greenberg, S., Hayne, S. and Rada, R. (eds.) "Groupware for Real-Time Drawing: A Designer's Guide," McGraw-Hill Book Company pp 130-142. Quoted in: Nam, Tek-Jin and

Wright, David (2001) "The development and evaluation of Syco3D: a real-time collaborative 3D CAD system," *Design Studies* Vol. 22 No. 6 (2001).

Wohlers, T. (2005). "Is Rapid Manufacturing Real?" *Time Compression Technologies* Vol. 13 Sep / Oct(No. 5).

Wong, Y. Y. (1992). Rough and Ready Prototypes: Lessons from Graphic Design - Posters and Short Talks. Proceedings of Human Factors in Computing Systems, ACM Press, New York.

Woodham, J. M. (1983). Pembridge History of Design Series: The Industrial Designer and the Public. London, Pembridge Press.

Woodtke, M. V. (2000). "Design with Digital Tools," Blacklick: McGraw Hill pp. 108. In: Evans, Mark Andrew (2002) "The Integration of Rapid Prototyping within Industrial Design Practice (Staff Thesis)," Loughborough: Department of Design and Technology Loughborough University.

Wright, I. (1998). Design Methods in Engineering and Product Design. Berkshire, McGraw Hill Publishing Company.

Yamamoto, M. and D. R. Lambert (1994). "The impact of product aesthetics on the evaluation of industrial products," *Journal of Product Innovation Management* No. 11 pp 309. In: Gemsera, Gerda and Leenders, Mark A. A. M. (2001) "How integrating industrial design in the product development process impacts on company performance," *Journal of Product Innovation Management* No. 18.

Yamamoto, Y., K. Nakakoji, *et al.* (2000). "Hands-on representations in a two-dimensional space for early stages of design." *Knowledge-Based Systems* No. 13: pp. 375-384.

Yang, M. C. (2003). "Concept generation and sketching: Correlations with design outcome," In: ASME Design Engineering Technical Conferences '03 held in Chicago, IL. Quoted in: Yang, Maria C. and Daniel, J. (2005) "A study of prototypes, design activity, and design outcome," *Design Studies* Vol. 26 No. 6.

Yang, M. C. and J. G. Cham (2007). "An Analysis of Sketching Skill and Its Role in Early Stage Engineering Design." Transactions of the ASME(No. 129).

Yang, M. C. and J. Daniel (2005). "A study of prototypes, design activity, and design outcome." *Design Studies* Vol. 26(No. 6).

Yin, R. K. (1989). Case Study Research: design and methods. Newbury Park, CA, Sage Publications.

Yin, R. K. (1994). Case Study Research: Design and Methods (2nd Edition). Thousand Oaks, CA, Sage Publications.

Young, R. A., G. J. Van Der Veen, *et al.* (2000). "Creating Enhanced User Experiences: The Designer is a 'Co-operator' by Facilitating Communication". Quoted in: Scrivener, Stephen A. R.; Ball, Linden J. and Woodcock, Andre (2000) "Collaborative Design - Proceedings of CoDesigning 2000," London: Springer-Verlag pp. 37.



## 13. APPENDIX

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### 13.1 *Categories of Design Methods*

These categories of design methods have been compiled from the literature review and are arranged in an alphabetical order.

**Acquiring and Processing Information** can be achieved through literature reviews, brainstorming, synectics and analogies. user surveys & questionnaires, benchmarking, reverse engineering, metric definitions, laboratory experiments, simulation & computer analysis and formal design reviews (Dym and Little 2003). Dym and Little

**Action Planning Methods** include storyboarding, solution selection diagrams, grouping techniques and nominal group techniques (Shetty 2002). Shetty

**Analytic-Systematic Methods** are based analyzing and describing a problem, then drawing solutions and variants and finally combining these variants. Examples are the morphological method, function analysis, choice of perimeters and AIDA (analysis of interconnected decision areas) (Roozenburg and Eekels 1995). Roozenburg and Eekels

**Combining Solutions** work by means by systematic combination and optimization (Dym and Little 2003). Dym and Little

**Convergent Methods** evaluate solutions and include checklists, selecting criteria, ranking and weighting, specification writing and Quirk's reliability index (Jones 1992). Jones

**Creative Associative Methods** encourage spontaneous reactions to proposed ideas. Some examples are psychological associations, brainstorming and brain-writing (Roozenburg and Eekels 1995). Roozenburg and Eekels

**Creative Confrontation Methods** are like associative methods connecting ideas, but they are enforced to bring new unexpected ideas. Some examples are synectics, analogies, synectics, random stimulus (stimulating words) and wishful thinking ideas (Roozenburg and Eekels 1995). Roozenburg and Eekels

**Design Management Tools** include work breakdown structures, linear responsibility charts, schedules, activity networks, Gantt charts, budgets and control tools (Dym and Little 2003). Dym and Little

**Divergent Methods** explore design solutions and include stating objectives, literature search, searching for visual inconsistencies, interviewing users,

questionnaires, investigating user behaviour, systemic testing, selecting scales of measurement, data logging and data reduction (Jones 1992). Jones

**Examining Results Methods** include the five whys and root cause analysis (Shetty 2002). Shetty

**Finding Patterns and Relationships Methods** include cause-and-effect diagrams, scatter diagrams, failure Modes and effects Analysis, event tree analysis, force-field analysis, guide data collection, statistical methods, storyboarding, function analysis and process analysis (Shetty 2002). Shetty

**Formal Conceptual Design Methods** include objectives trees, pairwise comparison charts, functional analysis, function-means trees, morphological charts, requirement matrices and performance specifications (Dym and Little 2003). Dym and Little

**Generative Methods** include brainstorming, force-field analysis, team forming and the five whys (Shetty 2002). Shetty

**Heuristic Decision Ruled Methods** decide on an action to achieve a goal by fulfilling only the minimum requirements. Examples are seeking an excellent solution and elimination by aspects (Roozenburg and Eekels 1995). Roozenburg and Eekels

**Intuitive Methods** come as quick, conscious thoughts and may be approached by the use of brainstorming, synectics, gallery method, Delphi, method 635 and others to generate ideas (Dym and Little 2003). Dym and Little

**Prioritizing Data or Action-based Methods** include histogram, pareto charts, solution selection diagram and nominal group techniques (Shetty 2002). Shetty

**Product Development Methods** include quality function deployment (QFD), product specification, business specification, milestones, project start-up seminar, design for manufacture (DFM), design for assembly (DFA), design for quality (DFQ), design for cost (DFC), competitor analysis, cash-flow analysis, computer support systems, life cycle synthesis (Hein 1994).Hein

**Product Synthesis Methods** include functional reasoning, morphology, design catalogues, systematic material and process selection, man-machine design, synthesis of mechanisms, CAD/CAM, form-design methods (Hein 1994). Hein

**Selecting and Using Design Technologies** Rosenthal noted that because the development process requires different information processing, he proposed six distinct function sets that incorporate a recommended lists of methods to be used (Rosenthal 1992) Rosenthal

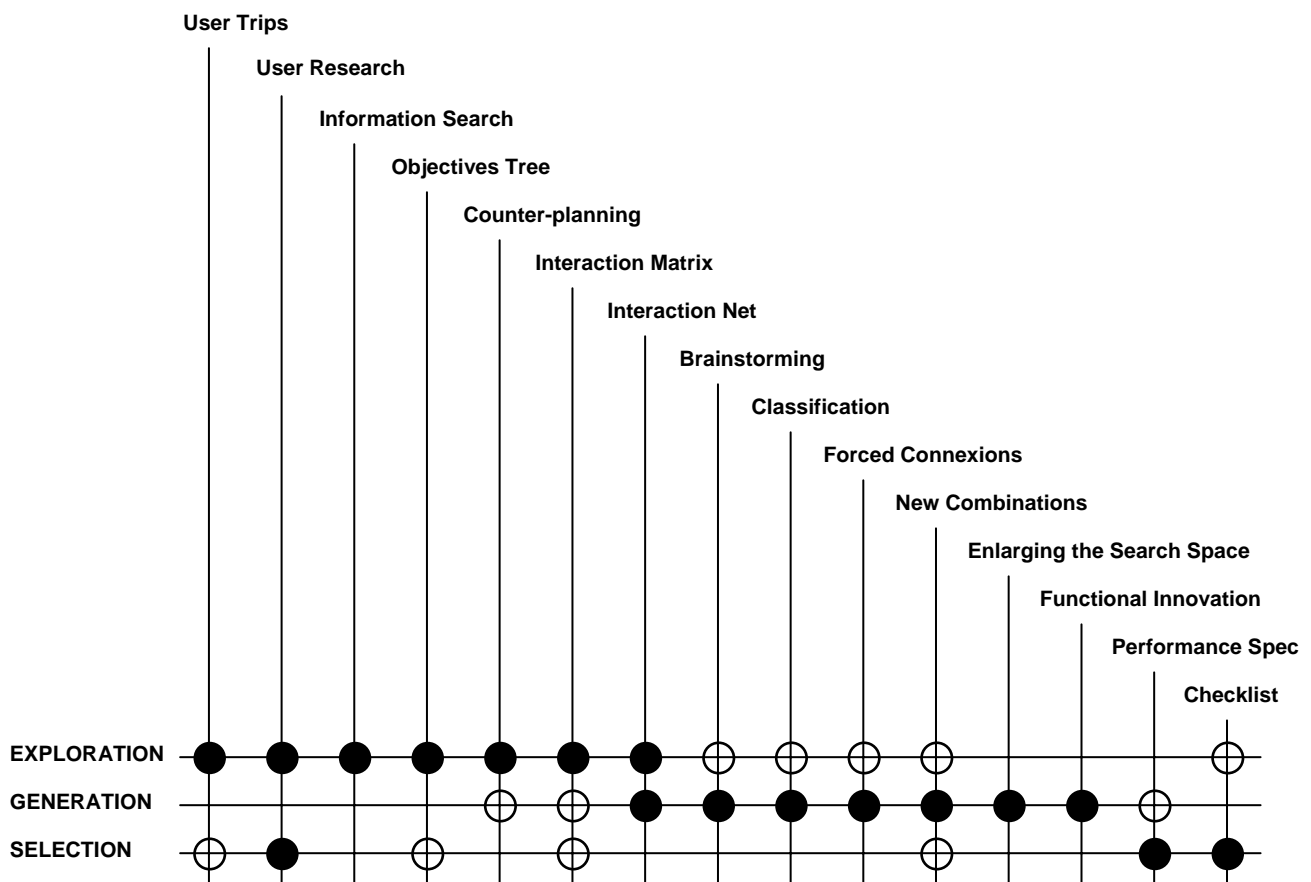
**Solution and Evaluation Methods** include an evaluation criteria, by comparing concept variants and searching for weak spots (Dym and Little 2003). Dym and Little

**Standardization Methods** set specific rules for how work gets done. Examples include standard operating procedures, planning and scheduling systems, monitoring systems and structured development processes (Fleischer and Liker 1997). Fleischer and Liker

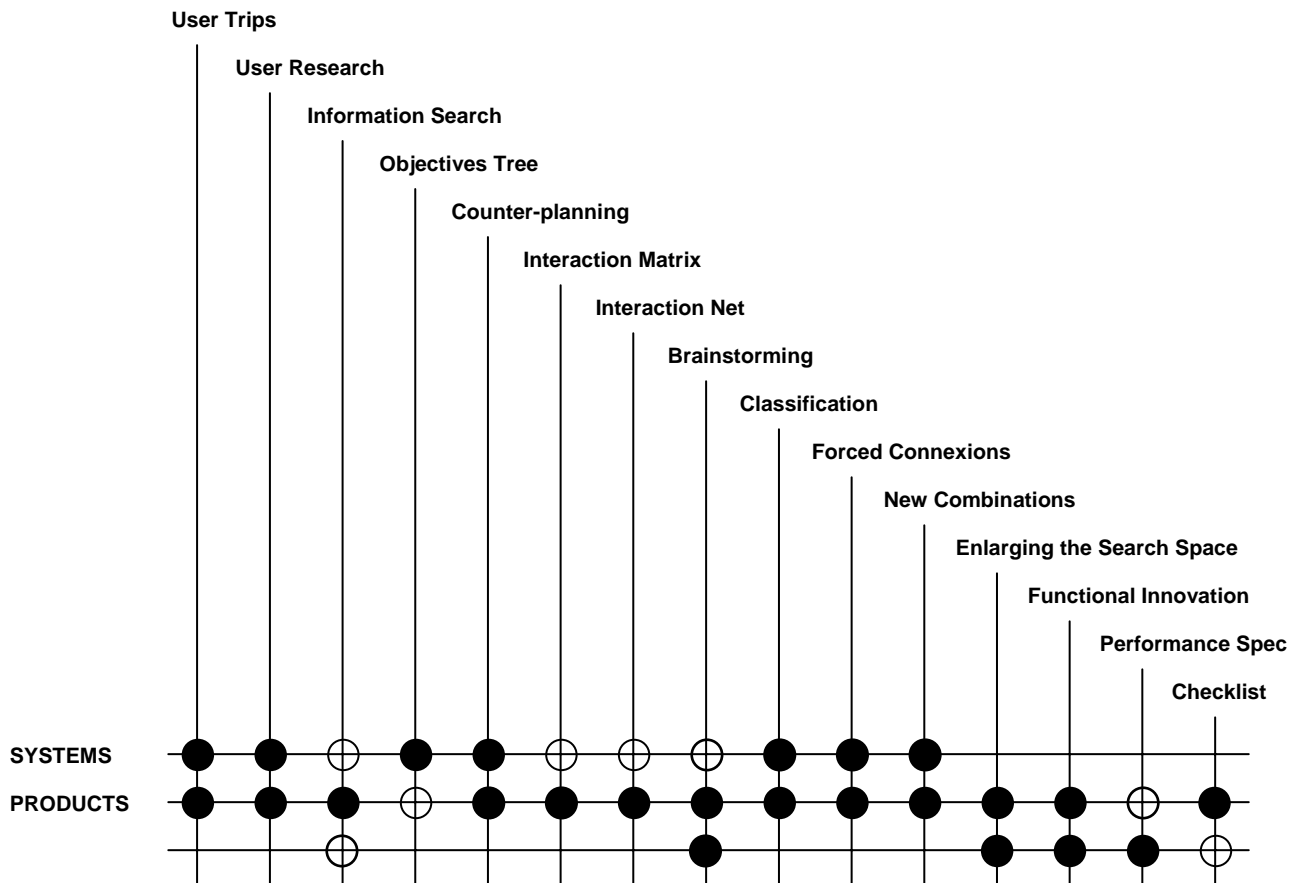
**Systematic Searches** include the use of classification searches and design catalogues (Dym and Little 2003). Dym and Little

**Transformation Methods** search for ideas and include the interaction matrix, interaction net, AIDA (Analysis of Interconnected Decision Areas), system transformation, innovation by boundary shifting, functional innovation, Alexander's method of determining components, classification of design information (Jones 1992). Jones

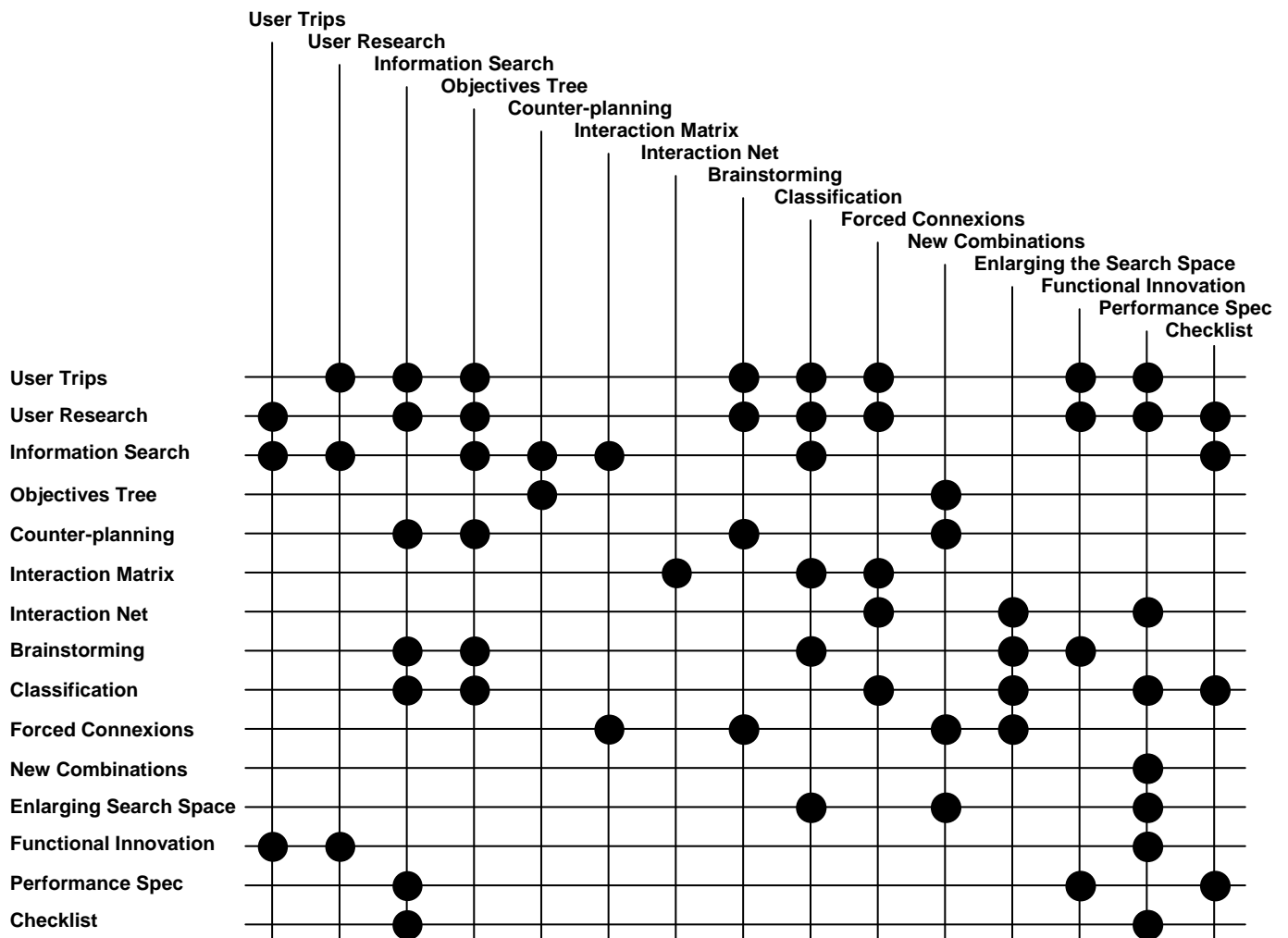
**Project Actions Chart** proposed by Cross and Roy (1975) suggests the method which is most appropriate (solid dot) or a relevant (circled) based on explorative, generative or selective requirements.



**Project Levels Chart** proposed by Cross and Roy (1975) suggests the method which is most appropriate (solid dot) or a relevant (circled) based on the problem levels of Systems Design, Products Design and Components Design.



**Routes through the methods** proposed by Cross and Roy (1975) in the chart below provides advice on what other methods could be used next.



## **13.2 List of Design Methods**

**Activity-based costing (ABC)** is a management accounting method used with manufacturers that investigates the cost of each activity and is based on the principle that costs are generated from the activities of planning, procuring and producing the products rather than the product itself (Erhorn and Stark 1994).

**Activity Network** shows activities and events in a sequential order to be carried out (Dym and Little 2003). Dym and Little

**Adaptation** modifies or partial transforms existing ideas for different conditions (Hubka 1983).

**Aggregation** combines sub-systems into a single simplified structure (Hubka 1983).

**Argumentative Techniques** aim to make design as an independent approach by explicating and documenting dialogues behind each decision made (Conklin and Begeman 1988).

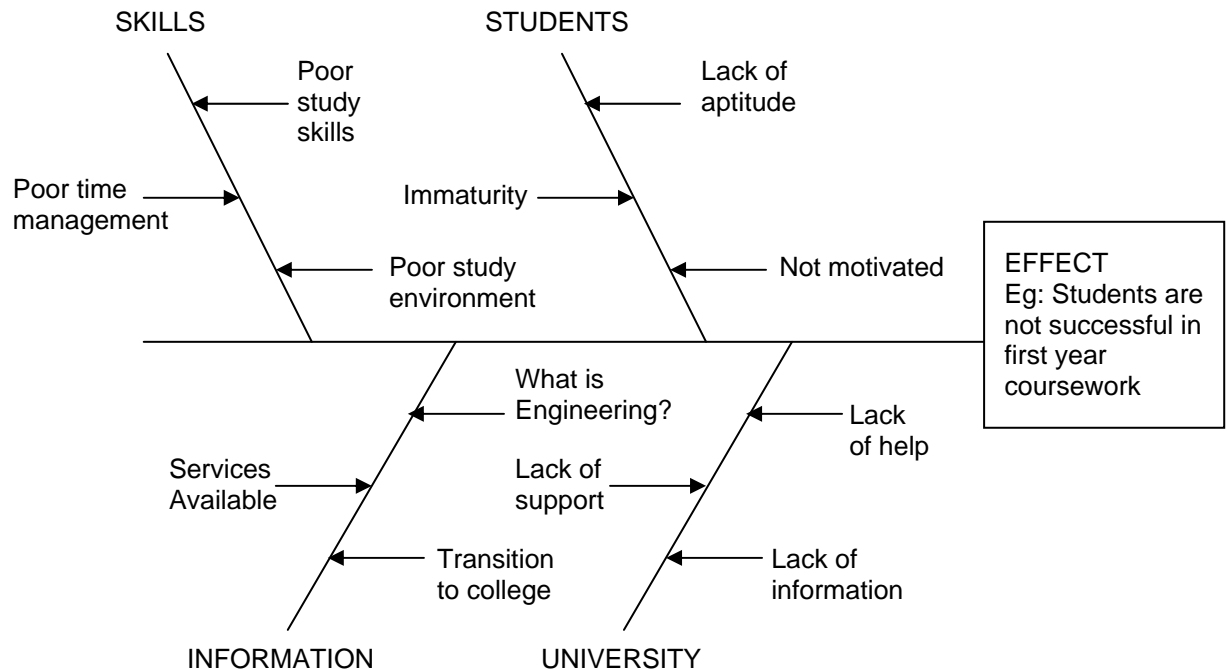
**Attribute Listing** seeks a thorough analysis of every property present in ideas (Hubka 1983).

**Benchmarking** measures products, services and practices against other competitors so that a company better understands how they work and why they are better that spurs on improvements (Erhorn and Stark 1994).

**Boundary searching** finds limits to known solutions by first writing performance specifications and then investigating these limitations through tests (Jones 1992).

**Brainstorming** is a three stage method whereby participants are selected, ideas are generated without criticism, and the results are structured for presentation. (Löwgren and Stolterman 1999) Löwgren and Stolterman

**Cause-and-Effect Diagram or the Ishikawa Fishbone Diagram** allows a users to graphically identify possible “causes” related to a specific “effect” or condition. The effect is placed the right hand box and major causes are then places on the expanding lines of the chart (Eide et al. 2001). Eide, Jenison *et al*

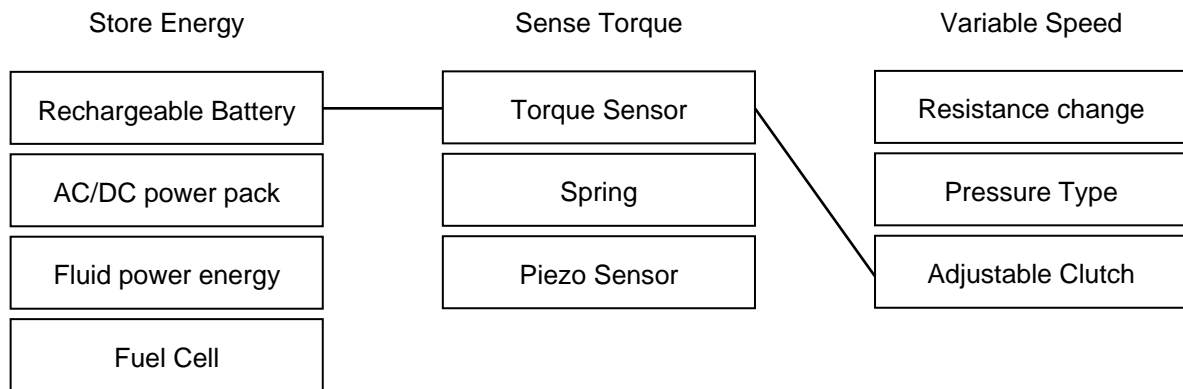


**Checklists** can be created by first preparing a list of important requirements and then confirmed to see if they are accomplished in the design solution (Cross and Roy 1975). Cross and Roy 1975

**Classification** sorts out items into a pattern on what would initially be considered as a random collection of data. By naming these categories, it encourages further thinking of ideas (Cross and Roy 1975). Cross and Roy 1975

**Communication Sketch Method (C-Sketch)** is similar to the 6-3-5 method where the first sketches are circulated through the team and communication is only permissible on paper. The use of sketches and visuals facilitate better understanding of the design dialogue (Dym and Little 2003).

**Concept Selection Using a Function Diagram** first clarifies the problem by breaking it into sub-problems and further dividing into functional parts represented as diagrams. Each function is then solved by means of electrical method, mechanical method etc. (Shetty 2002).



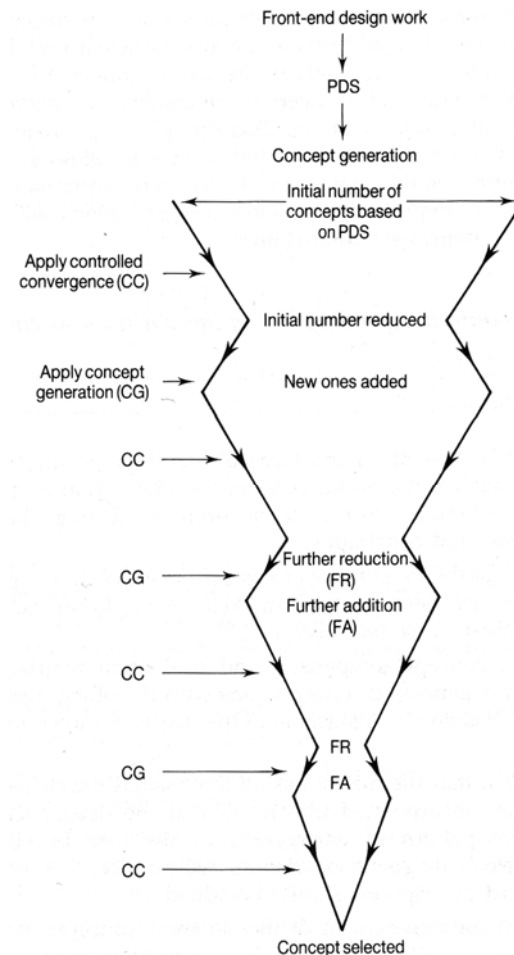
**Contiguous solutions** thinking of adjoining or adjacent ideas that are naturally connecting (Dym and Little 2003). Dym and Little

**Continuous Quality Improvement (CQI) or Total Quality Management or World Class Manufacturing** focuses not on individuals but on processes and seeks an objective view to improve processes in the workplace (Shetty 2002). Shetty

**Contrasting solutions** looking for opposite ideas (Dym and Little 2003).



**Controlled Convergence** utilizes the vertical axis of the matrix to express the criteria for selection. The horizontal axis is used to express the concepts. The procedure is through selection, reasoning and then reduction or the generation of new ideas. (Pugh 1981)



**Counter-planning** begins by starting with a proposal and then forecasting the future. An alternative is then generated by considering conflicting assumptions to seek a revised decision. Both choices are then considered to seek a synthesized plan (Cross and Roy 1975). Cross and Roy 1975

**Critical Path Method (CPM)** is a management method for planning that factors in cost and time with a scheduled graphical display of actions that must be followed to ensure that a deadline is met (Gibson 1968; Hubka 1983; Bucciarelli 1994)

**Decision Tree Analysis** works by identifying a number of options and then selects the suitable at a detailed level with more branches arising from each decision. When a decision turns out less satisfactorily, it is possible to back track up the levels of hierarchy in the decision tree. (Cross 2000) Cross 2000

Decision tree for a passenger vehicle

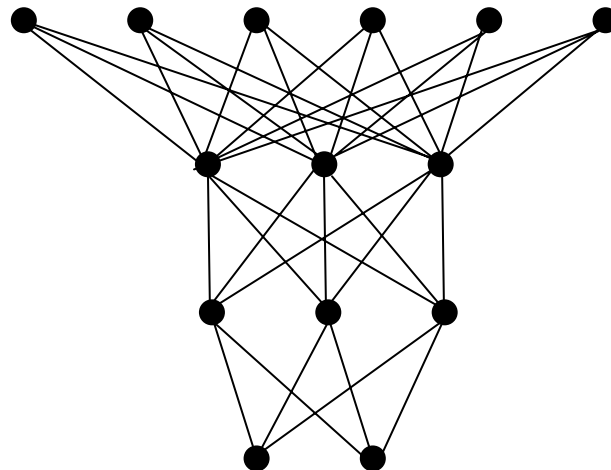
Options

Number of passengers

Propulsion system

Seating arrangement

Number of decks



**Delphi Technique** generates alternative ideas similar to brainstorming. Members comment anonymously on the topic and each reply is fed back to the group. The proposal is asked if there should be changes made and this is repeated until a consensus is arrived (Dominick et al. 2001).

**Descartes** applies the four principles of criticism, division, ordering and creating overview (Hubka 1983).

**Design-Analyse-Redesign** begins by analyzing the proposed solution based on the design criteria. The results of the analysis is then accepted or redesigned to correct the problems. This is repeated until an acceptable design is achieved (Stoll 1999). Stoll 1999

**Design for Assembly (DFA)** aims for cost and time reduction in simplifying the product and process through activities such as part reduction, combination, reduction, simplification, etc. (Erhorn and Stark 1994)

**Design for Manufacture (DFM)** can be used for reasons including providing product life-cycle characteristics, minimizing process and environmental variations, and to control manufacturing processes more effectively (Erhorn and Stark 1994).

**Design for X (DFX)** seeks simultaneous improvements to cost, production, assembly, quality, environmental effects, use, service, etc. in product development by having rationalized decisions in designing products, processes and resources (Huang 1996). Huang 1996

**Early Manufacturing Involvement (EMI)** includes manufacturing engineers early in the design development process rather than waiting until the design has been finalized that will be challenging to manufacture (Erhorn and Stark 1994).

**Enlarging the Search Space** requires users to search for ideas by looking at similar situations in a different perspectives. Asking 'why' and the use of word play and analogies would also help to explore alternatives (Cross and Roy 1975). Cross and Roy 1975

**Environmental Priority Strategies (EPS)** is a valuation system to calculate the "total environmental load unit" (ELU) for a product or a system in order to obtain quantitative data for Life Cycle Assessments (LCA) (Huang 1996).

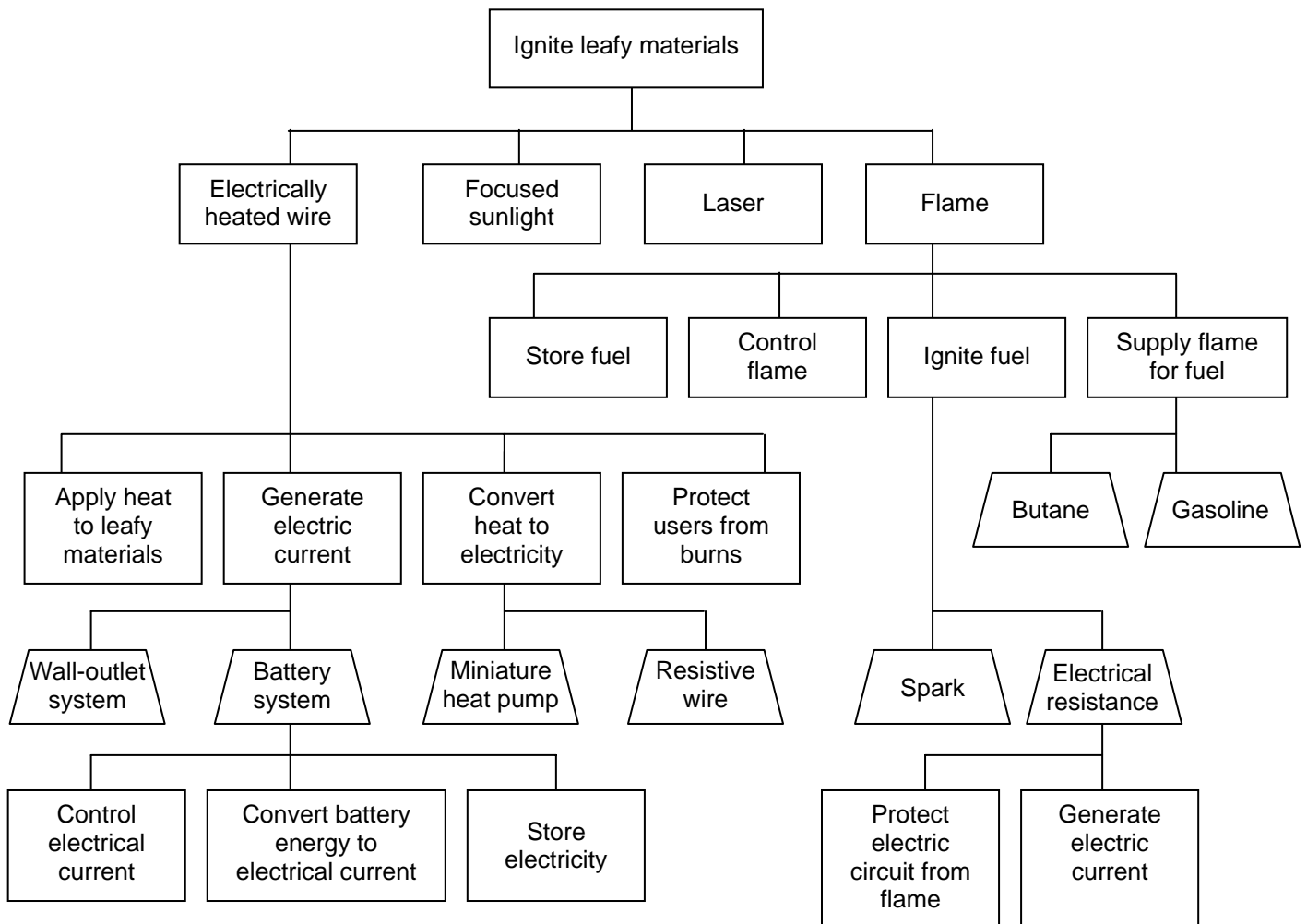
**Explore** is a 5-point technique to help users by defining, exploring, planning, acting and reflecting on the problem. It also includes recalling experiences, noting the constraints and relating to the issue with a written statement (Shetty 2002). Shetty 2002

**Failure Modes and Effects Analysis (FMEA)** finds and judges potential sources of error in products or manufacturing processes. Its steps include first defining all the systems and sub-systems, the operational characteristics, detail its functions and inputs, determine possible failures occurring on each hardware and the possible severity, listing the causes and ranking its occurrence, undertaking tests to detect failures, calculating the risk priority and to draw an action plan with recommendations (Huang 1996; Shetty 2002).

**Forced Connexions** finds associations or relationships with elements that do not presently exist with each other. An example is the matrix of a library system that now shows the connexion between shelves and loan records. For example, when a book is borrowed, the shelf would indicate the book loan record for easy access to library users searching for that particular book (Cross and Roy 1975). Cross and Roy 1975

	Books	Shelves	Catalogue	Loan Rec
Books		<b>X</b>	<b>X</b>	<b>X</b>
Shelves			<b>X</b>	
Catalogue				
Loan Records				

**Functional analysis or Function-means tree** identifies what a design must do by breaking down functions into smaller elements. It is a graphical representation of a design's basic and secondary functions. Below shows a function-means tree for a cigarette lighter. Functions are shown in rectangles while means are shown in trapezoids (Dym and Little 2003). Dym and Little 2003



**Functional Innovation** analyzes essential functions of a product to seek possible changes and to identify existing faults (Cross and Roy 1975). Cross and Roy 1975

An example: Cleaning teeth

Existing Solution: Toothbrush and Toothpaste

Components:	Functions:
Bristles:	Dislodge food particles
Handle:	Position and motion control
Toothpaste:	Foam carries away food particles
Tube:	Stores paste and transfers to bristles
New Sub-functions:	New possible Components:
Position control	Ergonomic handle
Motion control	Vibrator
Dislodge food particles	Disposable toothbrush head with toothpaste-impregnated bristles

**Future Workshops** are used to quickly clarify issues and to create scenarios of an outlook. Members work with small and large groups adopting critiques, imagination, and implementation (Löwgren and Stolterman 1999). Löwgren and Stolterman

**Futuring** asks questions such as how the ideal solution could appear in the future and ways to achieve it. (Shetty 2002) Shetty 2002

**Gantt Charts** are a horizontal bar graphs that show the design activities against the time frame (Dym and Little 2003). Dym and Little

**Gallery Method** is a group effort whereby members develop initial ideas and post these on a wall to form an open discussion. Questions and suggestions are made until no new ideas are produced (Dym and Little 2003). Dym and Little

**GRAI Integrated Methodology (GRIM)** is a methodology to design and specify manufacturing systems based on the GRAI model that uses systems and hierarchical theory (Huang 1996).

**Groupe de Recherche en Automatisation Integree (GRAI)** provides multiple perspectives in analyzing the system by looking at it at a control system level and at a manufacturing level which is divided into 3 subsystems: physical, decisional and informational (Huang 1996). Huang 1996

**Idea Trigger Method** uses a process of alternating tension and relaxation. It works by listening to others' ideas and then being forced to respond with better ideas that motivates one to generate new unexplored solutions (Horenstein 1999). Horenstein

**Incubation** refers to taking a break after an initial preparation of the problem (Hubka 1983). Also known as the **Gestation Method** (Hurst 1999).

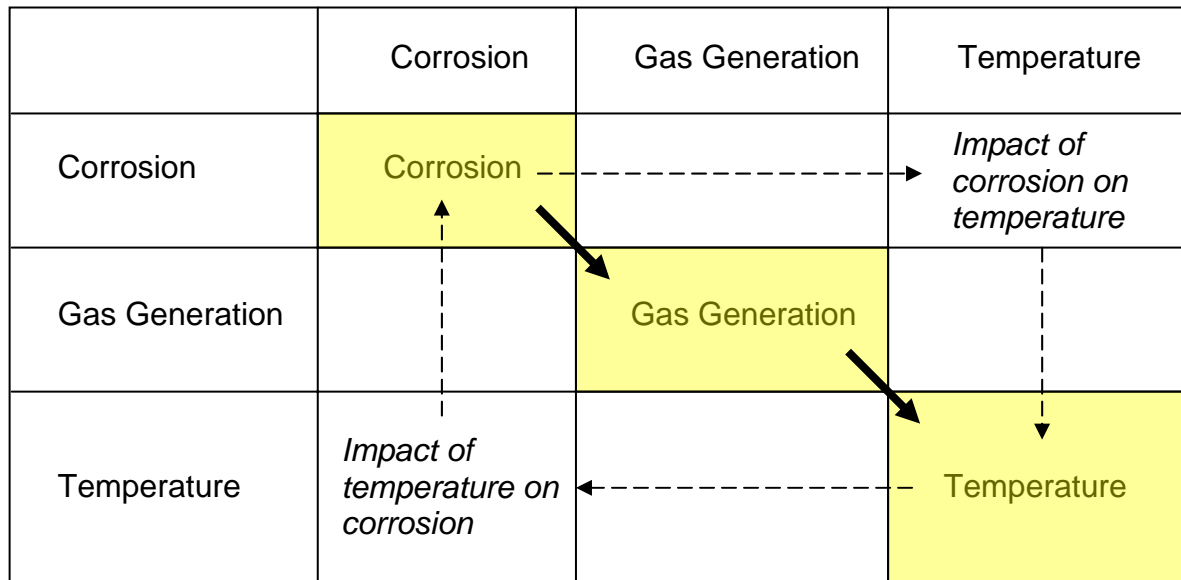
**Interaction Matrix** explores and marks the interactions occurring between elements in the form of a chart. The matrix below shows the train departure times corresponding to the next. It charts out every possible pair of interactions that occur. The crosses refer to the train that departs later and arrives earlier than the other one (Cross and Roy 1975). Cross and Roy 1975

An example: Train times

Train	Arrival time	Departure time
A	12.05	13.03
B	12.24	12.58
C	12.46	13.42
D	13.07	13.38
E	13.12	13.35
F	13.36	14.27
G	13.40	14.15
H	13.52	14.30

	A	B	C	D	E	F	G	H
A		X						
B								
C								
D			X					
E			X	X				
F							X	
G						X		
H								

**Interaction Net** converts the interaction matrix into a representation of relationships between elements of a problem. The example shows how corrosion in pipes occur, represented in an interaction matrix (Cross and Roy 1975). Cross and Roy 1975



**Inversion Methods** create new ideas by looking the original concept from a different perspective (Hurst 1999). Hurst

**Iteration** starts from assumed values and progressively obtains a better understanding through approximation (Hubka 1983).

**Linear Responsibility Chart (LRS)** allocates members with responsibilities and uses a matrix to match tasks and the stakeholders involved (Dym and Little 2003). Dym and Little

**Matchett's Fundamental Design Method (FDM)** enables the user to observe and control the thinking process in relation to the design development. Key strategies include thinking skills, decision making, judgement and having strategic and tactical options (Jones 1992). Jones 1992

**Method 635** is a variation of brainstorming where six participants acknowledge the problem, then write three initial solutions. These ideas are passed to the next participant who revises them. After five rounds, all participants have worked on all ideas (Pahl and Beitz 1996).

**Methodical Doubt** uses systematic negation of existing solutions, search for new solution paths (Hubka 1983).

**Mind Mapping Methods** are also known as the Hyperbolic Tree, Mind Manager, Brain Mapping and the Thinking Map. They allow problems to be presented in various ways with freedom, including use of text and pictures to suggest creativity and encourages innovation (Erlhoff 1987).

**Morphological Charts** widen the search for solutions to a design problem by first defining the functions, then listing the sub-solutions and then selecting best sub-solutions for each function (Wright 1998). Wright 1998

SOLUTIONS SUB-FUNCTIONS	MORPHOLOGY CHART										
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
PRODUCT LAYOUT	THE SWITCH LOOKS LIKE PHOTOGRAPHIC SLIDE AND SWITCH CONTROL PANEL	FAN SHAPE HEATING ELEMENT FINDER	HEATER FAN SHAPE POWER INPUT CONTROL	HEATER FAN SHAPE POWER INPUT CONTROL	FAN SHAPE HEATING ELEMENT FINDER	FAN SHAPE HEATING ELEMENT FINDER	CONTROL FAN SHAPE HEATING ELEMENT FINDER	CONTROL FAN SHAPE HEATING ELEMENT FINDER	HEATER SHAPE HEATING ELEMENT FINDER	HEATER SHAPE HEATING ELEMENT FINDER	POWER SHAPE HEATING ELEMENT FINDER
PACKAGING LAYOUT	BRIDGE (TOP OF COVER) TYPE OF STYLE LETTER	CIRCULAR CONTAINER WITH HANDLE SPECIFICATION STYLE LETTERS ON BODY	HEATER FAN SHAPE POWER INPUT CONTROL	HEATER FAN SHAPE POWER INPUT CONTROL	FAN SHAPE HEATING ELEMENT FINDER	FAN SHAPE HEATING ELEMENT FINDER	CONTROL FAN SHAPE HEATING ELEMENT FINDER	CONTROL FAN SHAPE HEATING ELEMENT FINDER	HEATER SHAPE HEATING ELEMENT FINDER	HEATER SHAPE HEATING ELEMENT FINDER	POWER SHAPE HEATING ELEMENT FINDER
HANDLE CONFIGURATION	HANDLE SHAPE POWER CONTROLS	NOT AIR CONTROL HANDLE	HEATER FAN SHAPE POWER INPUT CONTROL	HEATER FAN SHAPE POWER INPUT CONTROL	FAN SHAPE HEATING ELEMENT FINDER	FAN SHAPE HEATING ELEMENT FINDER	CONTROL FAN SHAPE HEATING ELEMENT FINDER	CONTROL FAN SHAPE HEATING ELEMENT FINDER	HEATER SHAPE HEATING ELEMENT FINDER	HEATER SHAPE HEATING ELEMENT FINDER	POWER SHAPE HEATING ELEMENT FINDER
CONTROLS	ROTATING RING CONTROLS ON HANDLE	TWO REDUCED BUTTONS (L.C.S.)	HEATER FAN SHAPE POWER INPUT CONTROL	HEATER FAN SHAPE POWER INPUT CONTROL	FAN SHAPE HEATING ELEMENT FINDER	FAN SHAPE HEATING ELEMENT FINDER	CONTROL FAN SHAPE HEATING ELEMENT FINDER	CONTROL FAN SHAPE HEATING ELEMENT FINDER	HEATER SHAPE HEATING ELEMENT FINDER	HEATER SHAPE HEATING ELEMENT FINDER	POWER SHAPE HEATING ELEMENT FINDER
ATTACHMENTS	SCREEN SHAPE CLIP CLIP	TRY TO ADD SOMETHING THAT WILL CAUSE TURBULENCE FLOW ATTACHMENTS	HEATER FAN SHAPE POWER INPUT CONTROL	HEATER FAN SHAPE POWER INPUT CONTROL	FAN SHAPE HEATING ELEMENT FINDER	FAN SHAPE HEATING ELEMENT FINDER	CONTROL FAN SHAPE HEATING ELEMENT FINDER	CONTROL FAN SHAPE HEATING ELEMENT FINDER	HEATER SHAPE HEATING ELEMENT FINDER	HEATER SHAPE HEATING ELEMENT FINDER	POWER SHAPE HEATING ELEMENT FINDER

Figure 7.9 A morphological chart for the segment M hairdryer design

**Morphological Matrix** refers to a categorized listing in matrix form (Hubka 1983).



**New Combinations** work by first listing the components of the system and then creating a morphological chart to identify possible combination sets (Cross and Roy 1975). Cross and Roy 1975

An Example: A Glue container

Body:       Flexible  
              Rigid

Seal:        Cap  
              Lid  
              Self-seal

Transfer:    Squeeze  
              Scoop  
              Dribble

'Eject' was added as a mode of transfer.  
A simple morphological chart is created:

<b>Body</b>	Flexible	Rigid		
<b>Seal</b>	Cap	Lid	Self-seal	
<b>Transfer</b>	Squeeze	Scoop	Dribble	Eject

Eliminate impractical solutions, for example, a qqueeze method of transfer with a rigid body would be impractical.

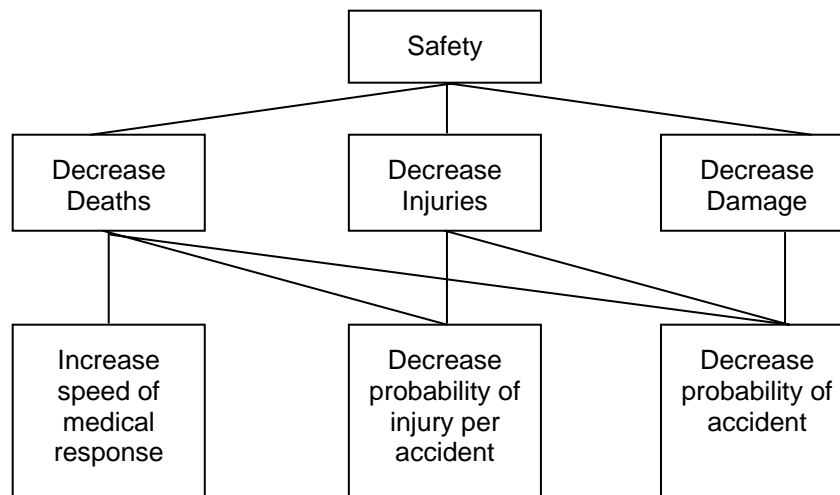
List of combinations:

Flexible – Cap – Squeeze  
Flexible – Cap – Scoop  
Flexible – Cap – Dribble  
Flexible – Cap – Eject

Rigid – Cap – Scoop  
Rigid – Cap – Dribble  
Rigid – Cap – Eject

Flexible – Lid – Squeeze  
Etc.

**Objectives Tree** lists the objectives and sub-objectives of a project and to construct a graphical diagram to show their relationships. It also shows that related elements can be grouped together (Cross and Roy 1975; Dym and Little 2003). Cross and Roy 1975 Dym and Little 2003



**Osborn's Checklist** assists in thinking by having a stimulating set of questions to change the view of the problem, with prompts such as adaption, modification, substitution, rearrangement and combination (Osborn 1957).

**Page's Cumulative Strategy** considers making bad mistakes in order to develop good ones and to reduce trial and error (Jones 1992). Jones 1992

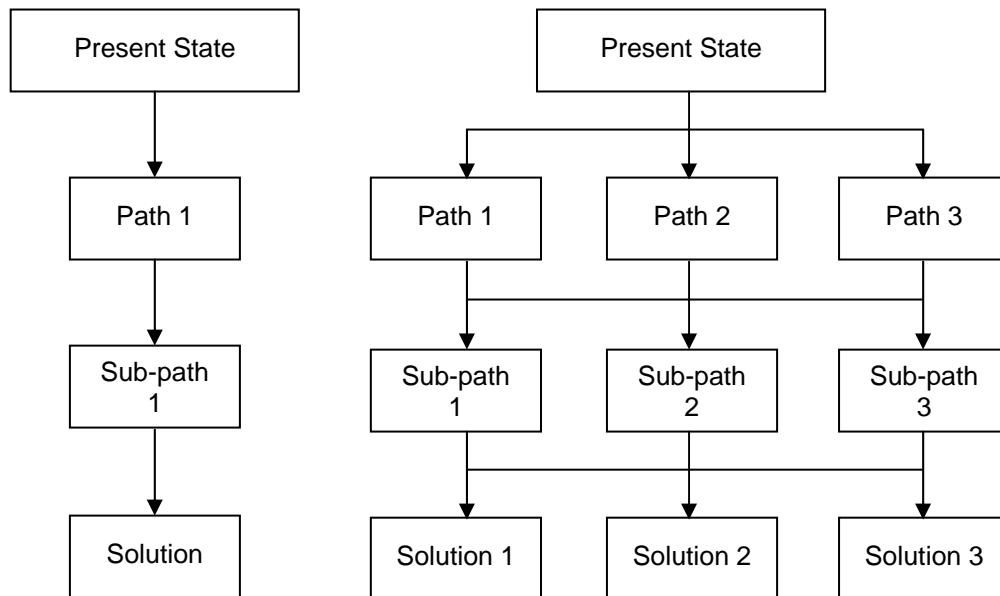
**Pairwise comparison charts** list objectives as in rows and columns of a matrix and which are then ranked in order and compared in pairs. It helps in choosing among competing attributes or requirements. Below is an example for a ladder design with 4 objectives: cost, portability, usefulness and durability (Dym and Little 2003). Dym and Little 2003

Goals	Cost	Portability	Usefulness	Durability	Score
Cost	-	0	0	1	1
Portability	1	-	1	1	3
Usefulness	1	0	-	1	2
Durability	0	0	0	-	0

**Performance Specifications** are descriptions of performance required in a design solution. It specifies specify values for attributes of the designed object. For example, "A step in the ladder is safe if it is made of grade A Fir, has a length that does not exceed 20in., and is attached in a full width groove slot at each end." A higher performance has less freedom for the designer (Cross and Roy 1975; Dym and Little 2003). Cross and Roy Dym and Little

**Poka Yoke** seeks quality assurance by preventing defects or incorrect assembly early in product design process (Schneider 1990). Schneider

**Present State and Desired State (PS-DS)** method uses a dunker diagram to help users visualize the path to the solution goals (Shetty 2002).



**Problem Analysis by Logical Approach (PBLA)** requires users to fill in PBLA forms to document the line of thought and to develop an in depth thinking of the problem. The forms pose questions that cover operational and environmental aspects of specification (form C1), engineering design specification (C2), the system principles to fulfil requirements through evaluation (C3) and requirements of system features (C4) for synthesis. These question prompts in the forms encourages the user to search for other methods and to consider external factors.

Operational & Environmental Aspects (C1)		
Usage	Influences	Existing Resources
1. Occasion	2. Environment	3. Previous Designs
4. Duration	5. Safety	6. Existing Equipment
7. Frequency	8. Policies	9. Services Available
10. Sequence	11. Test & Install	12. Experience
13. Operators	14. Time Scale	15.
16. Maintenance	17. Finance	18..
19. Personal Acceptability	10. Manufacture	

Engineering Design Specification (C2)				
Objective	Performance	Assumptions	Effect on Environment	Limitations

Principles of Systems - Methods of Fulfilling Requirement (C3)				
Theoretical	Practical	Size & Material	Production Aspects (Manufacture, Test, Installation, Transportation)	Probable Cost, Further Research Needed?

Requirements of System Features (C4)				
Feature				
Function & Method of Functioning				
Characteristics	Decided	Undecided		
Decision by	Customer	Project Engineer	Design Engineer	
Sources of Supply	Stores	Purchase	Design	Existing

**Problem Decomposition** seeks to find solutions by first breaking down the issue into sub-problems. When used at the concept generation stage, this method may encouraging creative thinking (Wright 1998). Wright 1998

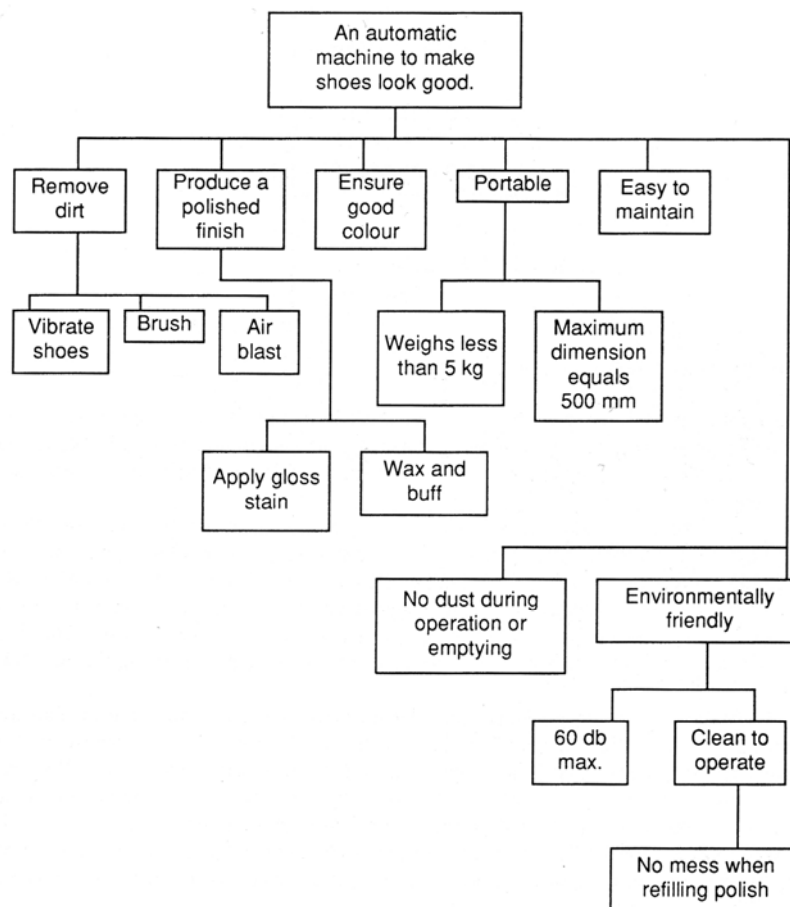
**Product and Cycle Time Excellence (PACE)** is a stage gate process whereby a permanent group of facilitators review the development process across all business groups of the company. This group thus builds knowledge of all business tools and mechanisms within the firm (Souder 1987). Souder

**Project Planning and Scheduling (PERT)** is a planning management program that emphasizes on time as a factor to complete each work task (Gibson 1968).

**Random Input Methods** form new associations by combining words together that may lead to new ideas (de Bono 1993). de Bono

**Removing Mental Blocks** opens up the search field when the current solution is deemed not acceptable. It works by 9 transformation elements of putting to other uses, adaptation, modification, magnification, reduction, substitution, re-arrangement, reversal and combination (Jones 1992).

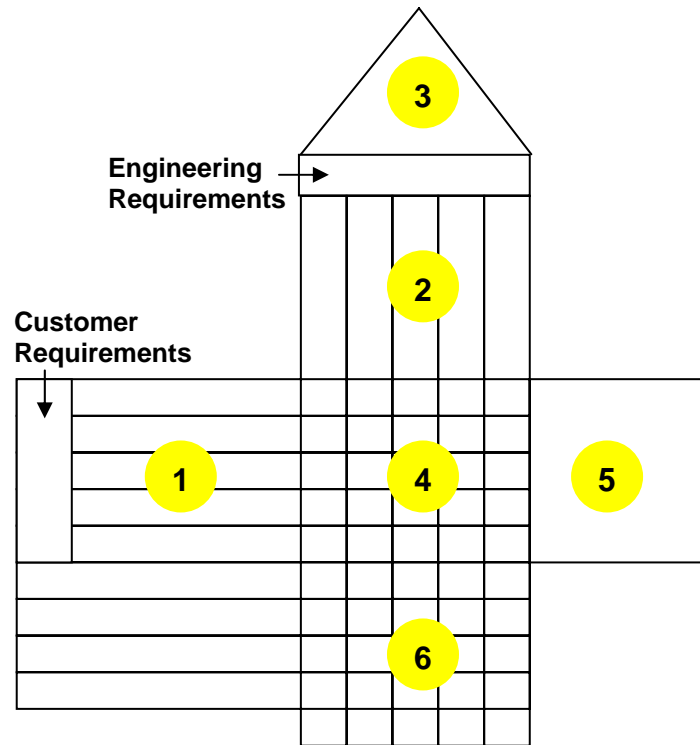
**Requirement trees** are used to encourage a structured investigation into the objectives and constraints of a project. It involves defining key design requirements that are branched into sub-requirements with quantified constraints to each object (Wright 1998). Wright 1998



**Robust Design** refers to a systematic approach to keep costs low but still delivering an excellent product. It concerns how to economically reduce the variation of a product's function and to ensure that manufacturing is kept optimal (Shetty 2002).

**Root Cause Analysis (RCA)** ensures that problems, defects and errors are eliminated in a logical way and finds solutions to prevent these from reoccurring. It also regards failures not problems but opportunities to improve quality and profitability. The steps include first identifying the problem and analysing it, followed by verifying the causes and then suggest and implement these recommendations (Shetty 2002)

**Quality Function Deployment (QFD)** identifies relationships between up and downstream processes. In the QFD matrix or the 'House of Quality', the customer requirements are linked with marketing data and the design specification, along with aims, benchmarking, priorities etc. QFD provides a structured framework that brings the 'voice of the customer' into actions needed to meet customer expectations (Syan and Menon 1994; Huang 1996; Fleischer and Liker 1997; Dym and Little 2003)



Structure and elements of the House of Quality (Syan and Menon 1994)

**Questioning** finds gaps in information to attain an overall complete picture (Hubka 1983).

**Seven Quality Control Tools** form the fundamentals of statistical quality control process, comprising of checklists, a pareto diagram to find the causes that create problems, a histogram that describes the manner of the data, a cause-and-effect diagram, stratification to find dissimilarities within the data and a graphical chat to analyze the whole process (Eide et al. 2001). Eide, Jenison *et al*

**Six Thinking Hats** use different perspectives to create clear-cut communication. The white hat is neutral and focused on information and data. The red hat is about feelings and intuition. The black hat is for critical assessment. The yellow is optimistic and positive, and the green is for creativity and growth. The blue hat is the process facilitator. (Löwgren and Stolterman 1999) Löwgren and Stolterman

**Subdivide Complex Design Problems** work by breaking the problem in sub-problems that are solved in parallel and the sub-solutions then recombined (Stoll 1999). Stoll 1999

**Systematic Design Technique** works through a systematic process of elimination so that solutions may evolve (Hawkes and Abinett 1985).

**Systematic Search (Decision Theory Approach)** solves design problems through a logical approach by identifying the elements of the problem and variables that can and cannot be controlled. The relationships and constraints of these variables are then determined. Finally a range of decisions is carried out and the best solution selected in consideration to the constraints and relationships (Jones 1992). Jones 1992

**Systematic Search of Field** researches all directions starting from fixed points of the region (Hubka 1983).

**Systems Approach** refers to a systematic working in every situation requiring a solution or decision (Hubka 1983).

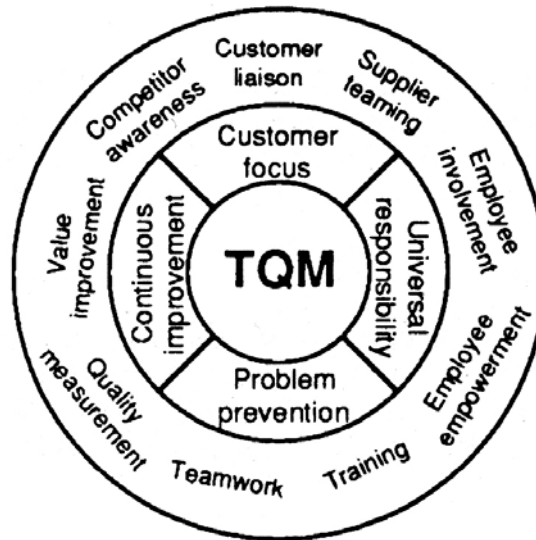
**Synectics** joins different irrelevant elements together by first having a problem statement and then rearticulating the statement to generate unusual solutions through personal analogy, direct analogy, symbolic analogy or fantasy analogy (Jones 1992; Shetty 2002)

**Taguchi methods** seek to identify a robust combination of design values by conducting a experiments in a statistical way (Taguchi 1986). Taguchi

**Team calendars** show available time and highlights deadlines and time frames for work to be completed (Dym and Little 2003). Dym and Little

**Theory of inventive problem solving (TRIZ)** works by having universal principles of invention as the basis for creative innovation across all scientific fields, whereby principles could be codified and to make innovation predictable. TRIZ principles do not necessarily give the answer but are likely to point the user in the right direction (Dominick et al. 2001).

**Total Quality Management (TQM)** highlights the customer's needs, seeks continuous improvement, prevents problems and advocates universal responsibility. The four objectives in turn require the actions of the outer ring, as well as good management support (Wright 1998). Wright 1998



**User Research** is a problem-finding method that observes and consults users of a system in order to seek improvements or modifications (Cross and Roy 1975). Cross and Roy 1975

**User Trips** work by finding problems, insights, and ideas by taking on a user's point of view and going through the process of using a product. By being a critical observer and recording actions, problems are identified further which suggestions can then be made for improvements (Cross and Roy 1975).

**Value Analysis** is the analysis and criticism of the existing solution from the viewpoint of economics to reduce product cost. It works by first identifying the functions, costs and values, then searching for cheaper alternatives. The cheaper alternative is accepted and the overall product redesigned (Hubka 1983; Jones 1992).



**Work Breakdown Structures (WBS)** puts forward tasks that is expected to be accomplished through a schedule. Work is broken down manageable enough so that resources and time can be allocated accordingly (Dym and Little 2003). Dym and Little

Example of a Work Breakdown Structure (WBS)

Engineering Projects

94E.101	General
94E.101.A	
94E.101.B	Air bag
94E.101.C	Mechanical release system
94E.101.D	Electrical systems
94E.101.E	Interior dashboard
94E.101.F	Structural door system
94E.102	Retrofit Automobile Plant
94E.102A	Enclosure
94E.102B	Structural System
94E.102C	Mechanical System
94E.102D	Electrical System
94E.102E	Estimating
94E.102F	Especifications
94E.102G	General
94E.103	Tooling and Equipment Installation
94E.103A	Structural slab
94E.103B	Piping
94E.103C	Equipment
94E.103D	Electricity
94E.103E	Interior finishes
94E.103F	Ventilation & Plumbing
94E.103G	General

### **13.3 Booklet Used for Empirical Research**

The following pages show pages from the booklet that was developed to allow respondents understand the research better.



## **Understanding the Use of Representations in the Industrial Design process**

Eujin Pei

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## The Research

As manufacturers employ increasing numbers of techniques to reduce product time to market, improving the interaction between industrial designers and engineering designers can be seen as a potential area for efficiency gains.

This study forms part of an on-going research with focus on the collaboration between industrial designers and engineering designers. It aims to provide an overview of general methods of collaboration and discusses the findings of empirical studies undertaken in 2006 that recorded the nature of interaction between industrial designers and engineering designers in Singapore.

## Aims & Objectives

The objective of this particular study is:

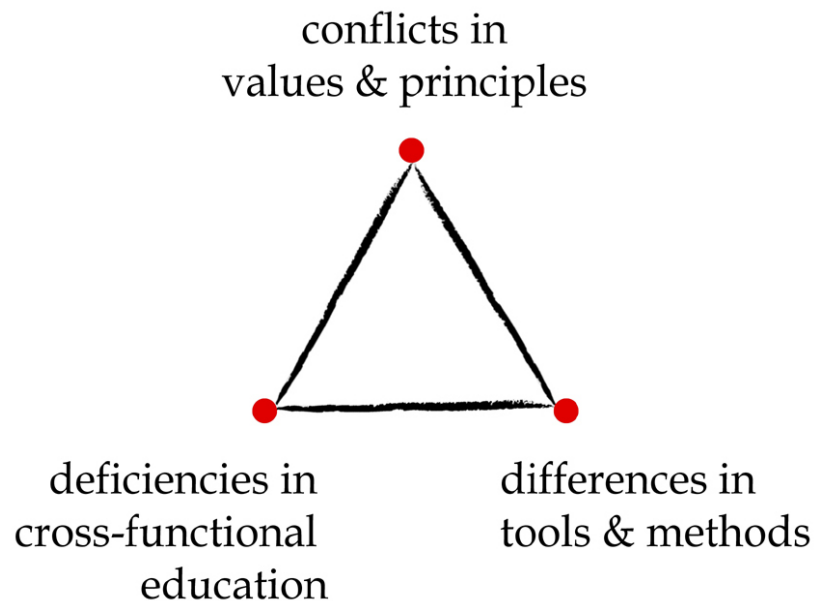
- To investigate aspects of design representations that affect collaboration between industrial designers & engineering designers.

The overall aim of the research is:

- To develop an integration tool for enhanced collaboration between the two disciplines in industrial design practice.

## Findings

The initial empirical studies involved interviews and observations in 17 companies that included consultancies and manufacturers. These studies resulted in the identification of 19 distinct issues that occurred with the greatest frequency which were then categorised under three generic headings: conflicts in values and principles; different tools and methods; and deficiencies in cross-functional education.

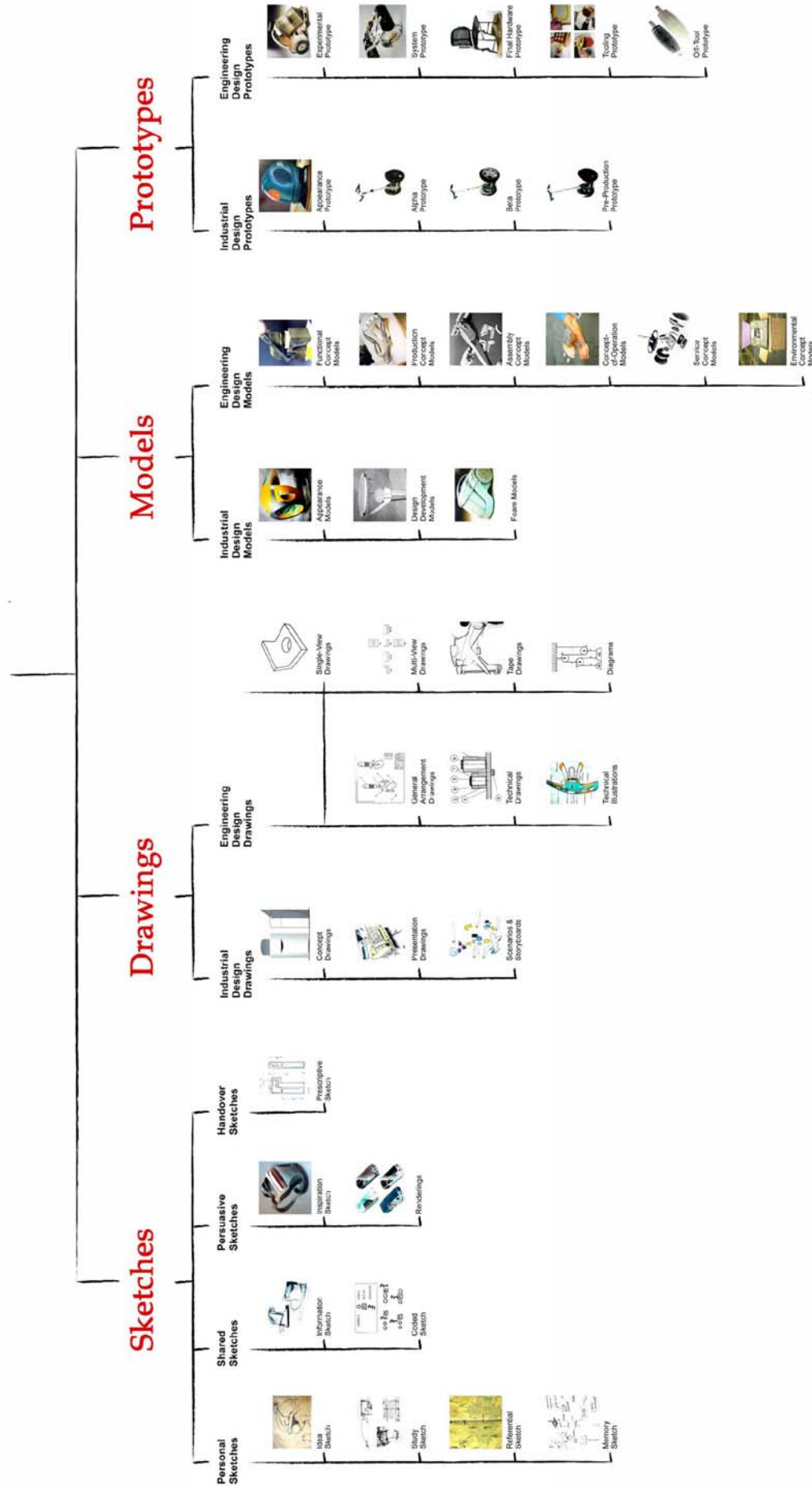


## The Taxonomy

The study investigated different approaches in tools and methods which led to the study on design representations. The taxonomy above illustrates design representations, including sketches, drawings, models and prototypes.

By having a clear definition and understanding of how representations are used in industrial design practice, researchers are better informed to clarify issues and to work towards approaches in bridging the gap between industrial designers and engineering designers.

# Taxonomy of Design Representations



## **The Study**

The interview investigates how different aspects of design representations are used and the information they provide during the design process.

### **Step 1:**

Fill in your personal details in the sheet provided.

### **Step 2:**

“A Matrix Matching Appropriate Design Representations to the Stage of Product Design” requires you to tick the corresponding boxes to investigate the design representations used during the product development process.

### **Step 3:**

“Which Representations Match the Level of Information Required by Engineering Designers?” is an open-ended spoken interview that aims to validate the design and technical information present in sketches, drawings, models and prototypes.

## **Further Work**

Future work will be directed towards developing an integration tool that focuses on design representation. This tool would provide support for a collaborative work environment within design practice. A long-term observation study would further provide testing and validation.

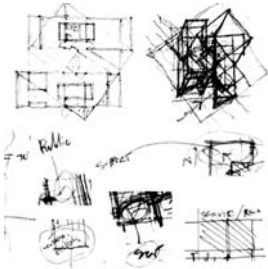
## References - Types of Design Representations

### Sketches



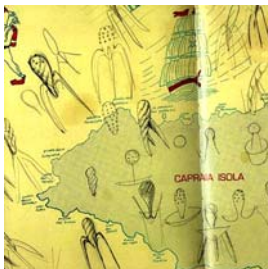
#### Idea Sketch

These show what the design ideas look like as physical objects and are used at a personal level to externalise thoughts, through quick execution. They are also known as thumbnail, thinking or napkin sketches



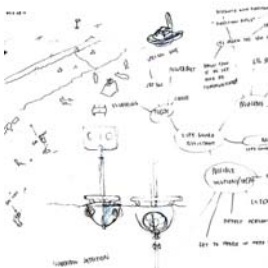
#### Study Sketch

These are used to investigate appearance and visual impact of ideas such as geometric configurations, scale, proportion, layout, mechanical and production engineering details.



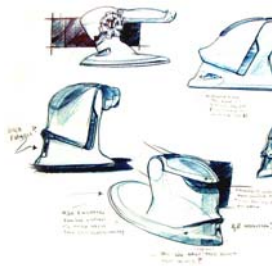
#### Referential Sketch

These are used as a diary to record observations or as a metaphor.



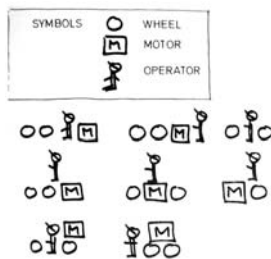
#### Memory Sketch

These help to recall elements and organizations from previous work and may include notes and text annotations.



## Information Sketch

They allow stakeholders to understand the designer's intentions by explaining information clearly and enable discussions where all parties share a common graphical setting for the idea being debated. They are also known as explanatory or talking sketches.



## Coded Sketch

These are informal representations as a means to categorise information, usually to show an underlying principle or a scheme.



## Inspiration Sketch

They are extremely form orientated and used as a means to communicate the look or feel of a product and to set the tone of a design, brand language or product range. They are also known as emotion or inspiration sketches.

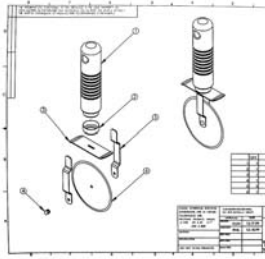


## Renderings

These are used for presenting the design concepts to a client as a formal proposal and involve the application of colour, tone and detail to add realism. They are also known as sketch renderings or first concepts.

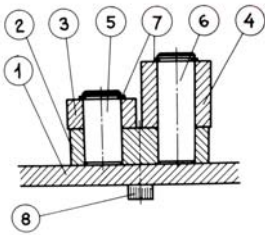






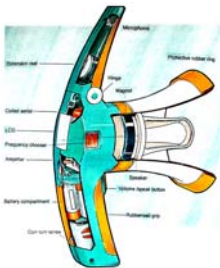
### General Arrangement Drawing

General Arrangement drawings embody the refined design but omit the most internal detail. They are used in the production of an appearance-model with limited detail. They are also known as model-making drawings.



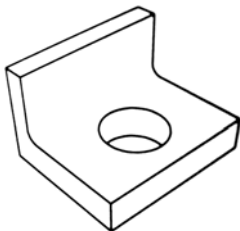
### Technical Drawing

These drawings represent the built object and cover every detail of the product to be manufactured. They are also known as engineering, production or construction drawings.



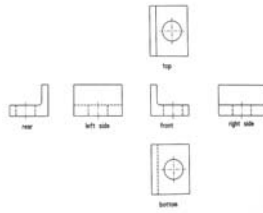
### Technical Illustration

They are graphical illustrations that may use conventions of engineering drawings and may also incorporate signs and symbols within the illustration.



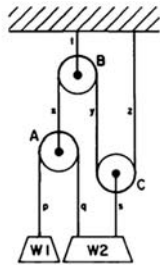
### Single-view Drawings

They comprise of isometric, trimetric, perspective, oblique and axonometric projection drawings.



## Multi-view Drawing

They are diagrammatic views through first-angle or third-angle projections in which the form is flattened out with plan views, front elevations and the end elevations.



## Diagram

These are abstract representations of the underlying principles of an idea or are used to represent relationships between objects. They are also known as schematic or diagrammatic drawings.

## Models



## Appearance Model

They are an exact representation of the proposal and are seen as the conclusion of an industrial design input as they accurately define the product form and use. They are also known as block, iconic or qualitative models.



### Design Development Model

These enable designers to understand more fully the complex relationships between components, cavities, interfaces and form. They are also known as sketch models or 3D sketches.



### Foam Model

This is a relatively accurate three dimensional representation and are different from the design development model with thought out details such as parting lines.



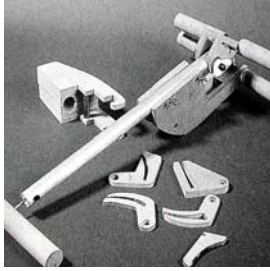
### Functional Concept Model

They show functionality, highlighting important functional parameters like yield and performance factors.



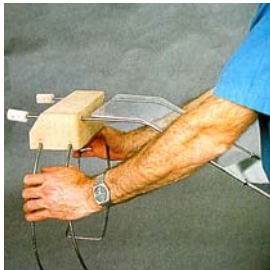
### Production Concept Model

They are typically used to assist in the evaluation of processes or manufacturing technologies for production.



### Assembly Concept Model

They show the assembly consequences so that assembly, cost and investments in equipment may be evaluated.



### Concept-of-Operation Model

They are based on considerations about operation strategy and usage procedure for the user.



### Service Concept Model

They illustrate how the product is serviced and maintained and may sometime be in the form of an exploded illustration to show the disassembly of parts.

## Prototypes



### Appearance Prototype

They combine the finalised product functionality with the final aesthetic outlook (form). They are highly detailed, working full-sized models very closely resembling the completed product.



### Alpha Prototype

They are fabricated using materials, geometry and layout that the design team believes will be used for the actual product. It is the first system construction of the subsystems that have been individually proven.



### Beta Prototype

They are the first full scale functional prototypes constructed from the actual materials as the final product.



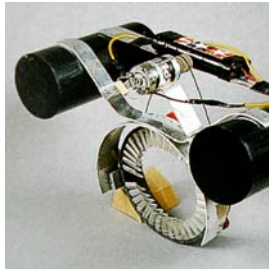
### Pre-Production Prototype

They are the final class of physical models that are used to perform a final part production and assembly assessment using the actual production tooling. Small batches are usually produced.



### Experimental Prototype

They are focused physical models where empirical data is sought to parameterize, lay out, or shape aspects of a product, usually made similar enough to replicate the real product's physics. They are also known as design-of-experiments prototypes.



### System Prototype

They utilise many components that were specified for the final product and are used to test and assess various aspects.



### Final Hardware Prototype

They are used to assist in product fabrication, part and assembly issues.



### Tooling Prototype

They allow the creation of a working product and enables potential tooling problems to be intercepted where any discrepancies of form or fit should appear at this stage.



### Off-Tool Prototype

They refer to components produced using the tooling and materials intended for the production item. This may be an injection moulding, steel pressing or die cast. The samples are subjected to tests to ensure product compliance.

## **References - Key Design & Technical Information**

### **1. Design Information**

#### **Design Intent**

This refers to an explanation of the design concept and the purpose of the product defined by the designer to be important, such as an emphasis on aesthetics, safety or usability.

#### **Form & Detail**

This refers to the aesthetic judgment of the product's external appearance with concern to form, comprising of structure, shape, proportion and size.

#### **Visual Character**

This refers to the product personality or character that a product conveys to the user, usually by means of its external form, and the choice of materials and finishing used.

#### **Usability & Operation**

This is used to explain how well a product is capable of being used and its functional effectiveness and efficiency.

#### **Scenario of Use**

This describes how a product would be used in a projected sequence of events. This may also include relationships between the user, the user environment and the product.

#### **Single-Views**

They comprise of isometric, trimetric, perspective, oblique and axonometric projections in the form of sketches or drawings.

#### **Multi-Views**

These are diagrammatic views through first-angle or third-angle projections in which the form is flattened out with plan views, front elevations and end elevations.



### **Areas of Concern**

This relates to issues that are of concern or interest to the overall design. They may include issues on safety, usability and production.

## **2. Technical Information**

### **Dimensions**

Dimensions generally comprise measurements in length, height, width, and thickness of the product.

### **Construction**

These refer to an arrangement and composition of parts that when put together make the product.

### **Assembly**

This describes the process where the manufactured parts are put together to make a completed product.

### **Components**

They consist of connecting parts where together they form the overall working product. They may be further classified into electrical and mechanical components, etc.

### **Mechanism**

They consist of connecting parts where together they form the overall working product. They may be further classified into electrical and mechanical components, etc.

### **Part & Section Profile Lines**

These comprise of form lines, crown lines and area lines that delineate the form, section or area of the product. They also include parting lines corresponding to seams appearing on the product surface where two parts are assembled together, or where the moulding dies meet.

**Exploded Views**

This is a representation showing the parts of a product slightly separated by distance, or suspended in surrounding space, showing the components contained in the assembly.

**Texture & Surface Finish**

Texture refers to the properties held and sensations caused by the external surface of objects received through the sense of touch. Surface finish describes the surface coating of the product.

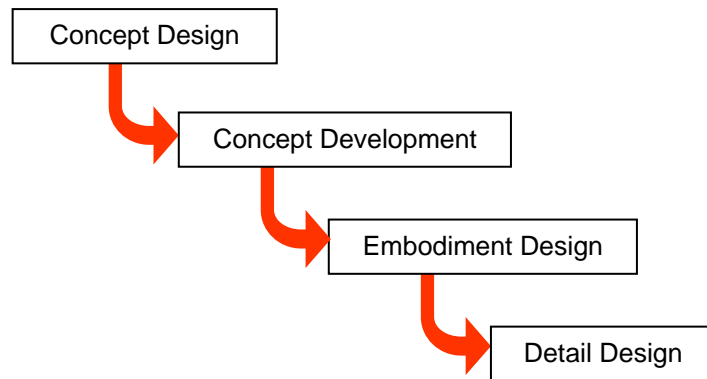
**Colour**

This refers to the visual attribute of the product's appearance in terms of hue, lightness and saturation.

**Material**

This refers to the visual attribute of the product's appearance in terms of hue, lightness and saturation.

## References - Stages of the Industrial Design Process



1. Concept Design - Generating product concepts based on form, function, features, specifications, benchmarking and economic justification
2. Concept Development - Suitable concepts are selected, developed and evaluated based on the specifications
3. Embodiment Design - Embodiment design is achieved through a fixed layout by means of a technical description
3. Detail Design - Detail design is achieved through physical realization of the product with final testing

## Contact Information

Please contact us if you require further information on this research.



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### ***13.4 Summary of Visual Design Representations***




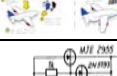
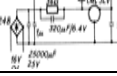


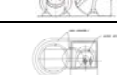

The following sections present a tabulated summary of visual design representations, design information and technical information as discussed in Chapter 7.

- Appendix 13.4.1: Summary of Sketches
- Appendix 13.4.2: Summary of Drawings
- Appendix 13.4.3: Summary of Models
- Appendix 13.4.4: Summary of Prototypes
- Appendix 13.4.5: Summary of Design Information
- Appendix 13.4.6: Summary of Technical Information









### 13.4.1 Summary of Sketches

2D Visual Design Representations	Sketches	Sub-group	Visual Design Representation	Definition	Visual Example
		Personal Sketches	Idea Sketch	Idea sketches are 2D visual design representations used at a personal level for externalizing thoughts quickly and to show how the design looks as a physical object.	
			Study Sketch	Study sketches are 2D visual design representations used for investigating the appearance and visual impact of ideas such as aspects of geometric proportion, configuration, scale, layout and mechanism.	
			Referential Sketch	Referential sketches are 2D visual design representations used as a diary to record observations for future reference or as a metaphor.	
			Memory Sketch	Memory sketches are 2D visual design representations that help users recall thoughts and elements from previous work with notes and text annotations.	
		Shared Sketches	Coded Sketch	Coded sketches are 2D visual design representations that categorise information to show an underlying principle or a scheme.	
			Information Sketch	Information sketches are 2D visual design representations that allow stakeholders to understand the designer's intentions by explaining information clearly and to provide a common graphical setting.	
		Persuasive Sketches	Renderings	Renderings are 2D visual design representations showing formal proposals of design concepts that involve the application of colour, tone and detail for realism.	
			Inspiration Sketch	Inspiration sketches are form-orientated 2D visual design representations used to communicate the look or feel of a product by setting the tone of a design, brand or a product range.	
		Handover Sketches	Prescriptive Sketch	Prescriptive sketches are informal 2D visual design representations that communicate design decisions and general technical information such as dimensions, material and finish.	

### 13.4.2 Summary of Drawings










2D Visual Design Representations	Drawings		Sub-group	Visual Design Representation	Definition	Visual Example
	Industrial Design Drawings			Concept Drawing	Concept drawings are 2D visual design representations that show the design proposal in colour with orthographic views and precise lines.	
				Presentation Drawing	Presentation drawings are 2D visual design representations drawn in perspective that act as final drawings for clients and other stakeholders.	
				Scenario and Storyboard	Scenarios and storyboards are 2D visual design representations to suggest user and product interaction, and to portray its use in the context of artefacts, people and relationships.	
	Engineering Design Drawings			Diagram	Diagrams are 2D visual design representations that show the underlying principle of an idea or to represent relationships between objects, represented with simple geometric elements.	
				Single View Drawing	Single view drawings are 2D visual design representations drawn in an axonometric projection made up of either isometric, trimetric, diametric, oblique or perspective views, drawn with little aesthetic detail.	
				Multi View Drawing	Multi view drawings are 2D visual design representations employed through first or third angle projections.	
				General Arrangement Drawing	General arrangement drawings are 2D visual design representations that embody the refined design but omit the internal details. They are used for the production of appearance models with limited detail.	
				Technical Drawing	Technical drawings are formal 2D visual design representations used to define, specify and graphically represent the built object and to cover every detail for manufacture.	
				Technical Illustration	Technical illustrations are 2D visual design representations that simplify the engineering details and highlight key features without omitting important information from the product.	

### 13.4.3 Summary of Models

3D Visual Design Representations	Models	Sub-group	Visual Design Representation	Definition	Visual Example
		Industrial Design Models	3D Sketch Model	3D sketch models are 3D visual design representations that represent an idea.	
			Design Development Model	Design development models are 3D visual design representations used to understand the relationships between components, cavities, interfaces, structure and form.	
			Appearance Model	Appearance models are 3D visual design representations that realistically define the visual aspects of a product, but do not contain any working mechanisms.	
		Engineering Design Models	Functional Concept Model	Functional concept models are 3D visual design representations that show functionality and highlight important functional parameters including yield and performance factors.	
			Concept of Operation Model	Concept of operation models are 3D visual design representations that help communicate the understanding of operational strategies and usage procedures relating to the product.	
			Production Concept Model	Production concept models are 3D visual design representations used to help assist the evaluation of production processes or manufacturing technologies for final production.	
			Assembly Concept Model	Assembly concept models are 3D visual design representations that provide confidence regarding the component relationships in terms of assembly, cost and investment.	
			Service Concept Model	Service concept models are 3D visual design representations that illustrate how the product may be serviced or maintained.	



### 13.4.4 Summary of Prototypes

Table 42: Summary of 3D Visual Design Representations - Prototypes				
3D Visual Design Representations				
Prototypes				
Sub-group	Visual Design Representation	Definition	Visual Example	
Industrial Design Prototypes	Appearance Prototype	Appearance prototypes are highly detailed, full-scale 3D visual design representations that combine function and aesthetics.		
	Alpha Prototype	Alpha prototypes are 3D visual design representations used to verify the outlook and construction of sub-systems that have been individually proven and accepted with the actual materials, aesthetics and layout for the actual product.		
	Beta Prototype	beta prototypes are full-scale and fully-functional 3D visual design representations constructed from the actual materials and used to examine how the product would be used in its intended environment and to work out regulatory issues.		
	Pre-Production Prototype	pre-production prototypes are final 3D visual design representations used to check the product and its finishing as a whole and to perform production and assembly assessment in small batches.		
Engineering Design Prototypes	Experimental Prototype	Experimental prototypes are 3D visual design representations that parameterizes the layout or shape of a product, usually to replicate the actual product's physics.		
	System Prototype	System prototypes are 3D visual design representations that combines the numerous components specified for the final product to test and assess functional aspects such as mechanism and performance.		
	Final Hardware Prototype	Final hardware prototypes are 3D visual design representations used to assist in the design and evaluation of product fabrication and other assembly issues.		
	Tooling Prototype	Tooling prototypes are 3D visual design representations that allow the tooling to be made for the actual product and to enable potential problems to be intercepted before discrepancies in form or fit occur.		
	Off-Tool Prototype	Off-tool prototypes are 3D visual design representations that consists of physical components produced from the actual tooling and materials intended for the final product.		

### 13.4.5 Summary of Design Information

Table 43: Summary of Design Information	Design Information	Definition
	Design Intent	Design intent refers to the intention of the design concept and product purpose including aesthetics, safety and usability.
	Form and Detail	Form and detail refers to the product's appearance with respect to form, in terms of structure, shape, proportion and size.
	Visual Character	Visual character refers to the product's personality or character that is conveyed to the user, usually through external form, materials, texture and finishing.
	Usability and Operation	Usability and operation refers to how well a product is capable of being used, including functional effectiveness, ergonomics and operational efficiency.
	Scenario of Use	Scenario of use describes how a product would be used in a projected sequence of events and may include relationships between the user, environment and product.
	Single Views	Single views comprise of 2D visual design representations made up of contour sketches and side-views, as well as axonometric projections encompassing isometric, dimetric, trimetric, perspective and oblique views.
	Multi Views	Multi views comprise of first-angle or third-angle projections in which the form is flattened out with plans views, front elevations and end elevations.
	Areas of Concern	Areas of concern refer to issues relating to the overall design concerning safety, usability and production.
	Finishing	Finishing refers to the texture (external surface perceived through touch) and surface finish (coating applied to the product) of a product.
	Colour	Colour refers to the visual attributes of the product's appearance in terms of hue, lightness and saturation.

### 13.4.6 Summary of Technical Information

Table 44: Summary of Technical Information	Technical Information	Definition
	Dimensions	Dimensions comprise the measurements of parts, including angles and tolerances with a specified unit of measurement.
	Construction	Construction refers to the arrangement and composition of parts used to systematically form, make or build the product.
	Assembly	Assembly describes the process of how the manufactured parts and components are put together to make the completed product.
	Components	Components refer to the connected parts which when assembled form the overall working product and may be grouped as electrical or mechanical components, etc.
	Mechanism	Mechanism refers to the assembly of connected moving parts and its physical operation to perform a function.
	Part and Section Profile Lines	Part and section profile lines are used to delineate the form, section or area of a product and includes parting lines where two parts are assembled together or where moulding dies meet.
	Exploded Views	Exploded views show part of a product slightly separated by distance to display the components contained within the assembly.
	Material	Material refers to the substance from which the physical product part is made up of.

### ***13.5 Empirical Survey Concerning the Use of Design Representations***

The following pages show the interview questions that were used to investigate design collaboration among industrial designers and engineering designers in new product development.

#### **Understanding the Use of Representations in the Industrial Design process**

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Dr R.I. Campbell

Dr M.A. Evans

### **Part 1. Your Details**

Thank you for taking part in our research study. We will need some information about you to obtain more accurate results. All information will be kept strictly confidential.

Name: \_\_\_\_\_

Company: \_\_\_\_\_

Position : \_\_\_\_\_

Role and Responsibility: \_\_\_\_\_

Educational Background: \_\_\_\_\_

Years of Experience: \_\_\_\_\_

Type of design projects undertaken: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Please proceed to **Part 2**.  
Thank you.

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## Part 2. Matching Appropriate Representations to the Stage of Product Design

Name: \_\_\_\_\_

Date: \_\_\_\_\_

### The Matrix:

This matrix aims to understand which design representations are used during the design stages of the product development process.

### Instructions:

The matrix is divided into 4 rows of design stages and classified into columns of design representations.

By going through each stage at a time, tick the appropriate design representation if you have used it during that particular stage.

				DESIGN STAGE			
				CONCEPT DESIGN	CONCEPT DEVELOPMENT	EMBODIMENT DESIGN	DETAIL DESIGN
DESIGN REPRESENTATION	SKETCHES	Personal Sketches	Idea Sketch				
			Study Sketch				
			Referential Sketch				
			Memory Sketch				
		Shared Sketches	Information Sketch				
			Coded Sketch				
		Persuasive Sketches	Inspiration Sketch				
			Renderings				
		Prescriptive Sketches	Prescriptive Sketch				
	DRAWINGS	Industrial Design Drawings	Concept Drawings				
			Presentation Drawings				
			Scenarios & Storyboards				
		Engineering Design Drawings	General Arrangement Drawings				
			Technical Drawings				
			Technical Illustrations				
			Single-view Drawings				
			Multi-view Drawings				
			Tape Drawings				
			Diagrams				
		Industrial Design Models	Appearance Models				
			Design Development Models				
			Foam Models				
	MODELS	Engineering Design Models	Functional Concept Models				
			Production Concept Models				
			Assembly Concept Models				
			Concept-of-Operation Models				
			Service Concept Models				
			Environment Concept Models				
	PROTOTYPES	Industrial Design Prototypes	Appearance Prototype				
			Alpha Prototype				
			Beta Prototype				
			Pre-Production Prototype				
		Engineering Design Prototypes	Experimental Prototype				
			System Prototype				
			Final Hardware Prototype				
			Tooling Prototype				
			Off-Tool Prototype				

### Part 3. Which Representations Match the Level of Information Required by Engineering Designers?

### The Matrix:

This matrix aims to validate the design and technical information present in sketches, drawings, models and prototypes.

**Instructions:**

The matrix is divided into rows of different design representations and classified into columns of information.

By going through each design representation one at a time, tick the appropriate information that you think is present in that column of representation.

[illegible]

## Part 4. Last Questions

We would like to ask a few questions on your opinion about the collaboration between Industrial Designers and Engineering Designers.

1. If you are an industrial designer, what information do you need from the engineering designer?

---

---

2. If you are an engineering designer, what information do you need from the industrial designer?

---

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3. In the development of a toolkit, what is your preferred format?

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
Checklist	Matrix	Table of Instructions	Flowchart on a Card	Mini-Booklet	
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Others (please describe)	<hr/>
Webpage	CD-ROM / DVD	Software for PDA	Software for laptops		<hr/>
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





















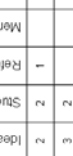

























































Thank you.



### 13.6 Results from the Design Representation Survey

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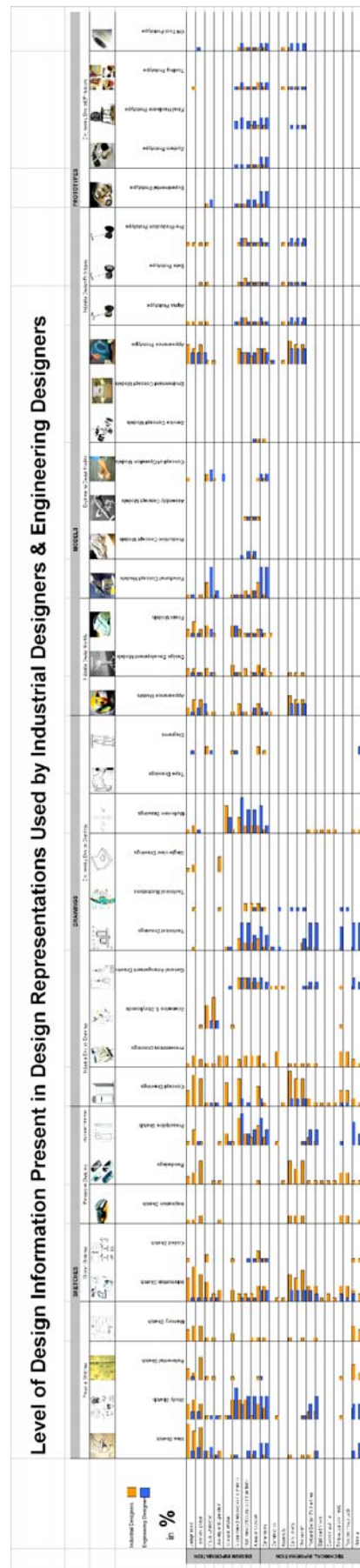
## Level of Design Information present in Design Representations used by Engineering Designers

Level of Design Information present in Design Representations used by Engineering Designers																
DESIGN INFORMATION																
	SKETCHES				DRAWINGS				MODELS				PROTOTYPES			
	Personal Sketches	Shared Sketches	Presentation Sketches	Industrial Design Sketches	Engineering Design Drawings	Industrial Design Models	Engineering Design Models	Industrial Design Prototypes	Engineering Design Prototypes							
1																
2																
																
																
																
																
																
																
																
																
																
	</															

Level of Design Information present in Design Representations used by Industrial Designers																																						
SKETCHES										DRAWINGS										MODELS										PROTOTYPES								
Personal Sketches	Shared Sketches	Persuasive Sketches	Relevant Design Sketches	Technical Design Drawings	Engineering Design Drawings	Technical Illustrations	Single-view Drawings	Multi-view Drawings	Tape Drawings	Diagrams	Appearance Models	Design Development Models	Team Models	Functional Concept Models	Production Concept Models	Assembly Concept Models	Concept-of-Operation Models	Service Concept Models	Environment Concept Models	Appearance Prototype	Alpha Prototype	Beta Prototype	Pre-Production Prototype	Experimental Prototype	System Prototype	Final Hardware Prototype	Tooling Prototype	Off-Tool Prototype										
1																																						
2																																						
in %	Idea Sketch <sup>1</sup>	Study Sketch <sup>2</sup>	Referential Sketch <sup>3</sup>	Memory Sketch <sup>4</sup>	Information Sketch <sup>5</sup>	Coded Sketch <sup>6</sup>	Inspiration Sketch <sup>7</sup>	Renderings <sup>8</sup>	Prescriptive Sketch <sup>9</sup>	Concept Drawings <sup>10</sup>	Presentation Drawings <sup>11</sup>	Scenarios & Storyboards <sup>12</sup>	General Arrangement Drawings <sup>13</sup>	Technical Drawings <sup>14</sup>	Technical Illustrations <sup>15</sup>	Single-view Drawings <sup>16</sup>	Multi-view Drawings <sup>17</sup>	Tape Drawings <sup>18</sup>	Diagrams <sup>19</sup>	Appearance Models <sup>20</sup>	Design Development Models <sup>21</sup>	Team Models <sup>22</sup>	Functional Concept Models <sup>23</sup>	Production Concept Models <sup>24</sup>	Assembly Concept Models <sup>25</sup>	Concept-of-Operation Models <sup>26</sup>	Service Concept Models <sup>27</sup>	Environment Concept Models <sup>28</sup>	Appearance Prototype <sup>29</sup>	Alpha Prototype <sup>30</sup>	Beta Prototype <sup>31</sup>	Pre-Production Prototype <sup>32</sup>	Experimental Prototype <sup>33</sup>	System Prototype <sup>34</sup>	Final Hardware Prototype <sup>35</sup>	Tooling Prototype <sup>36</sup>	Off-Tool Prototype <sup>37</sup>	
	94.4	38.8	27.7	33.3	61.1	11.1	11.1	16.6	5.5	38.8	77.7	33.3		5.5	11.1	16.6	16.6			22.2	16.6	16.6	5.5							5.5	11.1							
	86.6	50	22.2	38.8	68.8		11.1	33.3	38.8	77.7	33.3			5.5	11.1	16.6	16.6			38.8	22.2	38.8	5.5							5.5	11.1							
	77.7	38.8	50	38.8	68.6		22.2	61.1	5.5	72.2	22.2	5.5							16.6	5.5	16.6	27.7	38.8							5.5	11.1	5.5						
	22.2	11.1	11.1	5.5	56.5	22.2		5.5		11.1	5.5	55.5							16.6	5.5	16.6	27.7	38.8							5.5	11.1	5.5						
	11.1	11.1	11.1	22.2				5.5		5.5	5.5	77.7								5.5	5.5	11.1	11.1															
	16.6	11.1			27.7		5.5	11.1	5.5		33.3				5.5	44.4																						
	11.1																66.6																					
	11.1	56.5	11.1	22.2	27.7	5.5						11.1																										
	5.5				22.2					72.2	66.6	16.6		27.7	33.3		44.4			5.5	33.3	33.3	5.5															
TECHNICAL INFORMATION	Dimensions	5.5								72.2	66.6	16.6	27.7	33.3		44.4			5.5	33.3	33.3	5.5																
	Construction	5.5								72.2	66.6	16.6	27.7	33.3		44.4			5.5	33.3	33.3	5.5																
	Assembly	5.5	11.1		5.5	16.6				16.6		27.7	22.2	22.2	16.6		16.6			5.5	11.1	16.6	11.1															
	Components	38.8	5.5	44.4	27.7		5.5	50	50	33.3	22.2	5.5	11.1	22.2	16.6		22.2		16.6	27.7	33.3	22.2	38.8															
	Mechanism	5.5	33.3		5.5	38.8	11.1			22.2	5.5	11.1		11.1	5.5		5.5		5.5	5.5	22.2	11.1	11.1															
	Part and Section Profile Lines																																					
	Exploded Views	5.5																																				
	Colour match file																																					
	Texture (surface finish)	5.5			5.5	72.2	22.2	56.5																														
	Partone colour code																																					
	Material	5.5	5.5		5.5	77.7	22.2	56.5	5.5	72.2	11.1			22.2																								

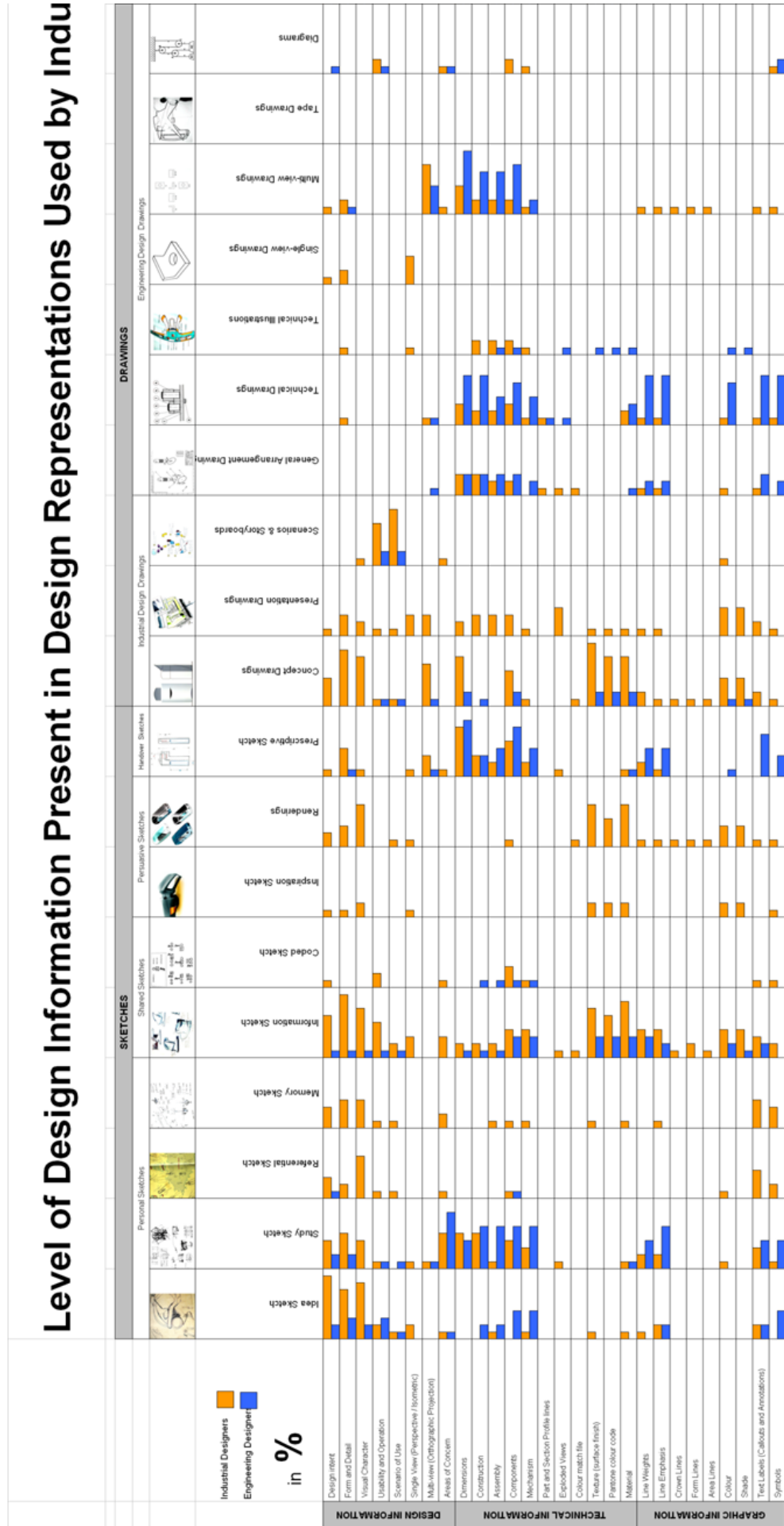
## Level of Design Information present in Design Representations used by Engineering Designers

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A larger image can be viewed in the following page

# Level of Design Information Present in Design Representations Used by Indu





## Industrial Designers & Engineering Designers

# Industrial Designers & Engineering Designers

Out of 18 Interviewees Industrial Designers					
		Concept Design	Concept Development	Embodiment Design	Detail Design
1	Idea Sketch	17	5	3	3
2	Study Sketch	13	6	3	3
3	Referential Sketch	12	2		
4	Memory Sketch	13	3	1	1
5	Information Sketch	10	13	2	1
6	Coded Sketch	6	5	2	
7	Inspiration Sketch	1	2	1	
8	Renderings	2	8	1	1
9	Prescriptive Sketch	2	11	6	6
10	Concept Drawings	7	15	5	4
11	Presentation Drawings	3	10	4	4
12	Scenarios & Storyboards	11	9		
13	General Arrangement Drawings		3	4	5
14	Technical Drawings		1	4	3
15	Technical Illustrations			2	3
16	Single-View Drawings	3	6	4	3
17	Multi-View Drawings	2	4	10	7
18	Tape Drawings				
19	Diagrams	2	4	1	1
20	Appearance Models		3	10	8
21	Design Development Models	5	10	1	
22	Foam Models	4	11	5	1
23	Functional Concept Models	3	5	5	3
24	Production Concept Models				
25	Assembly Concept Models		2		1
26	Concept of Operation Models	1	3	1	1
27	Service Concept Models		1	1	
28	Environment Concept Models				
29	Appearance Prototype	1	1	5	11
30	Alpha Prototype			2	2
31	Beta Prototype			2	1
32	Pre-Production Prototype			1	4
33	Experimental Prototype		1	1	1
34	System Prototype				1
35	Final Hardware Prototype				1
36	Tooling Prototype			1	3
37	Off-Tool Prototype				1

Out of 9 Interviewees Engineering Designers			
Concept Design	Concept Development	Embodiment Design	Detail Design
7	1		
8			
1			
1	1	1	
1			
	1		
4	6	1	
1	1		
	1	1	
1	1		
	2	1	
1		5	2
1			
4	7	2	2
2			
		3	1
		1	
	1	2	
4	5	2	
			2
		1	1
1	1	1	
			1
		2	3
		1	1
		1	
			2
3	3	2	1
	1	2	2
		1	3
		1	2
			2

Statistical results from the survey concerning the commonality of design representations used during the four stages of the design process



In Percentage of 18 Interviewees

Industrial Designers

		Concept Design	Concept Development	Embodiment Design	Detail Design
1	Idea Sketch	94.4	27.7	16.6	16.6
2	Study Sketch	72.2	33.3	16.6	16.6
3	Referential Sketch	66.6	11.1		
4	Memory Sketch	72.2	16.6	5.5	5.5
5	Information Sketch	55.5	72.2	11.1	5.5
6	Coded Sketch	33.3	27.7	11.1	
7	Inspiration Sketch	5.5	11.1	5.5	
8	Renderings	11.1	44.4	5.5	5.5
9	Prescriptive Sketch	11.1	61.1	33.3	33.3
10	Concept Drawings	38.8	83.3	27.7	22.2
11	Presentation Drawings	16.6	55.5	22.2	22.2
12	Scenarios & Storyboards	61.1	50		
13	General Arrangement Drawings		16.6	22.2	27.7
14	Technical Drawings		5.5	22.2	16.6
15	Technical Illustrations			11.1	16.6
16	Single-View Drawings	16.6	33.3	22.2	16.6
17	Multi-View Drawings	11.1	22.2	55.5	38.8
18	Tape Drawings				
19	Diagrams	11.1	22.2	5.5	5.5
20	Appearance Models		16.6	55.5	44.4
21	Design Development Models	27.7	55.5	5.5	
22	Foam Models	22.2	61.1	27.7	5.5
23	Functional Concept Models	16.6	27.7	27.7	16.6
24	Production Concept Models				
25	Assembly Concept Models		11.1		5.5
26	Concept of Operation Models	5.5	16.6	5.5	5.5
27	Service Concept Models		5.5	5.5	
28	Environment Concept Models				
29	Appearance Prototype	5.5	5.5	27.7	61.1
30	Alpha Prototype			11.1	11.1
31	Beta Prototype			11.1	5.5
32	Pre-Production Prototype			5.5	22.2
33	Experimental Prototype		5.5	5.5	5.5
34	System Prototype				5.5
35	Final Hardware Prototype				5.5
36	Tooling Prototype			5.5	16.6
37	Off-Tool Prototype				5.5

Statistical results in percentage concerning the commonality of design representations used by industrial designers during the four stages of the design process

In Percentage of 9 Interviewees

Engineering Designers

		Concept Design	Concept Development	Embodiment Design	Detail Design
1	Idea Sketch	77.7	11.1		
2	Study Sketch	88.8			
3	Referential Sketch	11.1			
4	Memory Sketch				
5	Information Sketch	11.1	11.1	11.1	
6	Coded Sketch	11.1			
7	Inspiration Sketch				
8	Renderings		11.1		
9	Prescriptive Sketch	44.4	66.6	11.1	
10	Concept Drawings	11.1	11.1		
11	Presentation Drawings		11.1	11.1	
12	Scenarios & Storyboards	11.1	11.1		
13	General Arrangement Drawings		22.2	11.1	
14	Technical Drawings	11.1		55.5	22.2
15	Technical Illustrations	11.1			
16	Single-View Drawings				
17	Multi-View Drawings	44.4	77.7	22.2	22.2
18	Tape Drawings				
19	Diagrams	22.2			
20	Appearance Models			33.3	11.1
21	Design Development Models			11.1	
22	Foam Models		11.1	22.2	
23	Functional Concept Models	44.4	55.5	22.2	
24	Production Concept Models				22.2
25	Assembly Concept Models			11.1	11.1
26	Concept of Operation Models	11.1	11.1	11.1	
27	Service Concept Models				11.1
28	Environment Concept Models				
29	Appearance Prototype			22.2	33.3
30	Alpha Prototype			11.1	11.1
31	Beta Prototype			11.1	
32	Pre-Production Prototype				22.2
33	Experimental Prototype	33.3	33.3	22.2	11.1
34	System Prototype		11.1	22.2	22.2
35	Final Hardware Prototype			11.1	33.3
36	Tooling Prototype			11.1	22.2
37	Off-Tool Prototype				22.2

Statistical results in percentage concerning the commonality of design representations used by engineering designers during the four stages of the design process

# Overall Percentage of 27 Interviewees

All

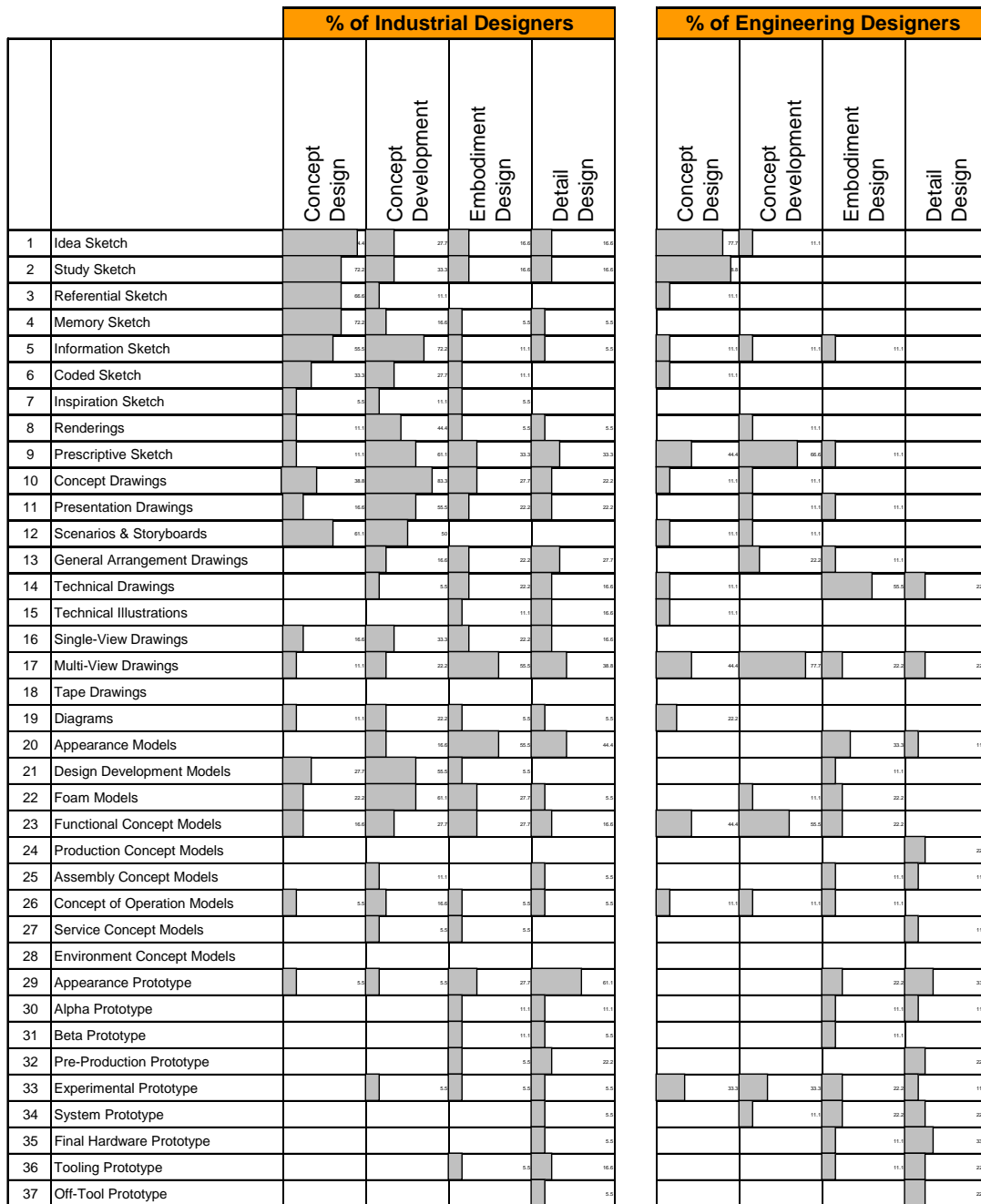
		Concept Design	Concept Development	Embodiment Design	Detail Design
1	Idea Sketch	86.05	19.4	16.6	16.6
2	Study Sketch	80.5	33.3	16.6	16.6
3	Referential Sketch	38.85	11.1		
4	Memory Sketch	72.2	16.6	5.5	5.5
5	Information Sketch	33.3	41.65	11.1	5.5
6	Coded Sketch	22.2	27.7	11.1	
7	Inspiration Sketch	5.5	11.1	5.5	
8	Renderings	11.1	27.75	5.5	5.5
9	Prescriptive Sketch	27.75	63.85	22.2	33.3
10	Concept Drawings	24.95	47.2	27.7	22.2
11	Presentation Drawings	16.6	33.3	16.65	22.2
12	Scenarios & Storyboards	36.10	30.55		
13	General Arrangement Drawings		19.4	16.65	27.7
14	Technical Drawings	11.1	5.5	38.85	19.4
15	Technical Illustrations	11.1		11.1	16.6
16	Single-View Drawings	16.6	33.3	22.2	16.6
17	Multi-View Drawings	27.75	49.95	38.85	30.5
18	Tape Drawings				
19	Diagrams	16.65	22.2	5.5	5.5
20	Appearance Models		16.6	44.4	27.75
21	Design Development Models	27.7	55.5	8.3	
22	Foam Models	22.2	36.1	24.95	5.5
23	Functional Concept Models	30.5	41.6	24.95	16.6
24	Production Concept Models				22.2
25	Assembly Concept Models		11.1	11.1	8.3
26	Concept of Operation Models	8.3	13.85	8.3	5.5
27	Service Concept Models		5.5	5.5	11.1
28	Environment Concept Models				
29	Appearance Prototype	5.5	5.5	24.95	47.2
30	Alpha Prototype			11.1	11.1
31	Beta Prototype			11.1	5.5
32	Pre-Production Prototype			5.5	22.2
33	Experimental Prototype	33.3	19.4	13.85	8.3
34	System Prototype		11.1	22.2	13.85
35	Final Hardware Prototype			11.1	19.4
36	Tooling Prototype			8.3	19.4
37	Off-Tool Prototype				13.85

Statistical results in percentage concerning the commonality of design representations used by industrial designers and engineering designers during the four stages of the design process

# Percentage of Visual Design Representations Applied during Stages of the Design Process

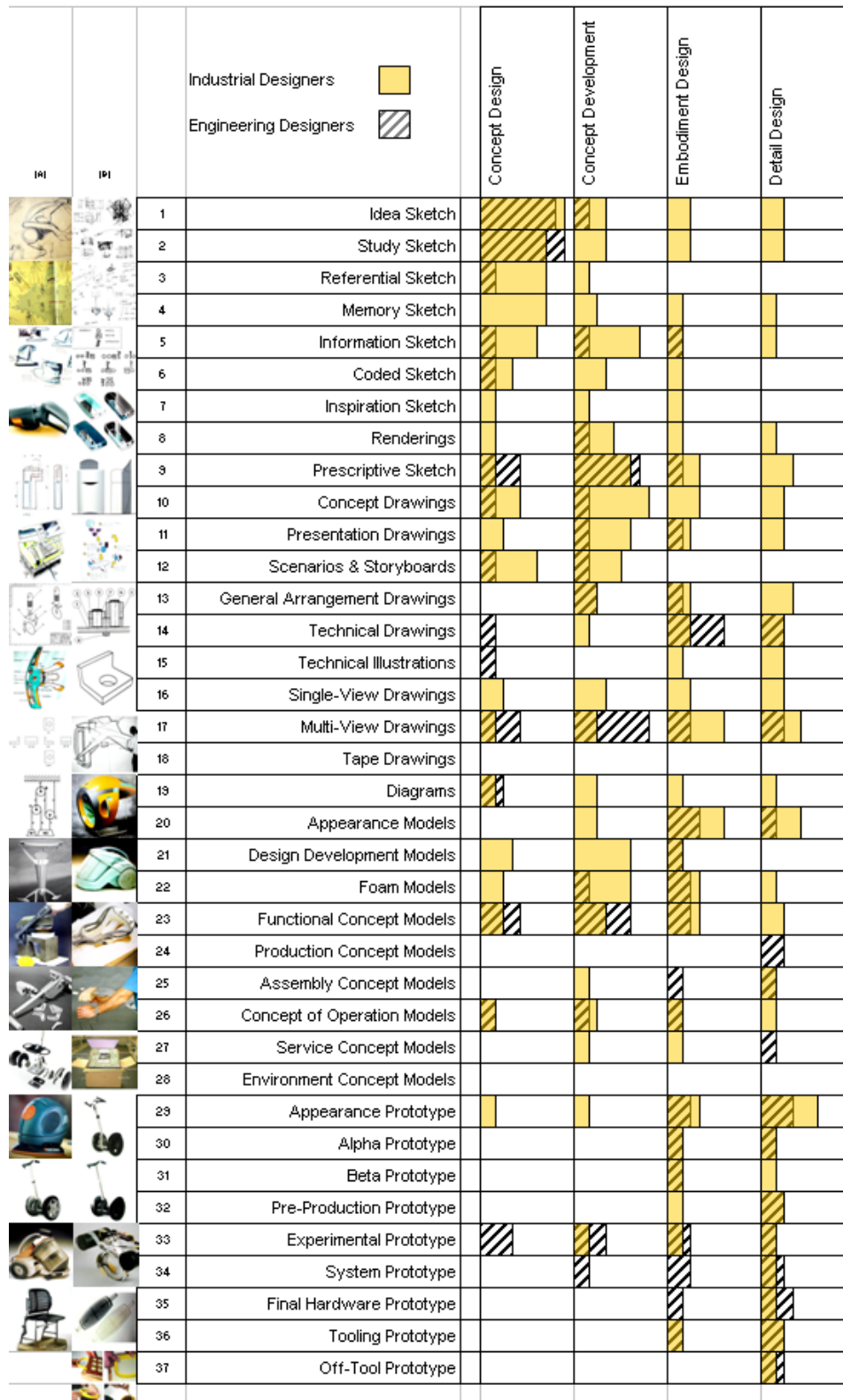
In Percentage of 18 Interviewees

In Percentage of 9 Interviewees



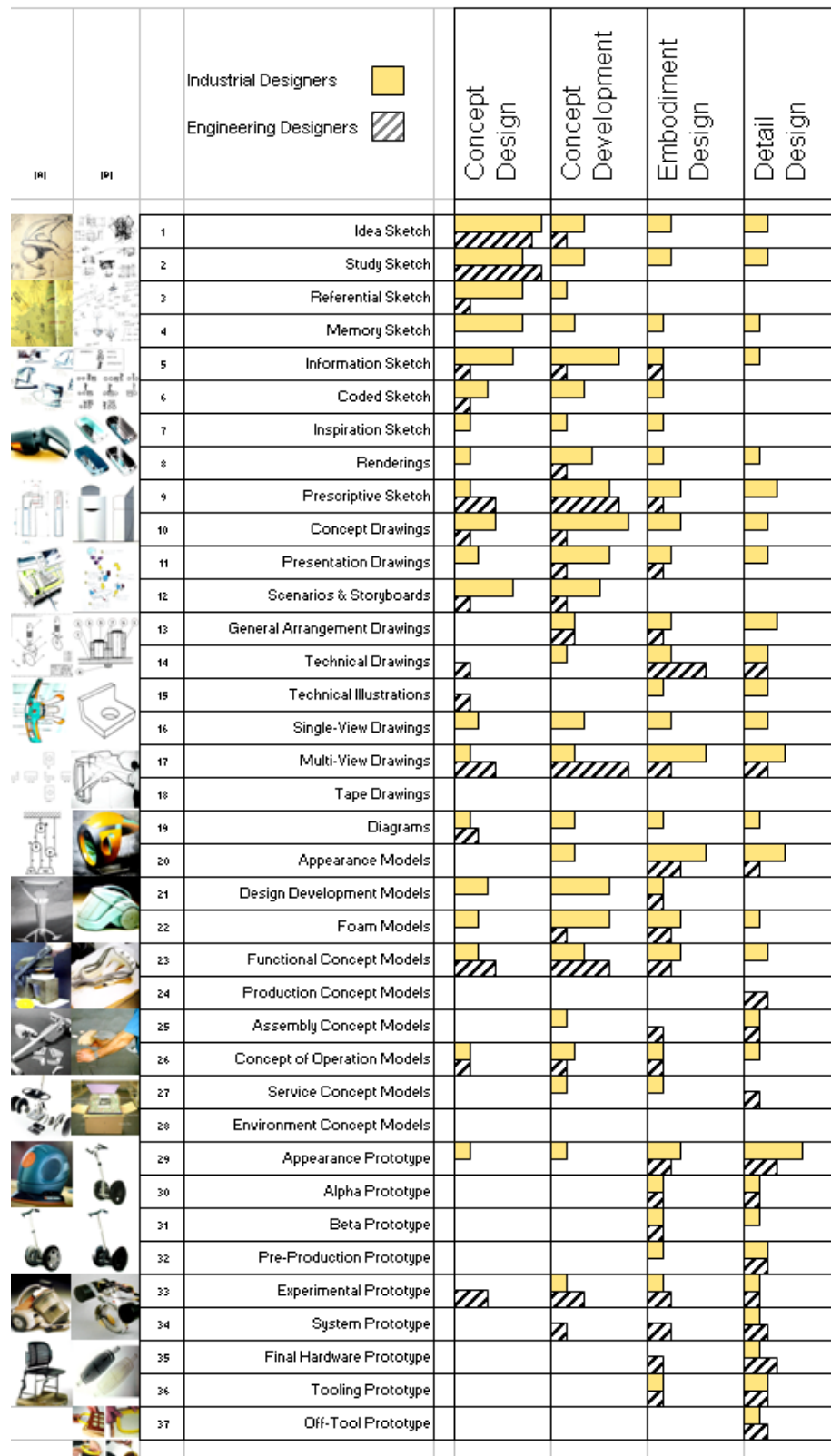
Statistical results in percentage comparing the commonality of design representations used by industrial designers and engineering designers during the four stages of the design process

## Percentage of Design Representations used during Stages of the Design Process



Overlay showing statistical results in percentage comparing the commonality of design representations used by industrial designers and engineering designers during the four stages of the design process

## Percentage of Visual Design Representations Applied during Stages of the Design Process



Side-by-side bar charts showing statistical results in percentage comparing the commonality of design representations used by industrial designers and engineering designers during the four stages of the design process

13.7 Matrix Design

Below shows an enlarged image for Figure 287 of Section 9.4.3.

DESIGN STAGES & INFORMATION IN DESIGN REPRESENTATIONS  
USED BY INDUSTRIAL DESIGNERS & ENGINEERING DESIGNERS



## **13.8 Card Design Iteration Two**

The next pages show the complete set of iteration two cards:

### **Design Stages**

Figure 1: Industrial Designers' set for Design Stages

Figure 2: Engineering Designers' set for Design Stages

### **Design Information**

Figure 3: Industrial Designers' set for Design Information (1)

Figure 4: Industrial Designers' set for Design Information (2)

Figure 5: Engineering Designers' set for Design Information (1)

Figure 6: Engineering Designers' set for Design Information (2)

### **Technical Information**

Figure 7: Industrial Designers' set for Technical Information

Figure 8: Engineering Designers' set for Technical Information

### **Sketches**

Figure 9: Industrial Designers' set for Sketches

Figure 10: Engineering Designers' set for Sketches

### **Drawings**

Figure 11: Industrial Designers' set for Drawings

Figure 12: Engineering Designers' set for Drawings

### **Models**

Figure 13: Industrial Designers' set for Models

Figure 14: Engineering Designers' set for Models

### **Prototypes**

Figure 15: Industrial Designers' set for Prototypes

Figure 16: Engineering Designers' set for Prototypes





Industrial Designers' set for Design Stages



Engineering Designers' set for Design Stages



Industrial Designers' set for Design Information (1)



Industrial Designers' set for Design Information (2)





Engineering Designers' set for Design Information (1)



Engineering Designers' set for Design Information (2)



Industrial Designers' set for Technical Information





Engineering Designers' set for Technical Information





Industrial Designers' set for Sketches



Engineering Designers' set for Sketches





Industrial Designers' set for Drawings



Engineering Designers' set for Drawings





Industrial Designers' set for Models



Engineering Designers' set for Models





Industrial Designers' set for Prototypes



Engineering Designers' set for Prototypes



## 13.9 Pilot Study Questions



Design Representation  
Quality Management  
Toolkit Beta 2.0

### Pilot Study A - Initial Opinions of the Index Cards

#### Enhancing Collaboration through Standardized Design Representations between Industrial Designers & Engineering Designers

Eujin Pei

Dr R.I. Campbell

Dr M.A. Evans

This pilot study aims to collect opinions about the DRQM index cards which serve as a collaboration platform between industrial designers and engineering designers.





## Interviewee Details

Thank you for taking part in our research study. We will need some information about you to obtain more accurate results. All information will be kept strictly confidential.

Date of Interview: \_\_\_\_\_

Name: \_\_\_\_\_

Company: \_\_\_\_\_

Position : \_\_\_\_\_

Role and Responsibility: \_\_\_\_\_

Educational Background: \_\_\_\_\_

Years of Experience: \_\_\_\_\_

Type of design projects undertaken: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

## Questions

1. How do you feel about the gaming card format?

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---

---

2. How do you feel about the physical size of the cards?

---

---

---

3. Are the textual content and pictorial data clear and easy to understand?

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---

---

4. Do you think the cards would provide you with an enhanced understanding and clearer definition of design representations?

---

---

---

5. Do you think the cards would be effective in understanding design representations between IDs and EDs?

---

---

---

6. Would the bar charts showing key design and technical information prove to be useful to you?

---

---

---

7. Would you be more able to identify the representation most commonly used during the different stages of the design process?

---

---

---

8. Do you think having accurately defined design representations would foster enhanced collaboration between IDs and EDs?

---

---

---

9. Do you think using the index cards will positively improve (your) design collaboration (between) other industrial designers / engineering designers?

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10. Would you have any suggestions to help us improve the cards?

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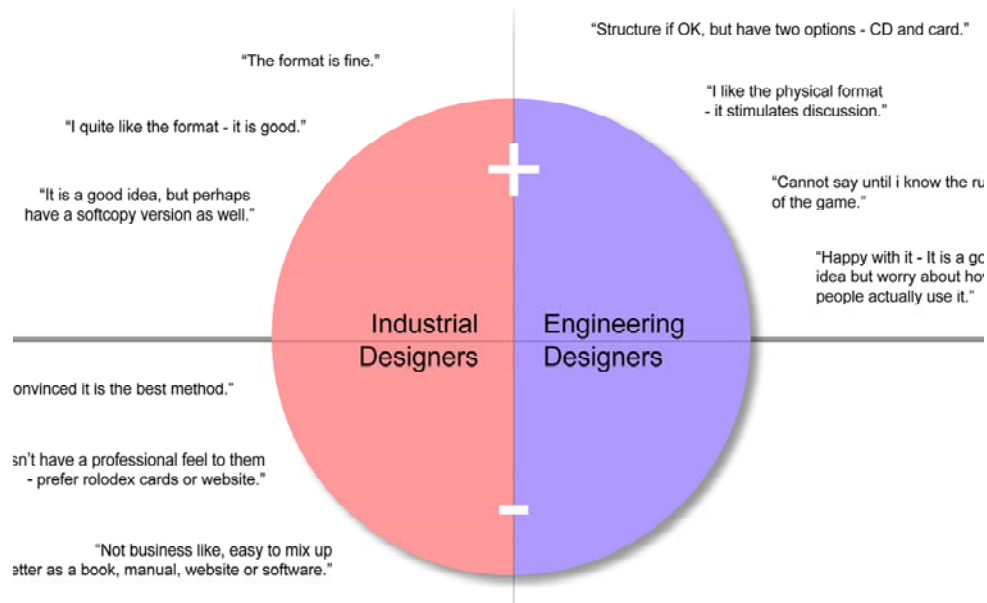
---

### 13.10 Results of Pilot Study

The following pages show the results of the pilot study summarized in a graphical format.

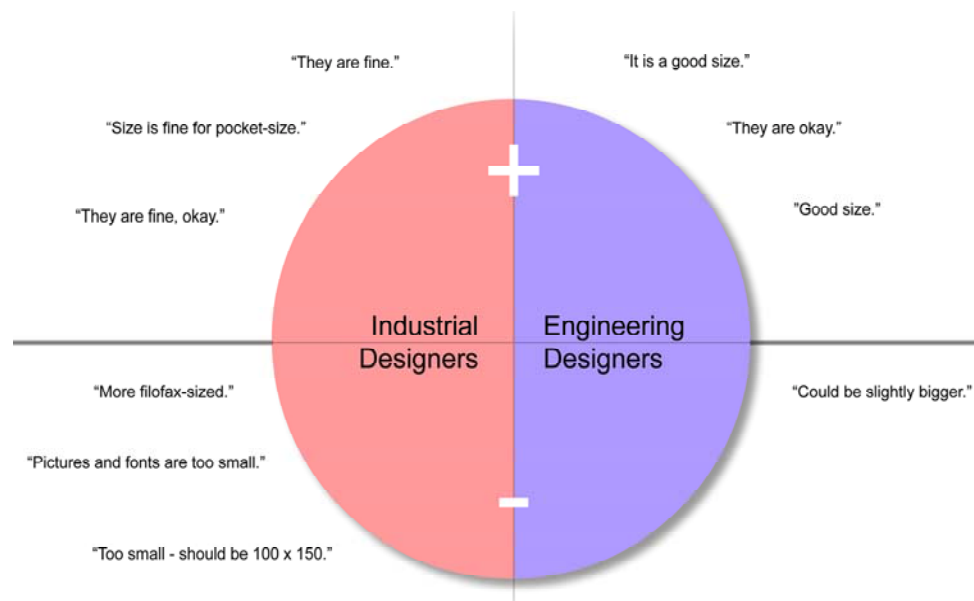
#### Pilot Study Question 1

How do you feel about the gaming card format ?



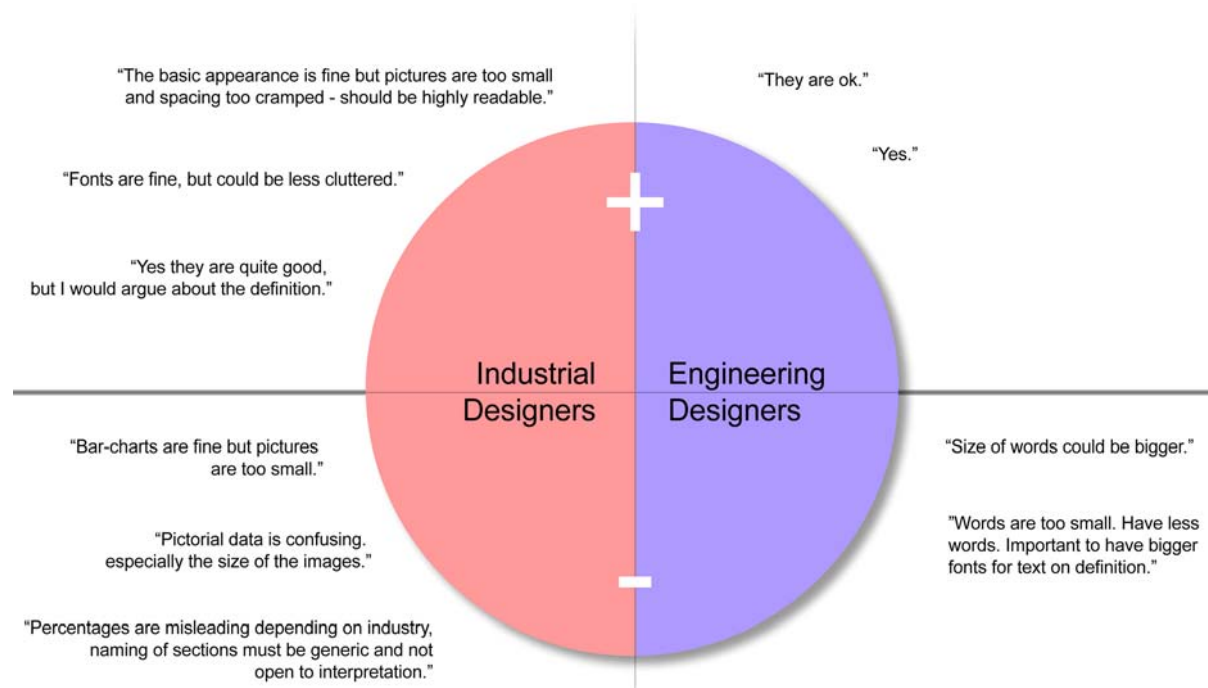
#### Pilot Study Question 2

How do you feel about the physical size of the cards?



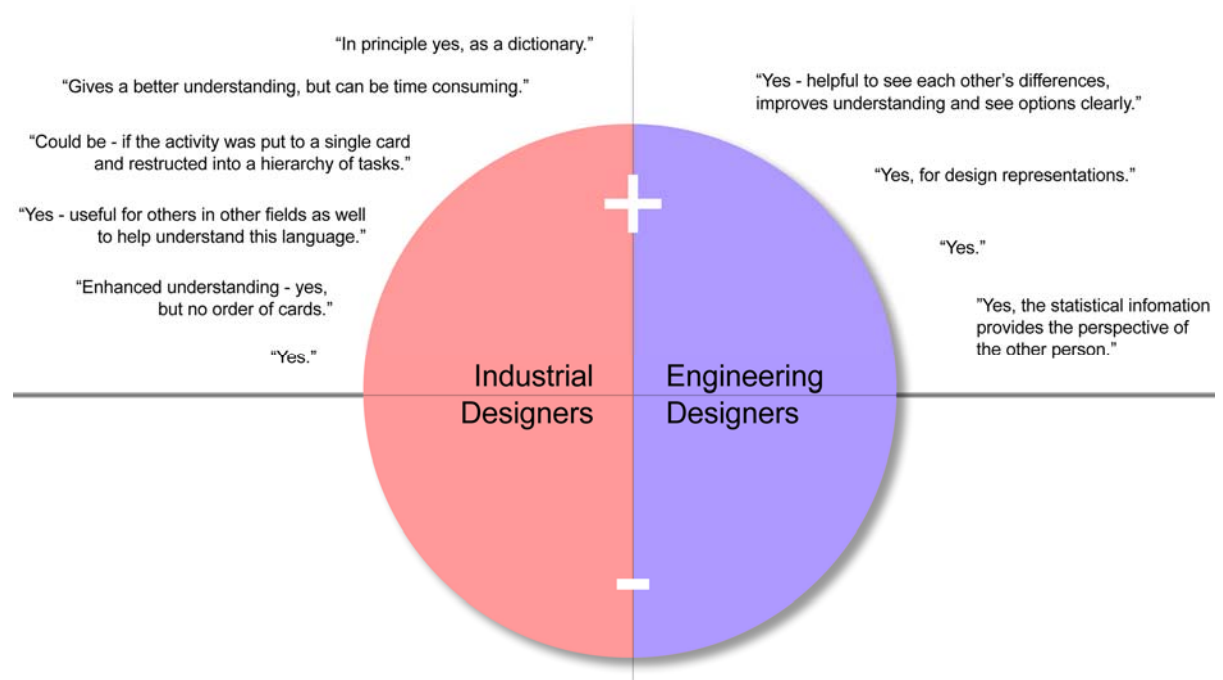
### Pilot Study Question 3

Are the textual content and pictorial data clear and easy to understand?



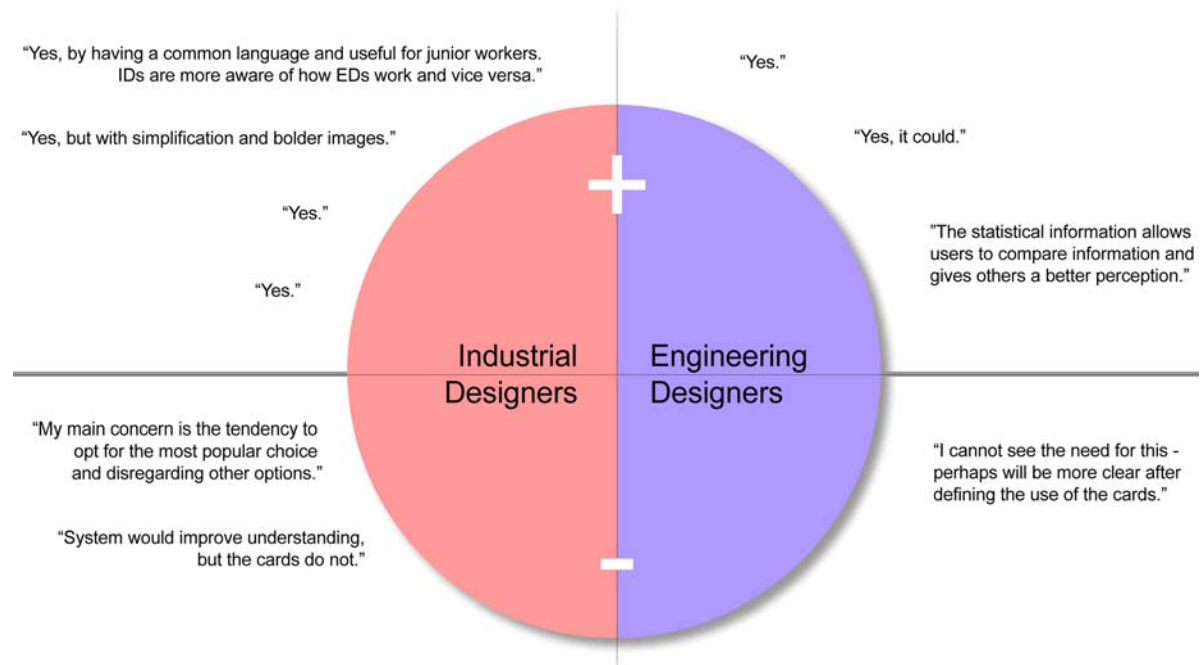
### Pilot Study Question 4

Do you think the cards would provide you with an enhanced understanding and clearer definition of design representations?



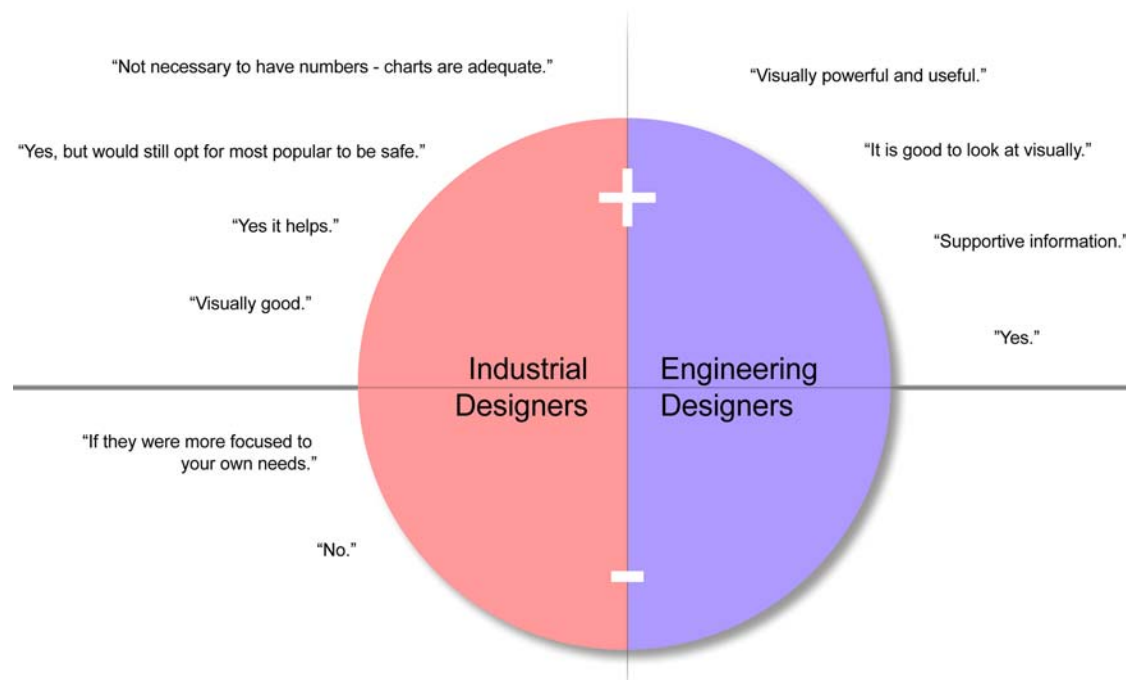
## Pilot Study Question 5

Do you think the cards would be effective in understanding design representations between industrial designers and engineering designers?



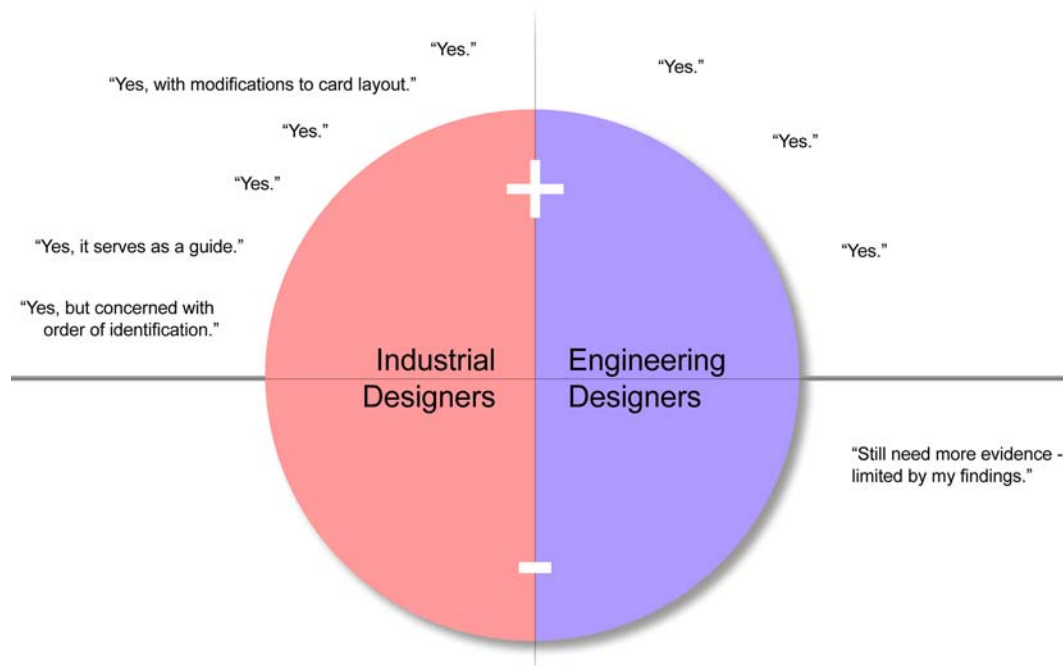
## Pilot Study Question 6

Would the bar charts showing key design and technical information prove to be useful to you?



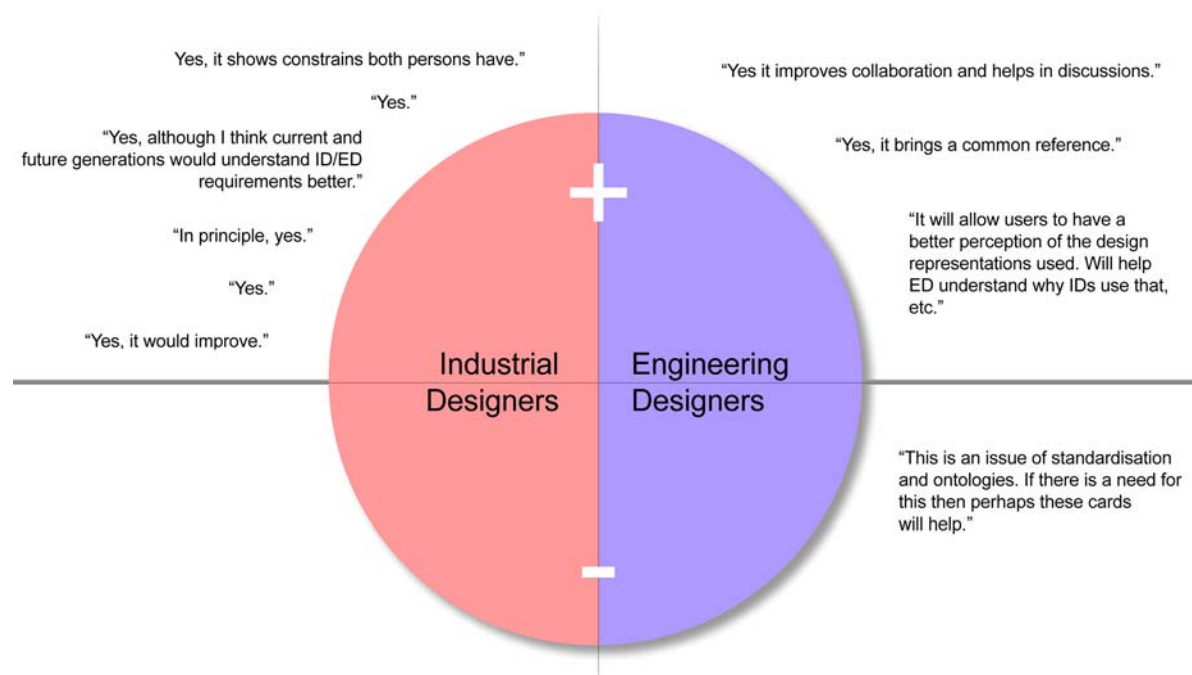
### Pilot Study Question 7

Would you be more able to identify the representation most commonly used during the different stages of the design process?



### Pilot Study Question 8

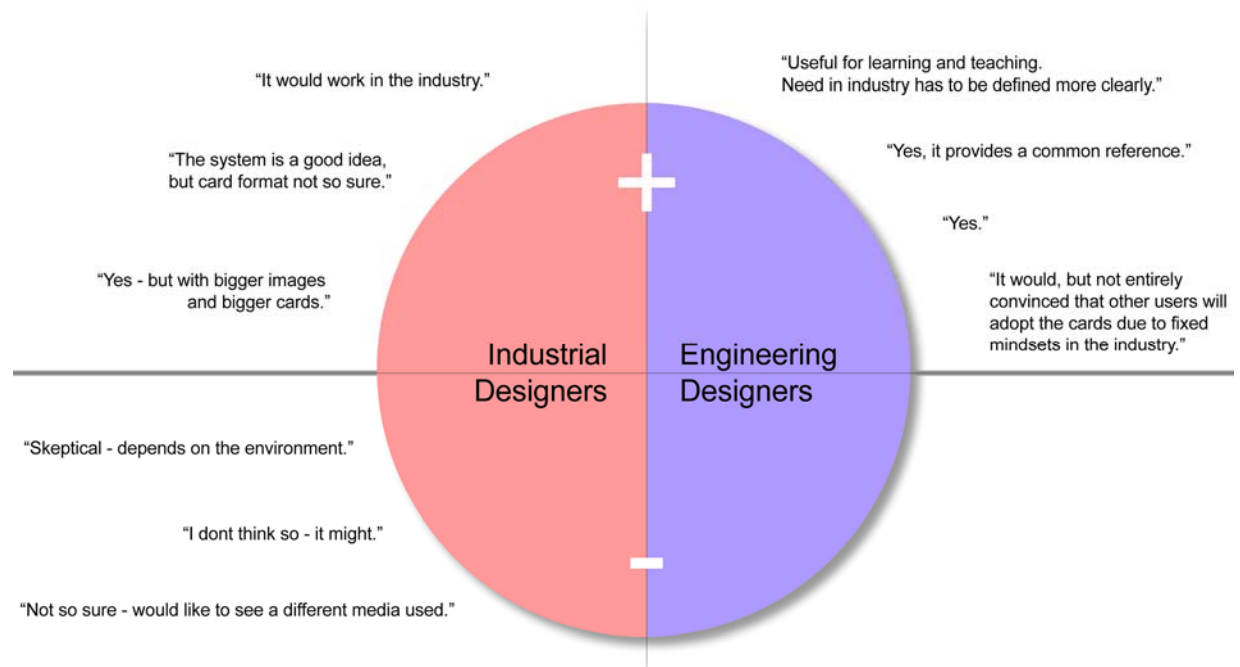
Do you think having accurately defined design representations would foster enhanced collaboration between industrial designers and engineering designers?





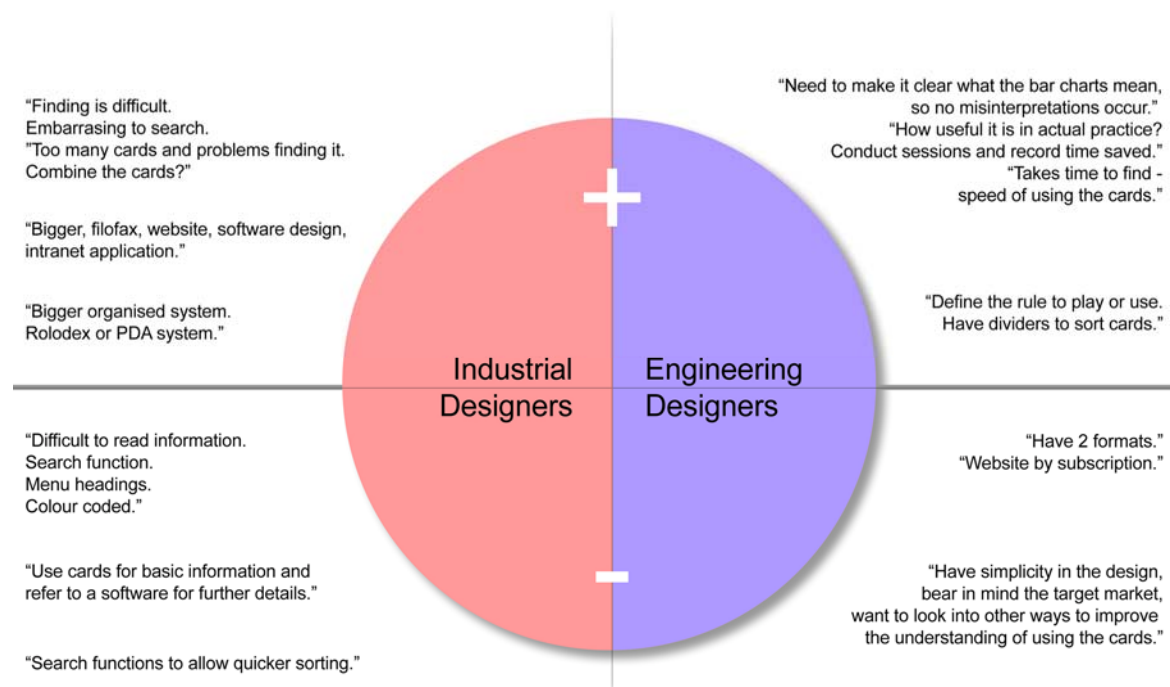
## Pilot Study Question 9

Do you think using the index cards will positively improve (your) design collaboration (between) other industrial designers / engineering designers?



## Pilot Study Question 10

Would you have any suggestions to help us improve the cards?



## 13.11 Card Design Iteration Three

The following pages show the proposed design tool that was subjected to the validation study.





**DES INFO** Industrial Designers 05

## Design Intent

This refers to explaining the design concept and product purpose defined by the designer to be important, such as aesthetics, safety or usability.

Key design representations used to show Design Intent

33 Idea Sketches	90
34 Information Sketches	60
43 Appearance Prototypes	50
32 Study Sketches	40
32 Concept Drawings	40
32 Referential Sketches	30
32 Memory Sketches	30

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**DES INFO** Engineering Designers 05

## Design Intent

This refers to explaining the design concept and product purpose defined by the designer to be important, such as aesthetics, safety or usability.

Key design representations used to show Design Intent

43 Appearance Prototype	30
33 Idea Sketches	20
32 Study Sketches	20
32 Referential Sketches	10
32 Information Sketches	10
32 Diagrams	10
43 Appearance Models	10
42 Design Development Models	10
41 3D Sketch Models	10
42 Functional Concept Models	10

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**DES INFO** Industrial Designers 06

## Form & Detail

This refers to the aesthetic judgement of the product's appearance with concern to form and comprising of structure, shape, proportion and size.

Key design representations used to show Form & Detail

34 Information Sketches	90
32 Concept Drawings	80
33 Idea Sketches	70
32 Study Sketches	50
32 Memory Sketches	40
42 Prescriptive Sketches	40
43 Appearance Models	40
41 3D Sketch Models	40
43 Appearance Prototypes	40

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**DES INFO** Engineering Designers 06

## Form & Detail

This refers to the aesthetic judgement of the product's appearance with concern to form and comprising of structure, shape, proportion and size.

Key design representations used to show Form & Detail

33 Idea Sketches	30
43 Appearance Prototypes	30
32 Study Sketches	20
43 Appearance Models	20
32 Information Sketches	10
42 Prescriptive Sketches	10
37 Multi-View Drawings	10
42 Design Development Models	10
41 3D Sketch Models	10
37 Off-Tool Prototypes	10

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**DES INFO** Industrial Designers 07

## Visual Character

This refers to the product personality or character that a product conveys to the user, usually through the external form, choice of materials, texture and finishing, etc.

Key design representations used to show Visual Character

33 Idea Sketches	80
34 Information Sketches	70
32 Concept Drawings	70
32 Renderings	60
32 Referential Sketches	50
43 Appearance Prototypes	50
32 Study Sketches	40
32 Memory Sketches	40
43 Appearance Models	40

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**DES INFO** Engineering Designers 07

## Visual Character

This refers to the product personality or character that a product conveys to the user, usually through the external form, choice of materials, texture and finishing, etc.

Key design representations used to show Visual Character

43 Appearance Models	30
43 Appearance Prototypes	30
33 Idea Sketches	20
32 Information Sketches	10

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**DES INFO** Industrial Designers 08

## Usability & Operation

This explains how well a product is capable of being used, including functional effectiveness, ergonomics and operational efficiency.

Key design representations used to show Usability & Operation

34 Information Sketches	60
34 Scenarios & Storyboards	60
42 Functional Concept Models	40
41 3D Sketch Models	30
33 Idea Sketches	20
32 Coded Sketches	20
32 Diagrams	20
42 Design Development Models	20
42 Concept of Operation Models	20

Design Representation Quality Management © 2008 All Rights Reserved

**DES INFO** Engineering Designers 08

## Usability & Operation

This explains how well a product is capable of being used, including functional effectiveness, ergonomics and operational efficiency.

Key design representations used to show Usability & Operation

42 Functional Concept Models	80
33 Idea Sketches	30
42 Concept of Operation Models	30
34 Scenarios & Storyboards	20
41 3D Sketch Models	20
42 Experimental Prototype	20
32 Study Sketches	10
32 Information Sketches	10
32 Concept Drawings	10
32 Diagrams	10
42 Design Development Models	10

Design Representation Quality Management © 2008 All Rights Reserved

**DES INFO** Industrial Designers 09

## Scenario of Use

**Design Information**

This describes how a product would be used in a projected sequence of events and may include relationships between the user, environment and product.

**DES INFO** Industrial Designers 09

## Scenario of Use

**Design Information**

This describes how a product would be used in a projected sequence of events and may include relationships between the user, environment and product.

Key design representations used to show Scenario of Use

24 Scenarios & Storyboards	20
24 Functional Concept Models	20
24 Concept of Operation Models	20
22 Idea Sketches	10
22 Study Sketches	10
22 Information Sketches	10
22 Concept Drawings	10

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**DES INFO** Engineering Designers 09

## Scenario of Use

**Design Information**

This describes how a product would be used in a projected sequence of events and may include relationships between the user, environment and product.

**DES INFO** Engineering Designers 09

## Scenario of Use

**Design Information**

This describes how a product would be used in a projected sequence of events and may include relationships between the user, environment and product.

Key design representations used to show Scenario of Use

24 Scenarios & Storyboards	80
22 Information Sketches	20
22 Idea Sketches	10
22 Referential Sketches	10
22 Memory Sketches	10
21 3D Sketch Models	10
24 Functional Concept Models	10

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**DES INFO** Industrial Designers 10

## Single-Views

**Design Information**

They comprise of isometric, trimetric, perspective, oblique and axonometric projections in the form of sketches or drawings.

**DES INFO** Industrial Designers 10

## Single-Views

**Design Information**

They comprise of isometric, trimetric, perspective, oblique and axonometric projections in the form of sketches or drawings.

Key design representations used to show Single-Views

24 Single-View Drawings	40
22 Information Sketches	30
22 Presentation Drawings	30
22 Idea Sketches	20
22 Study Sketches	10
22 Inspiration Sketches	10
22 Renderings	10
21 Prescriptive Sketches	10
20 Technical Illustrations	10

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**DES INFO** Engineering Designers 10

## Single-Views

**Design Information**

They comprise of isometric, trimetric, perspective, oblique and axonometric projections in the form of sketches or drawings.

**DES INFO** Engineering Designers 10

## Single-Views

**Design Information**

They comprise of isometric, trimetric, perspective, oblique and axonometric projections in the form of sketches or drawings.

Single-Views are not commonly used by engineering designers

Key design representations used to show Single-Views

24 Single-View Drawings	40
22 Information Sketches	30
22 Presentation Drawings	30
22 Idea Sketches	20
22 Study Sketches	10
22 Inspiration Sketches	10
22 Renderings	10
21 Prescriptive Sketches	10
20 Technical Illustrations	10

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**DES INFO** Industrial Designers 11

## Multi-Views

**Design Information**

These are diagrammatic views through first-angle or third-angle projections in which the form is flattened out with plan views, front elevations and end elevations.

**DES INFO** Industrial Designers 11

## Multi-Views

**Design Information**

These are diagrammatic views through first-angle or third-angle projections in which the form is flattened out with plan views, front elevations and end elevations.

Key design representations used to show Multi-Views

27 Multi-View Drawings	70
22 Concept Drawings	60
21 Prescriptive Sketches	30
22 Presentation Drawings	30
22 Study Sketches	10
22 Technical Drawings	10

Design Representation Quality Management © 2008 All Rights Reserved

**DES INFO** Engineering Designers 11

## Multi-Views

**Design Information**

These are diagrammatic views through first-angle or third-angle projections in which the form is flattened out with plan views, front elevations and end elevations.

**DES INFO** Engineering Designers 11

## Multi-Views

**Design Information**

These are diagrammatic views through first-angle or third-angle projections in which the form is flattened out with plan views, front elevations and end elevations.

Key design representations used to show Multi-Views

27 Multi-View Drawings	40
24 Study Sketches	10
21 Prescriptive Sketches	10
22 Concept Drawings	10
22 General Arrangement Drawings	10
21 Technical Drawings	10

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**DES INFO** Industrial Designers 12

## Areas of Concern

**Design Information**

This refers to issues concerning the overall design and may include issues on safety, usability and production, etc.

**DES INFO** Industrial Designers 12

## Areas of Concern

**Design Information**

This refers to issues concerning the overall design and may include issues on safety, usability and production, etc.

Key design representations used to show Areas of Concern

24 Study Sketches	90
21 3D Sketch Models	30
22 Final Hardware Prototypes	20
22 Idea Sketches	10
22 Diagrams	10
22 Design Development Models	10
24 Functional Concept Models	10
20 Alpha Prototypes	10
22 Experimental Prototypes	10
24 System Prototypes	10
22 Tooling Prototypes	10

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**DES INFO** Engineering Designers 12

## Areas of Concern

**Design Information**

This refers to issues concerning the overall design and may include issues on safety, usability and production, etc.

**DES INFO** Engineering Designers 12

## Areas of Concern

**Design Information**

This refers to issues concerning the overall design and may include issues on safety, usability and production, etc.

Key design representations used to show Areas of Concern

24 Study Sketches	60
22 Information Sketches	30
22 Design Development Models	30
21 3D Sketch Models	30
22 Memory Sketches	20
22 Idea Sketches	10
22 Referential Sketches	10
24 Scenarios & Storyboards	10

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**DES INFO** Industrial Designers 13 Design Information

## Texture & Surface Finish

Texture refers to the external surface of the object received through the sense of touch.  
Surface finish describes the surface coating of the product.

Key design representations used to show Texture & Surface Finish

32 Concept Drawings	90
31 Information Sketches	70
29 Renderings	60
49 Appearance Prototypes	60
42 Appearance Models	50
30 Inspiration Sketches	20

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**DES INFO** Engineering Designers 13 Design Information

## Texture & Surface Finish

Texture refers to the external surface of the object received through the sense of touch.  
Surface finish describes the surface coating of the product.

Key design representations used to show Texture & Surface Finish

49 Appearance Prototypes	40
31 Information Sketches	30
42 Appearance Models	30
32 Concept Drawings	20
30 Alpha Prototypes	20
42 Pre-Production Prototypes	20
27 Off-Tool Prototypes	20
40 Technical Illustrations	10
31 Beta Prototypes	10
33 Final Hardware Prototypes	10
48 Tooling Prototypes	10

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**DES INFO** Industrial Designers 14 Design Information

## Colour

This refers to the visual attributes of the product's appearance in terms of hue, lightness and saturation.

Key design representations used to show Colour

32 Concept Drawings	70
31 Information Sketches	60
49 Appearance Prototypes	50
29 Renderings	40
42 Appearance Models	40
30 Inspiration Sketches	20

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**DES INFO** Engineering Designers 14 Design Information

## Colour

This refers to the visual attributes of the product's appearance in terms of hue, lightness and saturation.

Key design representations used to show Colour

49 Appearance Prototypes	40
31 Information Sketches	30
42 Appearance Models	30
32 Concept Drawings	20
30 Alpha Prototypes	20
42 Pre-Production Prototypes	20
27 Off-Tool Prototypes	20
40 Technical Illustrations	10
31 Beta Prototypes	10
33 Final Hardware Prototypes	10
48 Tooling Prototypes	10

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**TECH INFO** Industrial Designers 15 Technical Information

## Dimensions

Dimensions generally comprise measurements of parts, including angles and tolerances with a specified unit of measurement.

Key design representations used to show Dimensions

31 Prescriptive Sketches	70
32 Concept Drawings	70
27 Multi-View Drawings	40
49 Appearance Prototypes	40
29 General Arrangement Drawings	30
33 Technical Drawings	30
42 Appearance Models	30
31 Information Sketches	20
32 Presentation Drawings	20
41 3D Sketch Models	20

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**TECH INFO** Engineering Designers 15 Technical Information

## Dimensions

Dimensions generally comprise measurements of parts, including angles and tolerances with a specified unit of measurement.

Key design representations used to show Dimensions

27 Multi-View Drawings	90
31 Prescriptive Sketches	80
33 Technical Drawings	70
27 Study Sketches	40
29 General Arrangement Drawings	30
49 Appearance Prototypes	30
33 Final Hardware Prototypes	30

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**TECH INFO** Industrial Designers 16 Technical Information

## Construction

Constructions refer to the arrangement and composition of parts that when put together make the product.

Key design representations used to show Construction

31 Prescriptive Sketches	30
32 Presentation Drawings	30
29 General Arrangement Drawings	30
49 Appearance Prototypes	30
33 Technical Drawings	20
27 Multi-View Drawings	20

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**TECH INFO** Engineering Designers 16 Technical Information

## Construction

Constructions refer to the arrangement and composition of parts that when put together make the product.

Key design representations used to show Construction

27 Study Sketches	70
33 Technical Drawings	70
27 Multi-View Drawings	60
31 Prescriptive Sketches	30
29 General Arrangement Drawings	30
49 Appearance Prototypes	30
22 Idea Sketches	20
41 Production Concept Models	20
42 Experimental Prototypes	20
33 Final Hardware Prototypes	20

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**TECH INFO** Industrial Designers 17

## Assembly

Technical Information

Assembly describes the process where the manufactured parts are put together to make the completed product

Key design representations used to show Assembly

33 Presentation Drawings	30
28 Information Sketches	20
21 Prescriptive Sketches	20
22 General Arrangement Drawings	20
23 Technical Drawings	20
24 Technical Illustrations	20
27 Multi-View Drawings	20
44 Functional Concept Models	20
45 Appearance Prototypes	20

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**TECH INFO** Engineering Designers 17

## Assembly

Technical Information

Assembly describes the process where the manufactured parts are put together to make the completed product

Key design representations used to show Assembly

24 Study Sketches	70
27 Multi-View Drawings	60
21 Prescriptive Sketches	40
23 Technical Drawings	40
22 General Arrangement Drawings	30
45 Appearance Prototypes	30
22 Idea Sketches	20
45 Appearance Models	20
44 Functional Concept Models	20
46 Production Concept Models	20
43 Experimental Prototypes	20
45 Final Hardware Prototypes	20

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**TECH INFO** Industrial Designers 18

## Components

Technical Information

Components consist of connecting parts where together form the overall working product and may be classified as electrical and mechanical components, etc.

Key design representations used to show Components

21 Prescriptive Sketches	50
22 Concept Drawings	50
24 Study Sketches	40
28 Information Sketches	40
24 Functional Concept Models	40
45 Appearance Prototypes	40
27 Coded Sketches	30
33 Presentation Drawings	30
23 Technical Drawings	30
45 Appearance Models	30
42 Design Development Models	30

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**TECH INFO** Engineering Designers 18

## Components

Technical Information

Components consist of connecting parts where together form the overall working product and may be classified as electrical and mechanical components, etc.

Key design representations used to show Components

44 Functional Concept Models	80
24 Study Sketches	70
21 Prescriptive Sketches	70
27 Multi-View Drawings	70
23 Technical Drawings	60
22 Idea Sketches	40
45 Appearance Prototypes	40
43 Experimental Prototypes	40
28 Information Sketches	30
22 General Arrangement Drawings	30
44 System Prototypes	30
45 Final Hardware Prototypes	30

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**TECH INFO** Industrial Designers 19

## Mechanism

Technical Information

Mechanism involves the assembly of connected moving parts of a product and its physical operation to perform a function.

Key design representations used to show Mechanism

28 Information Sketches	40
45 Appearance Prototypes	40
24 Study Sketches	30
21 Prescriptive Sketches	20
42 Design Development Models	20

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**TECH INFO** Engineering Designers 19

## Mechanism

Technical Information

Mechanism involves the assembly of connected moving parts of a product and its physical operation to perform a function.

Key design representations used to show Mechanism

44 Functional Concept Models	80
24 Study Sketches	70
22 Idea Sketches	40
21 Prescriptive Sketches	40
23 Technical Drawings	40
43 Experimental Prototypes	40
28 Information Sketches	30
45 Appearance Prototypes	30
44 System Prototype	30
45 Final Hardware Prototypes	30

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**TECH INFO** Industrial Designers 20

## Part & Section Profile Lines

Technical Information

These comprise of lines that delineate the form, section or area of a product and includes parting lines where two parts are assembled together or where molding dies meet.

Key design representations used to show Part & Section Profile Lines

45 Appearance Prototypes	10
22 General Arrangement Drawings	10
23 Technical Drawings	10
45 Appearance Models	10
42 Design Development Models	10
41 3D Sketch Models	10

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**TECH INFO** Engineering Designers 20

## Part & Section Profile Lines

Technical Information

These comprise of lines that delineate the form, section or area of a product and includes parting lines where two parts are assembled together or where molding dies meet.

Key design representations used to show Part & Section Profile Lines

23 Technical Drawings	10
45 Appearance Prototypes	10

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**TECH  
INFO**

Industrial Designers

**21**

**Exploded Views**

Exploded views show parts of a product slightly separated by distance to display the components contained within the assembly

Technical Information

[illegible]

**TECH  
INFO**

Engineering Designers

**21**

**Exploded Views**

Exploded views show parts of a product slightly separated by distance to display the components contained within the assembly

Technical Information

[illegible]

**TECH  
INFO**

Industrial Designers

**22**

**Material**

Technical Information

Material involves the substance of which the physical product part is made up of.

[illegible]

**TECH  
INFO**

Engineering Designers

**22**

**Material**

Technical Information

Material involves the substance of which the physical product part is made up of.

[illegible]

The image shows the front cover of a book titled 'Idea Sketch' by 'Industrial Designers'. The cover has a vibrant red background. In the top left corner, there is a circular logo for 'DES REPS' with 'SKETCHES' written in a curved banner above it. The title 'Idea Sketch' is prominently displayed in the center in a large, white, sans-serif font. To the right of the title, the subtitle 'Personal Sketches' is written vertically in a smaller white font. In the top right corner, the number '23' is printed in a large white font. A white rectangular area in the center of the cover contains several hand-drawn sketches of various objects, including what appear to be chairs, tables, and mechanical components, rendered in a simple, sketchy style. At the bottom of the cover, there is a paragraph of white text that reads: 'These show what design ideas look like as physical objects and are used at a personal level to externalise thoughts quickly. Also known as thumbnail, thinking or napkin sketches.'

Software Package	% of Industrial Designers using five software packages to form a total of 100%
01 Design Intent	90
07 Visual Character	80
06 Form & Detail	70
10 Single-Views	20
02 Usability & Operation	20
03 Concept Design	90
02 Design Development	30
03 Embodiment Design	20
04 Detail Design	20

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The image shows the front cover of a book titled 'Idea Sketch' by 'Engineering Designers'. The cover has a dark blue background. In the top left corner, there is a circular logo with the text 'DES REPS' and 'SKETCHES' around it. The title 'Idea Sketch' is written in large, white, sans-serif font. Below the title, there is a white rectangular box containing several hand-drawn sketches of furniture and objects, including a table, a chair, and some mechanical parts. To the right of the box, the text 'Personal Sketches' is written vertically in white. At the bottom, there is a paragraph of white text that reads: 'These show what design ideas look like as physical objects and are used at a personal level to externalise thoughts quickly. Also known as thumbnail, thinking or napkin sketches.' The number '23' is printed in large white digits in the top right corner.

[illegible]

Styling Technique	% of Industrial Designers using Styling Techniques to Enhance Product Appearance	% of Population using Styling Technique
12. Areas of Concern	60	70
04. Form & Detail	50	30
18. Components	40	20
05. Design Intent	40	20
07. Visual Character	40	20
19. Mechanism	30	20
01. Color	0	0
02. Design Development	0	0
03. Embodiment Design	0	0
06. Detail Design	0	0

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% of Expensive Designers using Study Tools in 1990	Task	Score
<div></div>	72 Areas of Concern	90
<div></div>	77 Assembly	70
<div></div>	78 Components	70
<div></div>	76 Construction	70
<div></div>	75 Mechanism	70
<div></div>	78 Dimensions	40
<div></div>	04 Design Intent	20
<div></div>	06 Form & Detail	20
<div></div>		
<div></div>		


% of Low-Cost Designers using Study Tools in 1990	Task	Score
<div></div>	01 Concept Design	90
<div></div>	02 Design Development	0
<div></div>	03 Embodiment Design	0
<div></div>	04 Detail Design	0
<div></div>		
<div></div>		

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16

**Industrial Designers 25**  
Personal Sketches

## Referential Sketch



These are mainly used as a diary to record observations for future reference or as a metaphor.

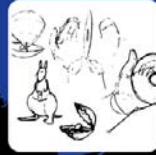
**Industrial Designers 25**  
Personal Sketches

% of Industrial Designers using Referential Sketches to show ...	% of population used during ...
07 Visual Character	50
08 Design Intent	30
09 Form & Detail	20
12 Areas of Concern	10
13 Components	10
14 Scenario of Use	10
09 Usability & Operation	10
01 Concept Design	70
02 Design Development	10
03 Embodiment Design	0
04 Detail Design	0

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**Engineering Designers 25**  
Personal Sketches

## Referential Sketch



These are mainly used as a diary to record observations for future reference or as a metaphor.


**Engineering Designers 25**  
Personal Sketches

% of Engineering Designers using Referential Sketches to show ...	% of population used during ...
01 Design Intent	10
13 Components	10
01 Concept Design	90
02 Design Development	0
03 Embodiment Design	0
04 Detail Design	0

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**Industrial Designers 26**  
Personal Sketches

## Memory Sketch



These help users recall thoughts and elements from previous work and usually include notes and text annotations.


**Industrial Designers 26**  
Personal Sketches

% of Industrial Designers using Memory Sketches to show ...	% of population used during ...
09 Form & Detail	40
07 Visual Character	40
08 Design Intent	30
12 Areas of Concern	20
17 Assembly	10
13 Components	10
22 Material	10
13 Mechanism	10
09 Scenario of Use	10
13 Texture & Surface Finish	10
09 Usability & Operation	10
01 Concept Design	70
02 Design Development	20
03 Embodiment Design	10
04 Detail Design	10

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**Engineering Designers 26**  
Personal Sketches

## Memory Sketch



These help users recall thoughts and elements from previous work and usually include notes and text annotations.

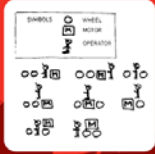
**Engineering Designers 26**  
Personal Sketches

% of Engineering Designers using Memory Sketches to show ...	% of population used during ...
Memory sketches are not commonly used by engineering designers.	
01 Concept Design	0
02 Design Development	0
03 Embodiment Design	0
04 Detail Design	0

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**Industrial Designers 27**  
Shared Sketches

## Coded Sketch



These are informal representations to categorise information, usually to show an underlying principle or a scheme.


**Industrial Designers 27**  
Shared Sketches

% of Industrial Designers using Coded Sketches to show ...	% of population used during ...
13 Components	30
09 Usability & Operation	20
12 Areas of Concern	10
08 Design Intent	10
13 Mechanism	10
01 Concept Design	30
02 Design Development	30
03 Embodiment Design	10
04 Detail Design	0

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**Engineering Designers 27**  
Shared Sketches

## Coded Sketch



These are informal representations to categorise information, usually to show an underlying principle or a scheme.


**Engineering Designers 27**  
Shared Sketches

% of Engineering Designers using Coded Sketches to show ...	% of population used during ...
17 Assembly	10
13 Components	10
16 Construction	10
13 Mechanism	10
01 Concept Design	10
02 Design Development	0
03 Embodiment Design	0
04 Detail Design	0

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**Industrial Designers 28**  
Shared Sketches

## Information Sketch



These allow stakeholders to understand the designer's intentions by explaining information clearly and to provide a common graphical setting. Also known as explanatory or talking sketches.


**Industrial Designers 28**  
Shared Sketches

% of Industrial Designers using Information Sketches to show ...	% of population used during ...
09 Form & Detail	90
22 Material	80
13 Texture & Surface Finish	70
07 Visual Character	70
08 Design Intent	60
09 Usability & Operation	60
14 Colour	60
01 Concept Design	60
02 Design Development	70
03 Embodiment Design	10
04 Detail Design	10

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**Engineering Designers 28**  
Shared Sketches

## Information Sketch



These allow stakeholders to understand the designer's intentions by explaining information clearly and to provide a common graphical setting. Also known as explanatory or talking sketches.

**Engineering Designers 28**  
Shared Sketches

% of Engineering Designers using Information Sketches to show ...	% of population used during ...
13 Components	30
14 Colour	30
22 Material	30
13 Mechanism	30
13 Texture & Surface Finish	30
17 Assembly	10
16 Construction	10
01 Design Intent	10
12 Dimensions	10
09 Form & Detail	10
03 Scenario of Use	10
09 Usability & Operation	10
01 Concept Design	10
02 Design Development	10
03 Embodiment Design	10
04 Detail Design	0


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**Industrial Designers 33**

## Presentation Drawing




These are final drawings created manually or digitally to communicate work to clients and others. They can be used for reference and may include exploded views with technical details.

27 Exploded Views	40
17 Assembly	30
18 Components	30
16 Construction	30
04 Form & Detail	30
11 Multi-Views	30
10 Single-Views	30
15 Dimensions	20
07 Visual Character	20
01 Concept Design	20
02 Design Development	60
03 Embodiment Design	20
04 Detail Design	20

**Engineering Designers 33**

## Presentation Drawing



These are final drawings created manually or digitally to communicate work to clients and others. They can be used for reference and may include exploded views with technical details.

01 Concept Design	0
02 Design Development	10
03 Embodiment Design	10
04 Detail Design	0

**Industrial Designers 34**

## Scenarios & Storyboards




These are used to suggest user and product interaction, and to portray usage in the context of artefacts, people and relationships.

05 Design Intent	80
07 Visual Character	60
06 Form & Detail	10
10 Single-Views	10
01 Concept Design	60
02 Design Development	60
03 Embodiment Design	0
04 Detail Design	0

**Engineering Designers 34**

## Scenarios & Storyboards

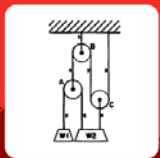


These are used to suggest user and product interaction, and to portray usage in the context of artefacts, people and relationships.

09 Scenario of Use	20
08 Usability & Operation	20
01 Concept Design	10
02 Design Development	10
03 Embodiment Design	0
04 Detail Design	0

**Industrial Designers 35**

## Diagrams

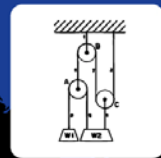


These are abstract representations of the underlying principles of an idea or represent relationships between objects. Also known as schematic or diagrammatic drawings.

18 Components	20
08 Usability & Operation	20
12 Areas of Concern	10
13 Mechanism	10
01 Concept Design	10
02 Design Development	20
03 Embodiment Design	10
04 Detail Design	10

**Engineering Designers 35**

## Diagrams




These are abstract representations of the underlying principles of an idea or represent relationships between objects. Also known as schematic or diagrammatic drawings.

12 Areas of Concern	10
05 Design Intent	10
08 Usability & Operation	10
01 Concept Design	20
02 Design Development	0
03 Embodiment Design	0
04 Detail Design	0

**Industrial Designers 36**

## Single-View Drawing



These drawings comprise of isometric, trimetric, perspective, oblique and axonometric projection drawings.

10 Single-Views	40
06 Form & Detail	20
05 Design Intent	10
01 Concept Design	20
02 Design Development	30
03 Embodiment Design	20
04 Detail Design	20

**Engineering Designers 36**

## Single-View Drawing



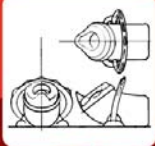
These drawings comprise of isometric, trimetric, perspective, oblique and axonometric projection drawings.

01 Concept Design	10
02 Design Development	0
03 Embodiment Design	0
04 Detail Design	0



**Industrial Designers 37**

## Multi-View Drawings

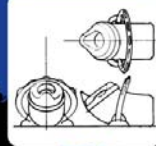


These are diagrammatic views through first-angle or third-angle projections in which the form is flattened out with plan views, front elevations and end elevations.

17 Multi-Views	70
18 Dimensions	40
17 Assembly	20
18 Components	20
18 Construction	20
20 Form & Detail	20
12 Areas of Concern	20
02 Design Intent	10
17 Mechanism	10
01 Concept Design	10
02 Design Development	20
03 Embodiment Design	60
04 Detail Design	40

**Engineering Designers 37**

## Multi-View Drawings

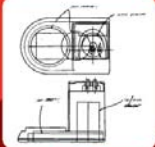


These are diagrammatic views through first-angle or third-angle projections in which the form is flattened out with plan views, front elevations and end elevations.

18 Dimensions	90
18 Components	70
17 Assembly	60
18 Construction	60
17 Multi-View	40
01 Concept Design	40
02 Design Development	80
03 Embodiment Design	20
04 Detail Design	20

**Industrial Designers 38**

## General Arrangement Drawings

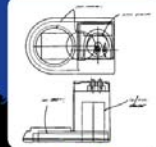


These embody the refined design but omit the most internal details. They are used in the production of an appearance model with limited details. Also known as model making drawings.

18 Construction	30
18 Dimensions	30
17 Assembly	20
18 Components	20
21 Exploded Views	10
20 Part & Section Profile Lines	10
01 Concept Design	0
02 Design Development	20
03 Embodiment Design	20
04 Detail Design	30

**Engineering Designers 38**

## General Arrangement Drawings

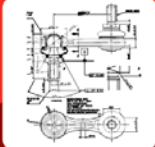


These embody the refined design but omit the most internal details. They are used in the production of an appearance model with limited details. Also known as model making drawings.

17 Assembly	30
18 Components	30
18 Construction	30
18 Dimensions	30
19 Mechanism	20
22 Material	10
17 Multi-Views	10
01 Concept Design	0
02 Design Development	20
03 Embodiment Design	10
04 Detail Design	0

**Industrial Designers 39**

## Technical Drawing

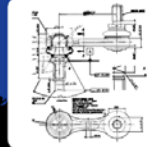


These drawings represent the built object and cover every detail of the product for manufacture. Also known as engineering, production or construction drawings.

18 Components	30
18 Dimensions	30
17 Assembly	20
18 Construction	20
22 Material	20
20 Form & Detail	10
19 Mechanism	10
17 Multi-Views	10
20 Part & Section Profile Lines	10
01 Concept Design	0
02 Design Development	10
03 Embodiment Design	20
04 Detail Design	20

**Engineering Designers 39**

## Technical Drawing

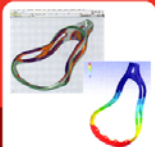


These drawings represent the built object and cover every detail of the product for manufacture. Also known as engineering, production or construction drawings.

18 Construction	70
18 Dimensions	70
18 Components	60
19 Mechanism	40
22 Material	30
01 Concept Design	10
02 Design Development	0
03 Embodiment Design	60
04 Detail Design	20

**Industrial Designers 40**

## Technical Illustration

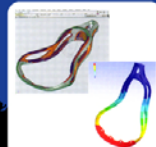


They are graphical illustrations to explain technical details and use conventions of engineering drawings incorporating signs and symbols within the illustration.

17 Assembly	20
18 Components	20
18 Construction	20
20 Form & Detail	10
19 Mechanism	10
10 Single-Views	10
01 Concept Design	0
02 Design Development	10
03 Embodiment Design	20
04 Detail Design	20

**Engineering Designers 40**

## Technical Illustration




They are graphical illustrations to explain technical details and use conventions of engineering drawings incorporating signs and symbols within the illustration.

17 Assembly	10
14 Colour	10
18 Components	10
21 Exploded Views	10
22 Material	10
17 Texture & Surface Finish	10
01 Concept Design	10
02 Design Development	0
03 Embodiment Design	0
04 Detail Design	0

**Industrial Designers 41**


## 3D Sketch Model



These are informal three dimensional block representations that represent the design idea. Also known as foam models, sketch models or 3D sketches.

**Industrial Designers 41**

## 3D Sketch Model



These are informal three dimensional block representations that represent the design idea. Also known as foam models, sketch models or 3D sketches.

**Engineering Designers 41**

## 3D Sketch Model



These are informal three dimensional block representations that represent the design idea. Also known as foam models, sketch models or 3D sketches.

**Industrial Designers 42**

## Design Development Model



These are used to help better understand the relationships between components, cavities, interfaces, structure and form.

**Industrial Designers 42**


## Design Development Model



These are used to help better understand the relationships between components, cavities, interfaces, structure and form.

**Engineering Designers 42**

## Design Development Model



These are used to help better understand the relationships between components, cavities, interfaces, structure and form.

**Industrial Designers 43**


## Appearance Model



These are exact visual representations of the design proposal defining the product form and use, but do not contain working mechanisms. Also known as block, iconic or qualitative models.

**Industrial Designers 43**

## Appearance Model



These are exact visual representations of the design proposal defining the product form and use, but do not contain working mechanisms. Also known as block, iconic or qualitative models.

**Engineering Designers 43**


## Appearance Model



These are exact visual representations of the design proposal defining the product form and use, but do not contain working mechanisms. Also known as block, iconic or qualitative models.

**Industrial Designers 44**


## Functional Concept Model



These show functionality and highlight important functional parameters including yield and performance factors relating to the product.

**Industrial Designers 44**


## Functional Concept Model



These show functionality and highlight important functional parameters including yield and performance factors relating to the product.

**Engineering Designers 44**

## Functional Concept Model




These show functionality and highlight important functional parameters including yield and performance factors relating to the product.



**Industrial Designers 45**

**Concept of Operation Model**



These help to assist the understanding of operational strategies and usage procedures relating to the product.

**DES REPS**

**Usability & Operation** 20

**18 Components** 10

**19 Design Intent** 10

**20 Mechanism** 10

**21 Scenario of Use** 10

**01 Concept Design** 10

**02 Design Development** 20


**03 Embodiment Design** 10

**04 Detail Design** 10

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**Engineering Designers 45**

**Concept of Operation Model**



These help to assist the understanding of operational strategies and usage procedures relating to the product.

**DES REPS**

**Usability & Operation** 30

**18 Components** 20

**19 Mechanism** 20

**20 Scenario of Use** 20

**01 Concept Design** 0

**02 Design Development** 10


**03 Embodiment Design** 10

**04 Detail Design** 10

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**Industrial Designers 46**

**Production Concept Model**



These are used to help assist the evaluation of production processes or manufacturing technologies for final production.

**DES REPS**

**17 Assembly** 10

**01 Concept Design** 0

**02 Design Development** 0


**03 Embodiment Design** 0

**04 Detail Design** 0

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**Engineering Designers 46**

**Production Concept Model**



These are used to help assist the evaluation of production processes or manufacturing technologies for final production.

**DES REPS**

**17 Assembly** 20

**18 Construction** 20

**19 Dimensions** 10

**01 Concept Design** 0

**02 Design Development** 0


**03 Embodiment Design** 0

**04 Detail Design** 20

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**Industrial Designers 47**

**Assembly Concept Model**



These show assembly consequences to allow assembly, cost and investments in the product to be calculated or evaluated.

**DES REPS**

**17 Assembly** 10

**18 Components** 10

**19 Construction** 10

**01 Concept Design** 0

**02 Design Development** 0

**03 Embodiment Design** 10

**04 Detail Design** 10

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**Engineering Designers 47**

**Assembly Concept Model**



These show assembly consequences to allow assembly, cost and investments in the product to be calculated or evaluated.

**DES REPS**

**17 Assembly** 20

**18 Construction** 10

**01 Concept Design** 0

**02 Design Development** 10

**03 Embodiment Design** 0

**04 Detail Design** 10

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**Industrial Designers 48**

**Service Concept Model**



These illustrate how the product is serviced and maintained, and may be in the form of exploded views to show the disassembly of parts with servicing information.

**DES REPS**

**18 Components** 10

**19 Mechanism** 10

**01 Concept Design** 0

**02 Design Development** 0

**03 Embodiment Design** 0

**04 Detail Design** 10

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**Engineering Designers 48**

**Service Concept Model**



These illustrate how the product is serviced and maintained, and may be in the form of exploded views to show the disassembly of parts with servicing information.

**DES REPS**

**17 Assembly** 10

**01 Concept Design** 0

**02 Design Development** 10


**03 Embodiment Design** 10

**04 Detail Design** 0

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**PROTOTYPES DES REPS** Industrial Designers **49** Industrial Design Prototypes

## Appearance Prototype




These are highly detailed, full-sized models that combine the finalised product functionality with the final aesthetic outlook, very closely resembling the actual completed product.

13 Texture & Surface Finish	60
14 Colour	50
15 Components	50
16 Design Intent	50
17 Material	50
18 Visual Character	50
19 Form & Detail	40
20 Mechanism	40
21 Construction	30
22 Dimensions	40
23 Usability & Operation	40
24 Visual Character	40
25 Part and Section Profile Lines	10
01 Concept Design	10
02 Design Development	10
03 Embodiment Design	30
04 Detail Design	60

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**PROTOTYPES DES REPS** Engineering Designers **49** Industrial Design Prototypes

## Appearance Prototype




These are highly detailed and full-sized prototypes that combine the finalised product functionality with the final aesthetic outlook, very closely resembling to the actual completed product.

14 Colour	40
15 Components	40
16 Design Intent	40
17 Material	40
18 Visual Character	40
19 Form & Detail	30
20 Mechanism	30
21 Construction	30
22 Dimensions	30
23 Usability & Operation	30
24 Visual Character	30
25 Part and Section Profile Lines	10
01 Concept Design	0
02 Design Development	0
03 Embodiment Design	20
04 Detail Design	30

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**PROTOTYPES DES REPS** Industrial Designers **50** Industrial Design Prototypes

## Alpha Prototype




These are the first construction of the sub-systems that have been individually proven and accepted, and are fabricated using materials, design and layout that will be used for the actual product.

13 Construction	20
14 Assembly	10
15 Colour	10
16 Components	10
17 Design Intent	10
18 Dimensions	10
19 Form & Detail	10
20 Material	10
21 Mechanism	10
22 Texture & Surface Finish	10
23 Usability & Operation	10
24 Visual Character	10
01 Concept Design	0
02 Design Development	0
03 Embodiment Design	10
04 Detail Design	10

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**PROTOTYPES DES REPS** Engineering Designers **50** Industrial Design Prototypes

## Alpha Prototype



These are the first construction of the sub-systems that have been individually proven and accepted, and are fabricated using materials, design and layout that will be used for the actual product.

14 Colour	20
15 Components	20
16 Dimensions	20
17 Material	20
18 Areas of Concern	10
19 Assembly	10
20 Construction	10
01 Concept Design	0
02 Design Development	0
03 Embodiment Design	10
04 Detail Design	10

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**PROTOTYPES DES REPS** Industrial Designers **51** Industrial Design Prototypes

## Beta Prototype



These are the first full-scale and fully-functional prototypes constructed from the actual materials as in the final product.

13 Construction	20
14 Assembly	10
15 Colour	10
16 Components	10
17 Design Intent	10
18 Dimensions	10
19 Material	10
20 Mechanism	10
21 Texture & Surface Finish	10
22 Usability & Operation	10
23 Visual Character	10
01 Concept Design	0
02 Design Development	0
03 Embodiment Design	10
04 Detail Design	10

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**PROTOTYPES DES REPS** Engineering Designers **51** Industrial Design Prototypes

## Beta Prototype




These are the first full-scale and fully-functional prototypes constructed from the actual materials as in the final product.

17 Assembly	10
18 Colour	10
19 Components	10
20 Construction	10
21 Dimensions	10
22 Material	10
23 Mechanism	10
24 Texture & Surface Finish	10
01 Concept Design	0
02 Design Development	0
03 Embodiment Design	10
04 Detail Design	0

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**PROTOTYPES DES REPS** Industrial Designers **52** Industrial Design Prototypes

## Pre-Production Prototype



These are the final class of prototypes that are used to perform a final part production and assembly assessment using the actual production tooling with small batches produced.

13 Construction	20
14 Assembly	10
15 Colour	10
16 Components	10
17 Design Intent	10
18 Dimensions	10
19 Form & Detail	10
20 Material	10
21 Mechanism	10
22 Texture & Surface Finish	10
23 Usability & Operation	10
24 Visual Character	10
01 Concept Design	0
02 Design Development	0
03 Embodiment Design	10
04 Detail Design	20

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**PROTOTYPES DES REPS** Engineering Designers **52** Industrial Design Prototypes

## Pre-Production Prototype



These are the final class of prototypes that are used to perform a final part production and assembly assessment using the actual production tooling with small batches produced.


14 Colour	20
15 Components	20
16 Dimensions	20
17 Material	20
18 Texture & Surface Finish	20
19 Assembly	10
20 Construction	10
21 Mechanism	10
01 Concept Design	0
02 Design Development	0
03 Embodiment Design	0
04 Detail Design	20

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**PROTOTYPE DES REPS** Industrial Designers **53** Engineering Design Prototypes

## Experimental Prototype




These are physical prototypes to parameterize, layout or shape aspects of a product, usually to replicate the actual product's physics. Also known as Design-of-Experiment Prototypes.

17 Components	10
18 Construction	10
19 Dimensions	10
20 Mechanism	10
21 Usability & Operation	10
01 Concept Design	0
02 Design Development	10
03 Embodiment Design	10
04 Detail Design	10

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**PROTOTYPE DES REPS** Engineering Designers **53** Engineering Design Prototypes

## Experimental Prototype




These are physical prototypes to parameterize, layout or shape aspects of a product, usually to replicate the actual product's physics. Also known as Design-of-Experiment Prototypes.

17 Components	40
18 Mechanism	40
19 Assembly	20
20 Construction	20
21 Usability & Operation	20
12 Areas of Concern	10
13 Dimensions	10
01 Concept Design	30
02 Design Development	30
03 Embodiment Design	20
04 Detail Design	10

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**PROTOTYPE DES REPS** Industrial Designers **54** Engineering Design Prototypes

## System Prototype




These combine the numerous components that were specified for the final product and are used to test and assess various aspects such as assembly, mechanism and performance.

17 Assembly	10
18 Components	10
19 Mechanism	10
01 Concept Design	0
02 Design Development	0
03 Embodiment Design	0
04 Detail Design	10

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**PROTOTYPE DES REPS** Engineering Designers **54** Engineering Design Prototypes

## System Prototype



These combine the numerous components that were specified for the final product and are used to test and assess various aspects such as assembly, mechanism and performance.

17 Components	30
18 Mechanism	30
19 Areas of Concern	10
20 Assembly	10
21 Construction	10
15 Dimensions	10
01 Concept Design	0
02 Design Development	20
03 Embodiment Design	20
04 Detail Design	20

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**PROTOTYPE DES REPS** Industrial Designers **55** Engineering Design Prototypes

## Final Hardware Prototype



These are used to assist in the design and evaluation of product fabrication, and part and assembly issues relating to the physical aspects of the product.

17 Assembly	10
18 Components	10
22 Material	10
19 Mechanism	10
01 Concept Design	0
02 Design Development	0
03 Embodiment Design	0
04 Detail Design	10

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**PROTOTYPE DES REPS** Engineering Designers **55** Engineering Design Prototypes

## Final Hardware Prototype




These are used to assist in the design and evaluation of product fabrication, and part and assembly issues relating to the physical aspects of the product.

17 Components	30
15 Dimensions	30
19 Mechanism	30
12 Areas of Concern	20
17 Assembly	20
18 Construction	20
14 Colour	10
22 Material	10
13 Texture & Surface Finish	10
01 Concept Design	0
02 Design Development	0
03 Embodiment Design	10
04 Detail Design	30

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**PROTOTYPE DES REPS** Industrial Designers **56** Engineering Design Prototypes

## Tooling Prototype




These allow the creation for the physical tooling of the actual product part and to enable potential tooling problems to be intercepted before any discrepancies of form or fit occur.

18 Components	20
22 Assembly	10
14 Colour	10
16 Construction	10
13 Dimensions	10
06 Form & Detail	10
22 Material	10
19 Mechanism	10
13 Texture & Surface Finish	10
01 Concept Design	0
02 Design Development	0
03 Embodiment Design	10
04 Detail Design	20

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**PROTOTYPE DES REPS** Engineering Designers **56** Engineering Design Prototypes

## Tooling Prototype



These allow the creation for the physical tooling of the actual product part and to enable potential tooling problems to be intercepted before any discrepancies of form or fit occur.

18 Components	20
15 Dimensions	20
12 Areas of Concern	20
17 Assembly	10
18 Construction	10
14 Colour	10
22 Material	10
13 Texture & Surface Finish	10
01 Concept Design	0
02 Design Development	0
03 Embodiment Design	10
04 Detail Design	20

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## 13.12 Validation Questions

The following pages show the validation questions that were used for the practitioner and student interviews.

Enhancing Collaboration through  
Standardized Design Representations between  
Industrial Designers & Engineering Designers



Eujin Pei

Dr R.I. Campbell

Dr M.A. Evans

## Validation Study - Feedback of the Index Cards

This validation aims to collect feedback about the design representation cards which serve as a collaboration platform between industrial designers and engineering designers.

Date of Interview: \_\_\_\_\_

Name: \_\_\_\_\_

Company: \_\_\_\_\_

Position : \_\_\_\_\_

Role and Responsibility: \_\_\_\_\_

Educational Background: \_\_\_\_\_

Years of Experience: \_\_\_\_\_

Type of design projects undertaken: \_\_\_\_\_

### Questions

1. How do you generally feel about the card format?

1. Excellent

2. Good

3. Neutral

3. Poor

4. Very Poor

☐☐☐☐☐

Other comments:

---

2. How do you feel about the physical size of the cards?

1. Excellent

2. Good

3. Neutral

3. Poor

4. Very Poor

☐☐☐☐☐

Other comments:

---

---

3. How would you rate the clarity and understandability of the textual content and pictorial data?

1. Excellent

2. Good

3. Neutral

3. Poor

4. Very Poor

☐☐☐☐☐

Other comments:

---

---

4. How would you rate the ability of the cards to provide you with an enhanced understanding and clearer definition of design representations?

1. Excellent

2. Good

3. Neutral

3. Poor

4. Very Poor

☐☐☐☐☐

Other comments:

---

---

5. How do you feel about the effectiveness of the cards to provide a common understanding of design representations between IDs and EDs?

1. Excellent      2. Good      3. Neutral      3. Poor      4. Very Poor

☐☐☐☐☐

Other comments:

---

---

6. How would you rate the use of bar charts that show key design and technical information?

1. Excellent      2. Good      3. Neutral      3. Poor      4. Very Poor

☐☐☐☐☐

Other comments:

---

---

7. How would you rate the ability of the cards to help you identify the representation most commonly used during different stages of the design process?

1. Excellent      2. Good      3. Neutral      3. Poor      4. Very Poor

☐☐☐☐☐

Other comments:

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8. How do you feel about the ability of the cards to foster enhanced collaboration between IDs and EDs?

1. Excellent

2. Good

3. Neutral

3. Poor

4. Very Poor

☐☐☐☐☐

Other comments:

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9. How do you feel about the ability of the cards to improve design collaboration between yourself and other industrial designers / engineering designers?

1. Excellent

2. Good

3. Neutral

3. Poor

4. Very Poor

☐☐☐☐☐

Other comments:

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10. Would you have any suggestions or additional feedback to help us improve the cards?

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## 13.13 Validation Results

### 13.13.1 Results from Students

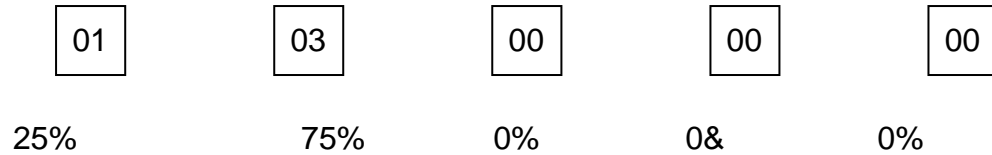
	Students Only	Excellent	Good	Neutral	Poor	Very Poor
Question 1	Industrial Designers	1	3	0	0	0
	Percentage	25.00%	75.00%	0.00%	0.00%	0.00%
	Engineering Designers	4	9	0	1	0
	Percentage	28.60%	64.30%	0.00%	7.10%	0.00%
Question 2	Industrial Designers	2	2	0	0	0
	Percentage	50.00%	50.00%	0.00%	0.00%	0.00%
	Engineering Designers	7	4	3	0	0
	Percentage	50.00%	28.60%	24.10%	0.00%	0.00%
Question 3	Industrial Designers	0	3	1	0	0
	Percentage	0.00%	75.00%	25.00%	0.00%	0.00%
	Engineering Designers	5	8	1	0	0
	Percentage	35.70%	57.20%	7.10%	0.00%	0.00%
Question 4	Industrial Designers	1	3	0	0	0
	Percentage	25.00%	75.00%	0.00%	0.00%	0.00%
	Engineering Designers	4	8	2	0	0
	Percentage	28.60%	57.20%	14.20%	0.00%	0.00%
Question 5	Industrial Designers	1	2	1	0	0
	Percentage	25.00%	50.00%	25.00%	0.00%	0.00%
	Engineering Designers	4	5	4	1	0
	Percentage	28.60%	35.70%	28.60%	7.10%	0.00%
Question 6	Industrial Designers	1	1	2	0	0
	Percentage	25.00%	25.00%	50.00%	0.00%	0.00%
	Engineering Designers	1	6	6	1	0
	Percentage	7.10%	42.90%	42.90%	7.10%	0.00%
Question 7	Industrial Designers	1	3	0	0	0
	Percentage	25.00%	75.00%	0.00%	0.00%	0.00%
	Engineering Designers	4	9	1	0	0
	Percentage	28.60%	64.30%	7.10%	0.00%	0.00%
Question 8	Industrial Designers	0	4	0	0	0
	Percentage	0.00%	100.00%	0.00%	0.00%	0.00%
	Engineering Designers	1	11	1	1	0
	Percentage	7.10%	78.70%	7.10%	7.10%	0.00%
Question 9	Industrial Designers	0	3	1	0	0
	Percentage	0.00%	75.00%	25.00%	0.00%	0.00%
	Engineering Designers	1	10	3	0	0
	Percentage	7.10%	71.50%	21.40%	0.00%	0.00%

Interview results from students (above)

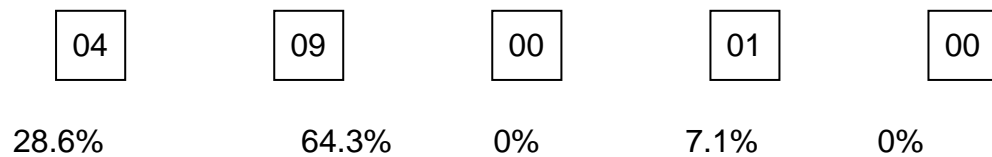
## Questions

1. How do you generally feel about the card format?

IDS: 1. Excellent 2. Good 3. Neutral 4. Poor 5. Very Poor



EDS: 1. Excellent 2. Good 3. Neutral 4. Poor 5. Very Poor



### Other comments:

1. A lot of information, could be complemented by a webpage. But as a tool to help two people understand each other, some thing hands-on is preferred. (ID)
2. Would like to have an overview. (ID)
3. Very hands-on, portable. (ID)
4. Good, provides a tool for engineers and design students to interact. However, it may be a hassle to run-through all the cards to look for the information needed. (ED)
5. Too many cards especially when my desk is already covered by drawings, calculation, etc. The flip and see idea is cute but very inconvenient as compared to click and browse. (ED)
6. – (ED)
7. Fresh idea more iterative. (ED)
8. Concise. Easy to understand. (ED)
9. – (ED)
10. – (ED)
11. – (ED)
12. make it into a program too, because one needs the whole 2 decks of cards to know his own way and the other's design way. (ED)
13. – (ED)
14. – (ED)
15. – (ED)
16. – (ED)
17. – (ED)
18. Good information. It can work as a reference for both designer and engineer to better understand each other when they discuss a project (as to what do they mean by this and that, coz we speak different languages at times). (ID)

## 2. How do you feel about the physical size of the cards?

IDS:	1. Excellent	2. Good	3. Neutral	4. Poor	5. Very Poor
	<div>02</div>	<div>02</div>	<div>00</div>	<div>00</div>	<div>00</div>
	50%	50%	0%	0%	0%
EDS:	1. Excellent	2. Good	3. Neutral	4. Poor	5. Very Poor
	<div>07</div>	<div>04</div>	<div>03</div>	<div>00</div>	<div>00</div>
	50%	28.6%	21.4%	0%	0%

### Other comments:

1. As normal cards, recognition. (ID)
2. Familiar. (ID)
3. – (ID)
4. – (ED)
5. Card size is good – palm size, but too many cards and need to refer here and there sounds troublesome to me. (and easy to lose). (ED)
6. – (ED)
7. Normal card size – no comment. (ED)
8. – (ED)
9. – (ED)
10. Pocket size – easy to use and see – gives a fun feel like playing poker cards. (ED)
11. Card size is easy to hold and print is readable. (ED)
12. – (ED)
13. Compact and portable yet there's no overload of information on each card. (ED)
14. It is compact and portable. (ED)
15. – (ED)
16. – (ED)
17. – (ED)
18. Just nice, it's portable. Good for putting in pocket but not easily lost. Good that it's standard size. (ID)

### 3. How would you rate the clarity and understandability of the textual content and pictorial data?

IDS:

1. Excellent	2. Good	3. Neutral	4. Poor	5. Very Poor
<div>00</div>	<div>03</div>	<div>01</div>	<div>00</div>	<div>00</div>
0%	75%	25%	0%	0%

EDS:

1. Excellent	2. Good	3. Neutral	4. Poor	5. Very Poor
<div>05</div>	<div>08</div>	<div>01</div>	<div>00</div>	<div>00</div>
35.7%	57.2%	7.1%	0%	0%

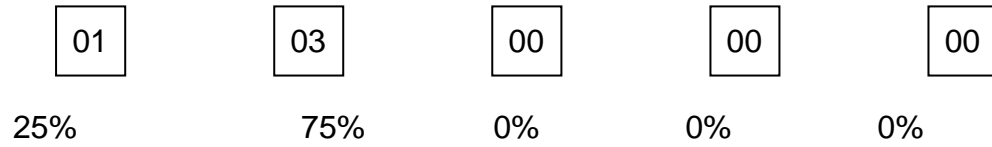
Other comments:

1. A lot of information, need a guide (instructions) to be able to access it. (ID)
2. Clear pictures. Too cluttered text. Simplicity required. (ID)
3. Too wordy. (ID)
4. – (ED)
5. Very easy to understand. Explanation is simple and clean.
6. – (ED)
7. – (ED)
8. – (ED)
9. Some data overlaps – simplification would be good, reduces confusion and easily understood. (ED)
10. There are a lot of information at the back – cannot understand at a glance. Better if we can reduce the % into high, medium, low, so the person using the cards can maybe use the top 2 options. (ED)
11. – (ED)
12. There is no need for the percentage of popularity. I think they can ask for what they want, especially everything has their own explanation. (ED)
13. Pictorial data will be very useful for both parties to understand the different kind of drawings each department uses. (ED)
14. I think that the pictorial content is more useful than the text, which tends to be a bit vague. (ED)
15. – (ED)
16. – (ED)
17. – (ED)
18. Picture size ok. Detail and text size a bit bigger. Info on the back is nice and concise, be careful not to put too much info or it'll look a bit cluttered. (ID)

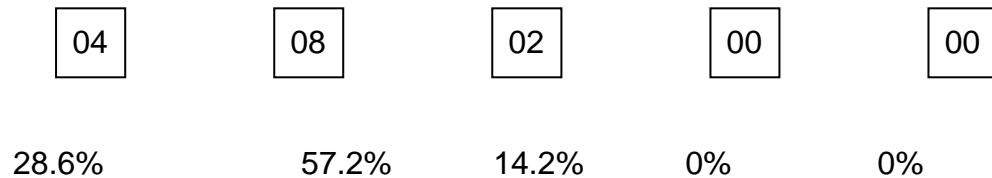


4. How would you rate the ability of the cards to provide you with an enhanced understanding and clearer definition of design representations?

IDS: 1. Excellent 2. Good 3. Neutral 4. Poor 5. Very Poor



EDS: 1. Excellent 2. Good 3. Neutral 4. Poor 5. Very Poor

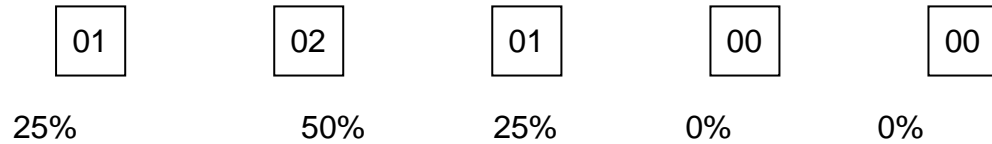


#### Other comments:

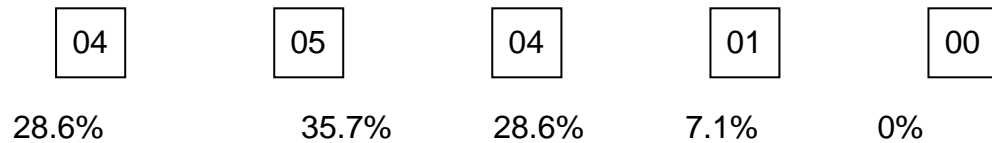
1. Use it as an understanding tool. (ID)
2. I think it would be a great tool as during the design management process. (ID)
3. – (ID)
4. – (ED)
5. Yes, very straightforward and especially good coz now the designer and engineer has common names that refer to different drawings. (ED)
6. – (ED)
7. – (ED)
8. Concepts are explained and standardised. Pictures aid in the understanding of the cards / concepts. (ED)
9. Standardizes the field for both parties. (ED)
10. The cards give concise definition / information on various types of methods and stages of design. (ED)
11. Would need to have some background to be able to understand the design representations in a few lines. Might be a bit brief for some of the design representations as either parties might not need or in touch with it before. (ED)
12. Good explanations. (ED)
13. – (ED)
14. – (ED)
15. – (ED)
16. – (ED)
17. – (ED)
18. Very informative. (ID)

5. How do you feel about the effectiveness of the cards to provide a common understanding of design representations between IDs and EDs?

IDS: 1. Excellent 2. Good 3. Neutral 4. Poor 5. Very Poor



EDS: 1. Excellent 2. Good 3. Neutral 4. Poor 5. Very Poor



Other comments:

1. Depends on users. (ID)
2. – (ID)
3. Sometimes I do not understand what the engineers are talking about. I think the cards will help. (ID)
4. – (ED)
5. there is potential improvement but I can't tell from 1<sup>st</sup> look. But I am sure the reference system can definitely minimise miscommunication. (ED)
6. Will be effective for learners only. (ED)
7. it's a good improvement and tool to actually make communication of technical info more systematic. (ED)
8. – (ED)
9. – (ED)
10. – (ED)
11. It would bridge the initial gap between them. (ED)
12. maybe not for the older engineers / ID they may not want to play with cards. (ED)
13. – (ED)
14. – (ED)
15. The tool, in its current format, may not be very attractive for designers to seek out to help in the design process, as it takes a bit of time and effort. (ED)
16. – (ED)
17. – (ED)
18. – (ID)

6. How would you rate the use of bar charts that show key design and technical information?

IDS:	1. Excellent	2. Good	3. Neutral	4. Poor	5. Very Poor
	<div>01</div>	<div>01</div>	<div>02</div>	<div>00</div>	<div>00</div>
	25%	25%	50%	0%	0%
EDS:	1. Excellent	2. Good	3. Neutral	4. Poor	5. Very Poor
	<div>01</div>	<div>06</div>	<div>06</div>	<div>01</div>	<div>00</div>
	7.1%	42.9%	42.9%	7.1%	0%

Other comments:

1. The numbers showing are clearer. (ID)
2. – (ID)
3. I thought the numbers are good enough. The bar chart is not very obvious. (ID)
4. there is too much information. (ED)
5. Now designers know what I am trying to highlight in my drawings when I choose to represent my problem in a particular type of drawing. (ED)
6. I do not see how bar charts can effectively express out the desired design and technical information. (ED)
7. Only the first 2 or 3 on the list is useful. The rest serves no purpose. (ED)
8. Personally, I think it is good as I prefer statistics instead of 'high, medium, low'. It is more precise. (ED)
9. Importance rating will be used instead (High, Medium, Low). Bar charts may look to statistical. (ED)
10. – (ED)
11. Bar charts a bit redundant with the percentage at the side. It does not really stand out. (ED)
12. Bar chart better than percentage. Self explanatory. (ED)
13. – (ED)
14. – (ED)
15. – (ED)
16. – (ED)
17. – (ED)
18. For me the chart is enough. (ID)

7. How would you rate the ability of the cards to help you identify the representation most commonly used during different stages of the design process?

IDS: 1. Excellent 2. Good 3. Neutral 4. Poor 5. Very Poor

<div>01</div>	<div>03</div>	<div>00</div>	<div>00</div>	<div>00</div>
25%	75%	0%	0%	0%

EDS: 1. Excellent 2. Good 3. Neutral 4. Poor 5. Very Poor

<div>04</div>	<div>09</div>	<div>01</div>	<div>00</div>	<div>00</div>
28.6%	64.3%	7.1%	0%	0%

Other comments:

1. Overview. (ID)
2. – (ID)
3. It really helps me understand what the engineers are expecting to do at the different design stages. (ID)
4. – (ED)
5. not in a position to rate this.
6. – (ED)
7. – (ED)
8. – (ED)
9. – (ED)
10. it is easy to use as the information at the back tells us exactly which card to take and read. (ED)
11. – (ED)
12. Need to read all then I would know. I myself also don't understand which process that engineers prefer to go. (ED)
13. – (ED)
14. – (ED)
15. I am concerned about representation styles that are hybrid of the ones defined in the cards. (ED)
16. – (ED)
17. Pictures are good. (ED)
18. – (ID)

8. How do you feel about the ability of the cards to foster enhanced collaboration between IDs and EDs?

IDS:

1. Excellent	2. Good	3. Neutral	4. Poor	5. Very Poor
<div>00</div>	<div>04</div>	<div>00</div>	<div>00</div>	<div>00</div>
0%	100%	0%	0%	0%

EDS:

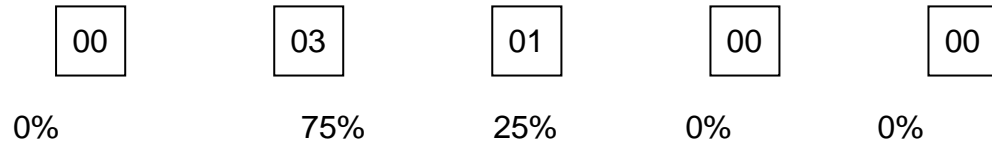
1. Excellent	2. Good	3. Neutral	4. Poor	5. Very Poor
<div>01</div>	<div>11</div>	<div>01</div>	<div>01</div>	<div>00</div>
7.1%	78.7%	7.1%	7.1%	0%

Other comments:

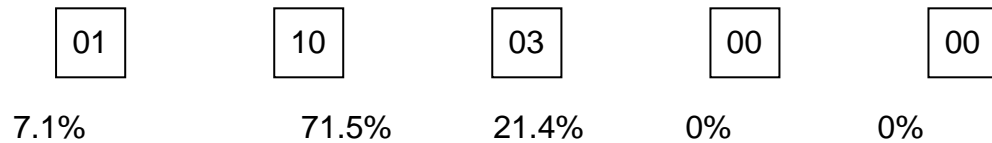
1. Especially in school. You can point out what your intention is. (ID)
2. – (ID)
3. Should really enhance my understanding of how engineers work and think. (ID)
4. – (ED)
5. – (ED)
6. I think these cards will not make a significant role to foster collaboration. It's just too troublesome to use. I will rather use my own way to explain to designers. But these cards undoubtedly may serve as an alternative if my method fails. (ED)
7. It will definitely improve the collaboration, saving time wasted on communicating unnecessary information. (ED)
8. Can be treated as a 'game session'. Reduce redundancies. Work more efficiently. (ED)
9. – (ED)
10. it is good as it can help IDs and EDs to communicate better and work more efficiently together. (ED)
11. – (ED)
12. Not in software form. But requires time and a lot of pack of cards. (ED)
13. – (ED)
14. – (ED)
15. the cards concerning design process will help IDs and EDs understand each other better. The cards concerning the design representations are not that necessary – can be explained by the artist. (ED)
16. it's hard for ID and ED to collaborate with each other because they think differently. With this set of cards, it might be useful. (ED)
17. – (ED)
18. Good reference to set up a working process for ID and ED to work together. (ID)

9. How do you feel about the ability of the cards to improve design collaboration between yourself and other industrial designers / engineering designers?

IDS: 1. Excellent 2. Good 3. Neutral 4. Poor 5. Very Poor



EDS: 1. Excellent 2. Good 3. Neutral 4. Poor 5. Very Poor



#### Other comments:

1. Depends on project. Show my intentions / theirs with it. (ID)
2. It would help the group to plan the project better and to understand at what stage we were working at. (ID)
3. I do not think the cards will be useful if I work with other IDs and we already share the same understanding of how the design process should go about. (ID)
4. it will be useful for an engineer to explain their way of doing things which a pictorial representation which can be found in the cards (similarly for the designers). (ED)
5. – (ED)
6. – (ED)
7. – (ED)
8. – (ED)
9. both sides would be able to tackle the key areas important to each side. Relevant information. (Stuff which is really important) (ED)
10. – (ED)
11. – (ED)
12. – (ED)
13. Reduce confusion of different terms. (ED)
14. – (ED)
15. – (ED)
16. – (ED)
17. – (ED)
18. – (ID)

10. Would you have any suggestions or additional feedback to help us improve the cards?

Other comments:

1. Instruction sheet. Pictures on all cards. (ID)
2. Sub-sections. (ID)
3. I thought that the cards were too wordy and the back contains too much information. Perhaps should find a way to simplify it. Should find a way to better organise the cards as I foresee that the cards will be messed up in random order. Should that happen, may be time consuming to find the right card. (ID)
4. – (ED)
5. Make it into a “click and browse” program rather than “flip and refer”. (ED)
6. Too many cards. These cards serve more like for educational usage rather than industrial application in real life. (ED)
7. Too many cards, too confusing sometimes. Some cards are quite similar, can combine into 1. (ED)
8. Remove the bar chart and increase font size for easy reading. Percentage are sufficient as they represent the same thing. Current size is fine. (ED)
9. Improve the back of the design stage card. Less complicated, easy to understand of % ratings / importance. Cards will allow more efficient designing to take place between both parties. (ED)
10. I think if I have this stack of cards for my design project, it will help me understand what the design students needs and wants and they will understand how engineers work better. (ED)
11. Might have a table of contents or list, showing all the design representations so others can have a glance of every one of them. (ED)
12. May need a lot of packs of cards. Software would be better for explanation, during general discussion might need one pack to foster relationship and get more understanding as each of them explain what the cards mean. (ED)
13. Addition of the timeline / sequence of different stages of work will enable both department to better plan the timeline for the project. – Better understanding of sequence of work too. (ED)
14. I feel that the description of some of the sketches is not clear enough to tell the user how exactly to produce the sketch the other party wants. I feel that the only advantage of these cards is to replace the communication between EDs and IDs when one party is not available to explain what he wants / or does not have the time. However, I feel that the bar charts showing the frequency of usage for each method to explain certain concept is very informative. (ED)
15. May be better to reduce the number of design representations, perhaps make it slightly more general, as it could take some time to browse through all and find the right one. Maybe instead of having many types of sketch, just have 1 sketch card. (ED)
16. Convert the cars to playing cards, in which both ID and ED can play with. Proportion of cards must be balanced for each group. (ED)
17. No need physical cards. No one will bring this card box along when doing project. Can it be upgraded to software? Prefer plastic if use physical cards instead of paper. (ED)
18. Write a nice user instruction so people can use it for its full-potential. (ID)

### 13.13.2 Results from Practitioners

	Practitioners Only	Excellent	Good	Neutral	Poor	Very Poor
Question 1	Industrial Designers	5	14	2	0	1
	Percentage	22.70%	63.70%	9.10%	0%	4.50%
	Engineering Designers	8	11	2	0	0
	Percentage	38%	52.50%	9.50%	0%	0%
Question 2	Industrial Designers	3	15	4	0	0
	Percentage	13.60%	68.20%	18.20%	0%	0%
	Engineering Designers	5	12	3	1	0
	Percentage	24%	57%	14%	5%	0%
Question 3	Industrial Designers	2	14	5	1	0
	Percentage	9.10%	63.70%	22.70%	4.50%	0%
	Engineering Designers	5	15	1	0	0
	Percentage	24%	71%	5%	0%	0%
Question 4	Industrial Designers	7	12	3	0	0
	Percentage	31.90%	54.50%	13.60%	0%	0%
	Engineering Designers	6	13	2	0	0
	Percentage	28.50%	62%	9.50%	0%	0%
Question 5	Industrial Designers	3	16	2	1	0
	Percentage	13.60%	72.80%	9.10%	4.50%	0%
	Engineering Designers	8	10	2	1	0
	Percentage	38%	47.50%	9.50%	5%	0%
Question 6	Industrial Designers	6	12	3	1	0
	Percentage	27.30%	54.50%	13.60%	4.60%	0%
	Engineering Designers	6	10	5	0	0
	Percentage	28.50%	47.50%	24%	0%	0%
Question 7	Industrial Designers	5	14	3	0	0
	Percentage	22.70%	63.70%	13.60%	0%	0%
	Engineering Designers	7	12	2	0	0
	Percentage	33.50%	57%	9.50%	0%	0%
Question 8	Industrial Designers	2	13	6	1	0
	Percentage	9.10%	59.10%	27.30%	4.50%	0%
	Engineering Designers	4	10	7	0	0
	Percentage	19%	47.50%	33.50%	0%	0%
Question 9	Industrial Designers	2	15	4	1	0
	Percentage	9.10%	68.20%	18.20%	4.50%	0%
	Engineering Designers	5	12	4	0	0
	Percentage	24%	57%	19%	0%	0%

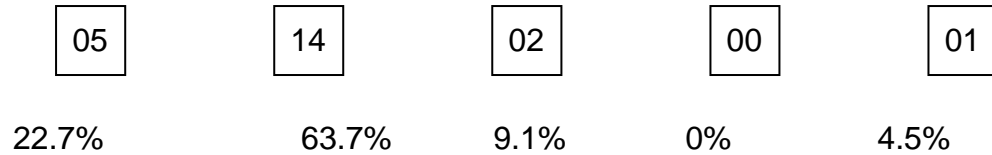
Interview results from practitioners (above)



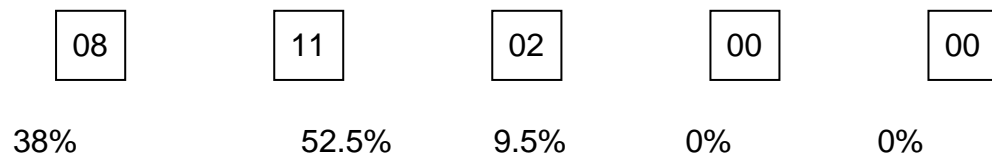
## Questions

1. How do you generally feel about the card format?

IDS: 1. Excellent 2. Good 3. Neutral 3. Poor 4. Very Poor



EDS: 1. Excellent 2. Good 3. Neutral 3. Poor 4. Very Poor



## Other comments:

1. Consider digital medium (ID)
2. Web 2.0 is a better platform for collaboration (ID)
3. The cards were easy to refer back and forth between the design processes and differences between ID & ED (ID)
4. Needs to address the information and the purpose. If the purpose is to inform, then this is ok. But if it is to resolve the collaboration issue, then more (verbal input) is needed. (ID)
5. It is good for discussion or understanding in the same location but not between two different locations. (ED)
6. - (ID)
7. Mixture of matrix and cards would be more user friendly. (ED)
8. Easy to understand, portable and bridging tool between IDs and EDs. (ED)
9. Pocket sized. However, thick and bulky. Needs to reduce thickness. Ring bind format to prevent loss. (ID)
10. I like this format that is hands-on. (ID)
11. - (ID)
12. Creative, hands-on practicality. (ED)
13. Interesting, novel approach to technical information. Fonts and detail info too small. (ID)
14. This feels like a card version of a design dictionary. What is a more convincing advantage a card version has over a book format? (ID)
15. - (ID)
16. It is a simple presentation. (ID)
17. Information layout is fine, but not on the use of physical cards. Will be better to implement it on PDA / Notebook. (ED)
18. Can get messed up and troublesome to find. (ID)
19. Instruction sheet for overview of use. Have a catalogue. Make sure it does not get mixed up when shuffled. Highlight similarity or common links between cards. (ED)
20. A chart would provide an overview. Cards are good for teaching and individual learning. (ED)
21. Comfortable. Font size can be slightly bigger. (ID)
22. - (ID)
23. - (ID)
24. - (ED)
25. It is a good way to standardize the terminology used in the product design process. (ID)
26. - (ID)
27. - (ID)
28. Perhaps use software format for easy access and quicker retrieval of information. (ED)
29. Very easy to visualise. (ED)
30. - (ED)
31. Useful for training and education and those who just joined the company as a training tool to gain same understanding as colleagues. (ED)
32. - (ID)
33. Classification can be improved using different colour codes to indicate main topic and subsections. (ID)
34. Have a common understanding and systematic review of the design process. (ED)
35. Appropriate as a group tool. Individuals may prefer a book format. (ID)
36. - (ED)
37. Cards are physical and can be use in all places. Flexibility is another advantage. (ED)
38. Software may be an enhancement. (ED)
39. Not too familiar with other approaches, but see this as useful to develop confidence in technique suitable to particular problems. (ED)
40. Convenient, easy to follow, well designed. (ED)
41. First impression is positive, however, previous experiments tells us that they won't be used. Software application would be more flexible – customization for companies – print and custom order. (ID)
42. An alternative format / guide. (ED)
43. It is a refreshing format and very interactive for the user. (ED)

## 2. How do you feel about the physical size of the cards?

IDS:

1. Excellent	2. Good	3. Neutral	3. Poor	4. Very Poor
03	15	04	00	00
13.6%	68.2%	18.2%	0%	0%

EDS:

1. Excellent	2. Good	3. Neutral	3. Poor	4. Very Poor
05	12	03	01	00
24%	57%	14%	5%	0%

Other comments:

1. - (ID)
2. Handy. (ID)
3. - (ID)
4. No problem. (ID)
5. It's excellent because it is easy to carry. (ED)
6. - (ID)
7. - (ED)
8. OK - pocket size (ED)
9. Slightly small for senior engineers and older people. (ID)
10. Too thick. Would paper edge bend? Make it more durable. (ID)
11. - (ID)
12. Right size. (ED)
13. Maybe a cue card size, more eligible. (ID)
14. - (ID)
15. - (ID)
16. - (ID)
17. Size is generally fine, but too many cards. (ED)
18. Too bulky for pocket. (ID)
19. Size is ok, but words are too small, especially back text. Maybe no need to include numbers, just bar charts. (ED)
20. - (ED)
21. - (ID)
22. Handy dimension. (ID)
23. - (ID)
24. - (ED)
25. I think it can be bigger to make the information on the cards more readable. (ID)
26. Standard size. (ID)
27. - (ID)
28. - (ED)
29. - (ED)
30. - (ED)
31. Good for small groups, big groups may not be able to see the cards. (ED)
32. Information small, but size is good for portability. (ID)
33. - (ID)
34. Size maybe can increase double. Too cramped. (ED)
35. Good, according to ISO standards, appropriate, looks normal card feel. Graphics is perfectly alright.
36. - (ED)
37. Good size, but may be limited to small groups. (ED)
38. Words are abit small. (ED)
39. Fine for the amount of information presented. However, what if the user wants to know more? (ED)
40. Comparable to other existing cards available in the market. Wordings are clear enough i.e. cards not too small. (ED)
41. Compact info is good. (ED)
42. Size is good. (ED)
43. It can be held comfortably when being used and very portable. (ED)

### 3. How would you rate the clarity and understandability of the textual content and pictorial data?

IDS:

1. Excellent	2. Good	3. Neutral	3. Poor	4. Very Poor
<div>02</div>	<div>14</div>	<div>05</div>	<div>01</div>	<div>00</div>
9.1%	63.7%	22.7%	4.5%	0%

EDS:

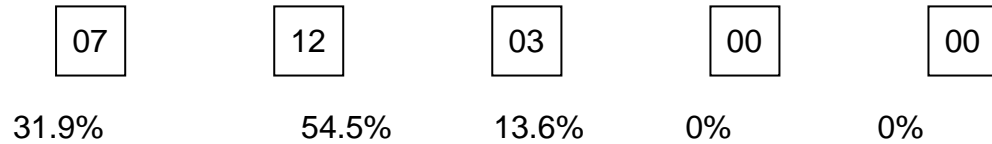
1. Excellent	2. Good	3. Neutral	3. Poor	4. Very Poor
<div>05</div>	<div>15</div>	<div>01</div>	<div>00</div>	<div>00</div>
24%	71%	5%	0%	0%

#### Other comments:

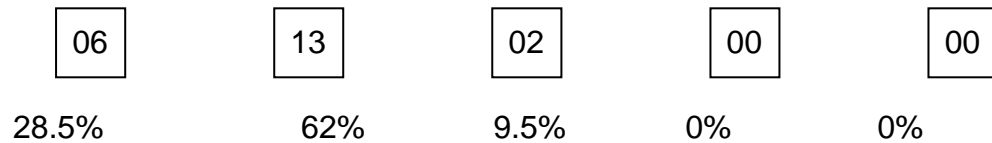
1. Limited by format, may improvise with digital format to allow magnification. (ID)
2. Too many layers of information. Hierarchy of information is unclear. % is not helpful. List of choice is fine. (ID)
3. Text are well layered. Different hierarchy makes it easy to find the vast amount of information presented. (ID)
4. I understand them but the application is called to question. (ID)
5. - (ED)
6. - (ID)
7. - (ED)
8. Prioritise information in order instead of percentage. Maybe 5 bars are sufficient. (ED)
9. Can be made bigger. Currently clear and easy to understand. (ID)
10. - (ID)
11. - (ID)
12. Overall it is simple and clear to understand. (ED)
13. Reverse sides (right column) numeric display a little misleading as the bar already gives a good visual comparison at a glance on the list. (ED)
14. Pictorial data can be improved. Idea sketch seems no different from study sketch. Missing a user context. Better images can be chosen? (ID)
15. - (ID)
16. - (ID)
17. Readable and comprehensive. (ED)
18. Too cluttered. (ID)
19. Put details in same row for easy comparison. (ED)
20. - (ED)
21. I find the content is clear. However these cards can be shown to target groups outside so as to find if they can understand them.
22. - (ID)
23. Cards look cluttered – too much writing. (ID)
24. Bigger pictures would communicate the idea better. (ED)
25. - (ID)
26. Words too small but it is because too much information in each card. (ID)
27. - (ID)
28. - (ED)
29. - (ED)
30. - (ED)
31. Gives adequate basic information. (ED)
32. More description. (ID)
33. The picture used should be understood generally by most users. (ID)
34. Very good to have pictures to focus on and decide on first impression. Maybe increase size and have supplementary pictures. (ED)
35. - (ID)
36. Space is a limited resource on the card. (ED)
37. - (ED)
38. - (ED)
39. Significance of numbers a little confusing. (ED)
40. In general, clear and representative. (ED)
41. Improvement – colour code within ED / ID to strengthen the clustering of cards. (Warm red – orange – yellow / cold blue, green, purple)
42. - (ED)
43. It will be more relevant if customised to my industry jargons and terminology. (ED)

4. How would you rate the ability of the cards to provide you with an enhanced understanding and clearer definition of design representations?

IDS: 1. Excellent 2. Good 3. Neutral 3. Poor 4. Very Poor



EDS: 1. Excellent 2. Good 3. Neutral 3. Poor 4. Very Poor



### Other comments:

1. – (ID)
2. – (ID)
3. It is a fast avenue to understand the way EDs work with respect to their design process. (ID)
4. I can understand them well. (ID)
5. – (ED)
6. – (ID)
7. – (ED)
8. – (ED)
9. Good overview and background of representations. (ID)
10. – (ID)
11. – (ID)
12. Pictures are easy to understand. (ED)
13. – (ED)
14. Do not understand how the card format can enhance understanding of design representations from book format. May even have a disadvantage when accessing design process flow in a graphic representation. (ID)
15. – (ID)
16. – (ID)
17. – (ED)
18. Good for others who have little knowledge. (ID)
19. Does not show how to do a sketch. Does not give details how it should be done. Where do we get the information from? What tools to use? (ED)
20. Useful for marketing, program managers, new engineers, students or others who are not trained in design process. (ED)
21. It is clear cut to people who are in this field. (ID)
22. Good reference. (ID)
23. Good way to standardize terms. (ID)
24. – (ED)
25. – (ID)
26. – (ID)
27. – (ID)
28. – (ED)
29. Summarised meaning on cards will be useful. (ED)
30. – (ED)
31. – (ED)
32. – (ID)
33. – (ID)
34. Mostly people are still not used to this new system. More of a familiarity issue. Need time to get used to. (ED)
35. Provides a general overview. (ID)
36. It is as good as the space allows. (ED)
37. It gives the designer a good idea of what his counterpart designer's perspective. (ED)
38. – (ED)
39. Depends on level of enhancement required.
40. Provides clear definitions for parties involved in design to understand each other. (ED)
41. It's deeper layers then practically used however for educational purpose that is an advantage. Sees application for project managers. (ID)
42. – (ED)
43. It would be more relevant if customised to my industries' needs. (ED)

5. How do you feel about the effectiveness of the cards to provide a common understanding of design representations between IDs and EDs?

IDS:	1. Excellent	2. Good	3. Neutral	3. Poor	4. Very Poor
	<div>03</div>	<div>16</div>	<div>02</div>	<div>01</div>	<div>00</div>
	13.6%	72.8%	9.1%	4.5%	0%
EDS:	1. Excellent	2. Good	3. Neutral	3. Poor	4. Very Poor
	<div>08</div>	<div>10</div>	<div>02</div>	<div>01</div>	<div>00</div>
	38%	47.5%	9.5%	5%	0%

Other comments:

1. – (ID)
2. Card format isn't suitable. Difficult to integrate to current modes of communication. (ID)
3. – (ID)
4. I provided the comments on usefulness of the headings. – need clearer headings. (ID)
5. The terms used are general terms. In certain organisation they will have their own terms in certain items. (ED)
6. A total picture is needed to clearly illustrate the concept behind the cards. (ID)
7. – (ED)
8. – (ED)
9. One to one communication can be the solution. (ID)
10. – (ID)
11. – (ID)
12. I felt it is more effective than the traditional textbook style. (ED)
13. Encompasses a broad range of practices at a glance. (ED)
14. Information is positive and relevant. But perhaps the example of the sketches can be better? In a way, I do think the type of sketches have been categorised too finely. (ID)
15. – (ID)
16. This is a good tool to bridge the communication gap between designers and engineers. (ID)
17. Data extracted from study of ID's and ED's modes of operation. (ED)
18. – (ID)
19. Not showing how the two cards are used. Need to highlight similarity. (ED)
20. Good for project management to look and see options. Useful for someone who have not worked with ID before or for engineers who want to know more. (ED)
21. – (ID)
22. Good combination between pictures and words to describe each process. (ID)
23. A good way to link the 2 sets of designers together. Is a simplistic way. (ID)
24. – (ED)
25. – (ID)
26. Theoretically, yes. But in practicality, in the real running of projects, other problems surface. However, these cards are a good start. (ID)
27. – (ID)
28. – (ED)
29. Effective enough to capture all information. (ED)
30. – (ED)
31. For first timers. (ED)
32. Very good. (ID)
33. – (ID)
34. Still related to the familiarity. If the IDs / EDs already have the same design process then it will be useful / effective. (ED)
35. – (ID)
36. Not able to comment on possible dynamics. (ED)
37. Can establish common ground for better understanding and cooperation. (ED)
38. – (ED)
39. Seems to be the primary goal / benefit of the cards. (ED)
40. Yes, positively effective, although information provided may be more than sufficient. (ED)
41. More in educational context and potentially wider if in software application (customised to company culture). (ID)
42. – (ED)
43. This will bridge the gap between professionals who come from different backgrounds, with different knowledge and ways of thinking. (ED)

## 6. How would you rate the use of bar charts that show key design and technical information?

IDS:

1. Excellent	2. Good	3. Neutral	3. Poor	4. Very Poor
06	12	03	01	00
27.3%	54.5%	13.6%	4.5%	0%

EDS:

1. Excellent	2. Good	3. Neutral	3. Poor	4. Very Poor
06	10	05	00	00
28.5%	47.5%	24%	0%	0%

### Other comments:

1. – (ID)
2. Don't need, or a clearer way to represent. (ID)
3. – (ID)
4. They are good, easy to understand but contents need to be modified. (ID)
5. – (ED)
6. – (ID)
7. – (ED)
8. Remove bar charts. Use priority numbering system. (ED)
9. Visually good and allows better understanding. (ID)
10. Needs to explain what it is for. Have an instruction sheet / card. (ID)
11. – (ID)
12. Visual representation is more obvious than reading the text. (ED)
13. Gives new users a good idea which suitable options are available. (ED)
14. Relevant. It's something that comes with communication with the engineers and stakeholders. But is the rating absolute? If in the case of experienced designers, maybe information can be communicated more succinctly and effectively than suggested in the cards? (ID)
15. – (ID)
16. – (ID)
17. Can serve as guide on good practices by those in industry. (ED)
18. – (ID)
19. Might need to say relevance to industry. Good as overview but not accurate or specific. (ED)
20. Might be too confusing. (ED)
21. Good ass-on (ID)
22. Good graphic cognition, but double information? (ID)
23. Not very obvious on the card itself – make it more visible. The information is useful but may be missed when glancing at the card. (ID)
24. – (ED)
25. However, I was a little misled by the numerical percentages because of the small font. (ID)
26. – (ID)
27. – (ID)
28. – (ED)
29. Good, but may not be visible in the first looks. (ED)
30. – (ED)
31. Depends on individual preference. (ED)
32. Not necessary to have numbers and charts. Maybe number is enough. (ID)
33. – (ID)
34. Will need to have more explanation, figures or bar. Either one should be enough. Make the card layout more understandable. Not understood immediately. (ED)
35. – (ID)
36. No other fundamental way to show difference with variance. It is optimal. (ED)
37. A percentage next to the description is good enough. (ED)
38. – (ED)
39. Need bars and numbers. Would prefer numbers to be more precise rather than the nearest 10. (ED)
40. Need improvements in clarity. (ED)
41. Bar was seen only after pointing it out. Test it out without selling. Explain only what would go on one page instruction of use.
42. – (ED)
43. It helps my thought process by helping me to cross-reference to other cards. Perhaps replace the ranking into other relevant information. (ED)

7. How would you rate the ability of the cards to help you identify the representation most commonly used during different stages of the design process?

IDS:	1. Excellent	2. Good	3. Neutral	3. Poor	4. Very Poor
	<div>05</div>	<div>14</div>	<div>03</div>	<div>00</div>	<div>00</div>
	22.7%	63.7%	13.6%	0%	0%
EDS:	1. Excellent	2. Good	3. Neutral	3. Poor	4. Very Poor
	<div>07</div>	<div>12</div>	<div>2</div>	<div>00</div>	<div>00</div>
	33.5%	57%	9.5%	0%	0%

Other comments:

1. Reliability requires industrial testing. Accuracy is the important criteria. (ID)
2. – (ID)
3. – (ID)
4. However I would prefer if there was a clearer recommendation. (ID)
5. – (ED)
6. Limited space for information. (ID)
7. – (ED)
8. – (ED)
9. It shows the representations. (ID)
10. – (ID)
11. – (ID)
12. The clarity on the cards may need to be explained somewhere. (ED)
13. Concise, good for new users who do not have an existing practice. (ED)
14. – (ID)
15. – (ID)
16. – (ID)
17. A Guide to practice by understanding – will be better if implemented on a PDA. (ED)
18. Common practice guide. More for students. (ID)
19. – (ED)
20. Can see other options. (ED)
21. – (ID)
22. Probably good aid to newer EDs / IDs, but seemingly rather irrelevant for more experienced EDs / IDs? (ID)
23. Well displayed order. (ID)
24. – (ED)
25. – (ID)
26. – (ID)
27. – (ID)
28. Usually most companies already have a structured system in place. This cards are applicable for those who are less experienced. (ED)
29. – (ED)
30. – (ED)
31. Would like to know in a particular stage, what should be applied, then I can learn. (ED)
32. Good. (ID)
33. – (ID)
34. Maybe only at certain stages of the design process are critical. Need to explain more at the actual development, conceptualization maybe just a brief note. (ED)
35. New knowledge created. (ID)
36. There might be other suitable information but the common representation should be fine. (ED)
37. The steps on procedures are useful for relating to the other party. (ED)
38. – (ED)
39. Clear enough. (ED)
40. Needs some user manual to explain how the cards work for effective application. (ED)
41. Helps to build a product creation process. To a new organisation when done, cards goes to the side. (ID)
42. - (ED)
43. The cards will help the different parties involved in the project to pinpoint on the stage of the project they are currently upon. (ED)

8. How do you feel about the ability of the cards to foster enhanced collaboration between IDs and EDs?

IDS:

1. Excellent	2. Good	3. Neutral	3. Poor	4. Very Poor
02	13	06	01	00
9.1%	59.1%	27.3%	4.5%	0%

EDS:

1. Excellent	2. Good	3. Neutral	3. Poor	4. Very Poor
04	10	07	00	00
19%	47.5%	33.5%	0%	0%

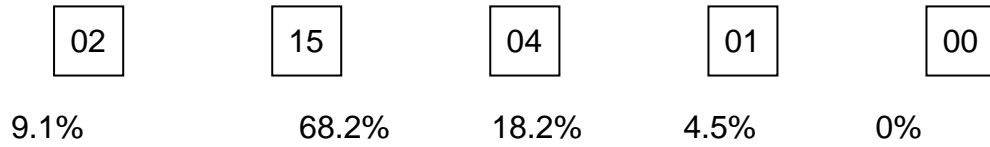
Other comments:

1. Final design needs testing to ensure ease of use and understanding. (ID)
2. Card format is awkward and not intuitive. (ID)
3. – (ID)
4. It would do an excellent job if some of the changes recommended are made. (ID)
5. – (ED)
6. – (ID)
7. – (ED)
8. – (ED)
9. They will have a brief summary and understanding. (ID)
10. Helps to understand differences. (ID)
11. Need to use with an engineer in teamwork kind of project. (ID)
12. Need to validate practicality. (ED)
13. Especially for new users and non-ID fields (ED)
14. – (ID)
15. – (ID)
16. – (ID)
17. Again cards too tedious – having to find from one to another. Will be better facilitated by implemented by a PDA, etc. (ED)
18. – (ID)
19. A bit confusing to use. Good as teaching but not for industry practice. (ED)
20. Good reference tool. (ED)
21. – (ID)
22. Creates common grounds that may not have been established previously. (ID)
23. – (ID)
24. – (ED)
25. Less conflict when it comes to understanding. (ID)
26. – (ID)
27. – (ID)
28. For less experienced people, outside of the design industry. (ED)
29. Interaction between ID and ED students by providing a game to play or interact together. (ED)
30. A chart with system perspective for both ED and ED would be helpful. (ED)
31. – (ED)
32. Good before project starts. Meanings must be interpreted corrected. (ID)
33. – (ID)
34. There is now a system to force the designers and engineers to work hand-in-hand. Natural tendency is for them to drift off in their own ideas and subsequent break-down in the communication. (ED)
35. Not really a breakthrough. Usually sit down. Every company has operating procedures, booklets. But good attempt. (ID)
36. Unable to comment. (ED)
37. It gives good understanding of the other party's thinking process. Hence enhanced collaboration. (ED)
38. – (ED)
39. For IDs, I think it will work quite well. Don't know what EDs would make of it, but would like to see. (ED)
40. Provide more common forms of understanding. (ED)
41. Collaboration questionable. Understanding, Yes. (ID)
42. – (ED)
43. Yes, it will help if customised to the companies' requirements. (linked to Qn. 5 and 7)

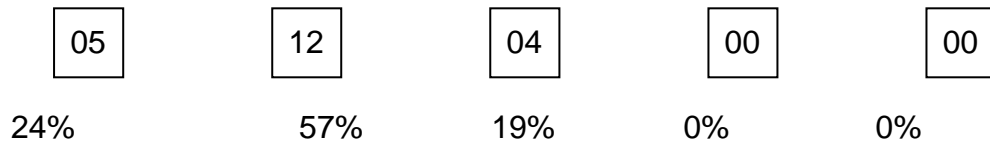


9. How do you feel about the ability of the cards to improve design collaboration between yourself and other industrial designers / engineering designers?

IDS: 1. Excellent 2. Good 3. Neutral 3. Poor 4. Very Poor



EDS: 1. Excellent 2. Good 3. Neutral 3. Poor 4. Very Poor



#### Other comments:

1. – (ID)
2. Not intuitive. (ID)
3. Have not exactly worked with EDs. (ID)
4. To some extent. (ID)
5. – (ED)
6. – (ID)
7. – (ED)
8. Cards do explain the definitions of ID processes. (ED)
9. Can clarify better. (ID)
10. – (ID)
11. – (ID)
12. A good tool to use as a communication platform. (ED)
13. Greater interactivity between users (ID and ED) and also understanding the different aspects. (ED)
14. I would give a 'not bad' rating. (ID)
15. – (ID)
16. – (ID)
17. Identifies and helps guide the roles of IDs and EDs. (ED)
18. – (ID)
19. – (ED)
20. Good for knowledge, to find out more. But not really day to day use. (ED)
21. As a designer, this card will certainly help when communicating with engineers whom I have not worked with before. (ID)
22. – (ID)
23. Meanings will be made clear and standardised. (ID)
24. – (ED)
25. – (ID)
26. – (ID)
27. – (ID)
28. – (ED)
29. Yes, it will enhance the understanding of ID and EDs. (ED)
30. – (ED)
31. – (ED)
32. Will be helpful. (ID)
33. Cards as point of contact. Website for further details of the topic. (ID)
34. Have a system to bring different IDs and EDs at different levels of expertise to a common design goal. (ED)
35. – (ID)
36. It does define role and responsibility. (ED)
37. – (ED)
38. Because I am already very familiar with the design process and the communication between IDs and EDs. (ED)
39. Potentially. Definitely there is a difference in their understanding and anything that helps in bridging the gap is good. (ED)
40. Provide a better interface. (ED)
41. IDs and EDs have biggest gap in cultural approach – which cards do not address. Understanding is better than project managers. (ID)
42. – (ED)
43. Tied to Qn. 7. To bridge the gap between parties who are personally willing to try a fresh approach. (ED)

10. Would you have any suggestions or additional feedback to help us improve the cards?

Other comments:

1. Have a softcopy with internet access. Customizable software. How does this system apply to other products that are non-mechanical, or electronic? Perhaps sort the cards for different types of product industry? Specialised pack. (ID)
2. Too much information may take time to digest. More colour codes to quickly identify. Too much detail. Have simple key words, bullet points and context words. (ID)
3. Cards seem more useful as an introduction to the different working methods of ID and ED, not too sure about how well it will serve the working ID and ED persons. (ID)
4. Communicated verbally. Teach people how to apply and how to use. Or what types of tools to recommend. Break representations into different stages?
5. It would be good if there is a web-based copy (ED)
6. Instruction manual. Good as a teaching aid to reduce friction and misunderstanding. Need to explain how it is used. Physical format is good, so no need to memorise what was seen on a screen or limited by screen size. (ID)
7. – (ED)
8. Simplify the definitions to 3 phrases or sentences for concise read. (ED)
9. Ring-bound. Slightly bigger. Less thick. (ID)
10. Thinner, durable material. Too thick and bulky. Look at sentence structure. (ID)
11. Words loosely defined. Format is ok. Look at Ideo method cards. Tool as a facilitator. (ID)
12. This is a very hands-on format. Educational opportunities. Top management may not be applicable. Good start for others to know about things people do. More convincing than textbook. Consolidates information. On the whole is clear with colour coding. Maybe too much information. Filter some information. Application must be clear. Every industry has different selections. Customise. (ED)
13. Excellent idea for new users or users that doesn't have an existing process practice, or users that deal with different products (design house). (ED)
14. Would be good to make use of the card format to help illustrate design process. Cos the process is often subjected to change, redos and responds more to shifting market changes, the card format may actually prove more advantageous than a book. I feel a more realistic problem in design world is the communication of the workflow, what is required at what stage, and how much time is available. Maybe think of it beyond the classroom context? (ID)
15. Different company has different design process styles. May you should get more information from other companies. (ID)
16. This is an excellent representation tool for students / new IDs EDs. It serves a good guide especially it comes to understand the process. (ID)

17. Implement on PDA / notebook. These are pervasive tools. (ED)  
Information is ok. But at this time and age, PDAs would be more useful. Pops-up information according to amount of complexity required. Too many cards in whole stack. What if cards are dropped? Why not digital? (ED)
18. Neater package for easy reference. Get information quickest. Can be frustrating. Cell phone memory card. (ID)
19. how to apply it? The tools? (ED)
20. – (ED)
21. Perhaps you might want to look at how this card can be used after serving its intended purpose. How the lifespan can be prolonged or extended? (ID)
22. Digital format. (ID)
23. As a teaching tool it is very effective. Will help to develop projects in more varied practices. (ID)
24. – (ED)
25. Make the cards more targeted towards other fields, eg, marketing, etc. (ID)
26. Innovative, great for an educational tool. Has commercial potential. (ID)
27. To have a “Final card” that summarises the overview of the system: that design is an iterative process. (ID)
28. Software based tool would make it more effective. Webpage allows user to click links for more or external information. Flash format, etc. Most people in industry are computer literate. (ED)
29. it will be good to think of some games related to product design, so the two groups can really play and interact together. (ED)
30. A chart with system perspective. (ED)
31. Physical communication. Being apart, use website. (ED)
32. Have red, orange, yellow for Red pack. Too many segments within red pack to differentiate. Information useful. Likes card format. Good for schools. Japanese culture uses cards very frequently.
33. – (ID)
34. Need to substantiate the bar chart, how the % is derived? A separate instruction sheet to have detailed explanations. (ED)
35. Packaging? Quite clear – straight to the point. Some pictures are subjective – eg (26). Use more colour coding.
36. Combining the cards could be a direction to test as well. Single cards and two sets does paint or support individual groups rather than cohesion of strength. (ED)
37. Background presentation on the cards to present the typical EDs and IDs. ID cards perhaps more fanciful colours and shape? ED cards more practical and square looking? (ED)
38. Make card number on link bigger to stand out more. Develop a software version. (ED)
39. Backup information, probably web-based. (ED)
40. Layout of cards - % to be clearly placed. Some figures at front of cards not clear. Icons need to be simpler to bring our clarity.
41. Software application. Customised solution – let the users build on it. Colour coding.
42. - (ED)
43. it could be enlarged for use in brain-storming groups as information boards, etc. (ED)

### 13.14 Records from the Design Diary

The following pages show records from the design diary. Confidential information relating to the project, participants and the companies involved have been omitted.

## Design Diary

### End-of-the-Day Diary



Design Representation  
Quality Management

Eujin Pei  
Loughborough University  
Department of Design & Technology

Diary Log No: 01

Date: 29/2/2008

Location: 

People involved: 

#### What happened today?

Points of day's main activities:

- provided design brief on project for a headset.
- to come up with inspiration board that focuses on "fun and fashion".
- look at the design brief & technical specifications.

#### Use of Design Representation cards:

Any interactions / events related to the use of cards / feedback ?

- none.

# Design Diary

## End-of-the-Day Diary



Design Representation  
Quality Management

Eujin Pei  
Loughborough University  
Department of Design & Technology

Diary Log No: 02

Date: 3/3/08

Location: [redacted]

People involved: [redacted]

### What happened today?

Points of day's main activities:

- Created inspiration board for concepts.
- Started to sketch loosely some ideas.
- Referred to technical limitations.

### Use of Design Representation cards:

Any interactions / events related to the use of cards / feedback ?

- none.

# Design Diary

## End-of-the-Day Diary



Design Representation  
Quality Management

Eujin Pei  
Loughborough University  
Department of Design & Technology

Diary Log No: 03 A

Date: 4/3/08

Location: [redacted]

People involved: [redacted]

### What happened today?

Points of day's main activities:

- continued work on concept design.
- new mood board for "fashion trends".
- Introduced the representation cards to [redacted]

### Use of Design Representation cards:

Any interactions / events related to the use of cards / feedback ?

- Shared the cards to [redacted] for the first time.
- Gave background introduction on the research context & why designers & engineers have card-based mindsets.
- The card format (4 sub-sections).
- Using the cards (how to use)
- Its application & benefits.

Design Representation  
Card Used

Technical Information  
Card Used

Design Information  
Card Used

Design Stages  
Card Used

(continued).

# Design Diary

## End-of-the-Day Diary



Design Representation  
Quality Management

Eujin Pei  
Loughborough University  
Department of Design & Technology

Diary Log No: 03 B.

Date: 4/3/18.

Location: [redacted]

People involved: [redacted]

### What happened today?

Points of day's main activities:

### Use of Design Representation cards:

Any interactions / events related to the use of cards / feedback ?

(continued).

- initial feedback { useful for [redacted] with little knowledge on ID.
- [redacted] {
  - cards may get mixed-up.
  - perhaps punch hole or put in a booklet or slots on wall.
- [redacted] {
  - perhaps software version.
  - good for reference to see how IDs & EDs work differently.

# Design Diary

## End-of-the-Day Diary



Design Representation  
Quality Management

Eujin Pei  
Loughborough University  
Department of Design & Technology

Diary Log No: 04.

Date: 5/3/08

Location: [redacted]

People involved: [redacted]

### What happened today?

Points of day's main activities:

- Client chose some concepts to be developed further.
- post-sticks were used to highlight changes or for further development of the ear piece.
- Engineer did not comment at all as it was still in the concept design stage.
- drawings & sketches were of handover sketches (information sketches).

### Use of Design Representation cards:

Any interactions / events related to the use of cards / feedback ?

- Cards not used.
- only concept selection.



# Design Diary

## End-of-the-Day Diary



Design Representation  
Quality Management

Eujin Pei  
Loughborough University  
Department of Design & Technology

Diary Log No: 05

Date: 6/3/08

Location: [redacted]

People involved: [redacted]

### What happened today?

Points of day's main activities:

- Project leader [redacted] attended the meeting where we shared him our progress & where the client had shortlisted several concepts for development. Some recommendations were made to further refine some ideas.
- [redacted] (ED) did not participate in today's discussion much.
- Developed the Ball & socket concept with articulation - design.
- To draw some prescriptive sketches.



### Use of Design Representation cards:

Any interactions / events related to the use of cards / feedback ?

- Yet to formally introduce the design representation cards to the project team leader [redacted] (held back due to inconvenient time slots available).

# Design Diary

## End-of-the-Day Diary



Design Representation  
Quality Management

Eujin Pei  
Loughborough University  
Department of Design & Technology

Diary Log No: 06

Date: 7/3/08.

Location: [redacted]

People involved: [redacted]

### What happened today?

Points of day's main activities:

- Presented Design Representation cards to the team formally & explained the uses, key benefits and research progress related to the cards.
- Began concept development in detail, putting some concept platform to the lineup - all done using information sketches.

### Use of Design Representation cards:

Any interactions / events related to the use of cards / feedback ?

- used the cards to clarify which sketches were required.
- In all, idea sketches, study sketches, information sketches & prescriptive sketches were used.
- validated that idea & study sketches were used very frequently in the concept design stage; whilst
- information & prescriptive sketches used in the concept development stages.

Design Representation  
Card Used

Design Stages  
Card Used

# Design Diary

## End-of-the-Day Diary



Design Representation  
Quality Management

Eujin Pei  
Loughborough University  
Department of Design & Technology

Diary Log No: 07.

Date: 10/3/08

Location: [redacted]

People involved: [redacted]

### What happened today?

Points of day's main activities:

- Converted information sketches to prescriptive sketches.
- From hand-drawn prescriptive sketch, ideas are refined & consulted with project leader.
- The hand-drawn prescriptive sketches are then converted into illustrator line-art, known as concept drawings.
- transformation of sketches to drawing stage.

### Use of Design Representation cards:

Any interactions / events related to the use of cards / feedback ?

- validated use of prescriptive sketches.
- used concept drawings in concept development stage.
- use of cards & validated card notes.
- wanted to show informal dimensions:  
cards reflected that prescriptive sketches enabled this information.

Design Representation  
Card Used

# Design Diary

## End-of-the-Day Diary



Design Representation  
Quality Management

Eujin Pei  
Loughborough University  
Department of Design & Technology

Diary Log No: 08

Date: 11/3/08

Location: [redacted]

People involved: [redacted]

### What happened today?

Points of day's main activities:

- Refined the prescriptive sketches into concept drawings.
- Lineart of concept drawings are made up of multi-view drawings but rendered in illustrator.  
∴ prescriptive sketches → multi-view-draws → concept draws  
(hand drawn) ..... Rhino lineart ..... illustrator.
- used & created ~~representational models~~ functional concept models & design development models with project leader & engineering designer to sort technical issues with ball & socket.

### Use of Design Representation cards:

Any interactions / events related to the use of cards / feedback ?

- validated that prescriptive sketches, multi-view draws & concept draws are used extensively ~~with~~ in concept development phase.
- that functional concept models & design dev. models helped clarify ideas better with ED.

Design Representation  
Card Used

# Design Diary

## End-of-the-Day Diary



Design Representation  
Quality Management

Eujin Pei  
Loughborough University  
Department of Design & Technology

Diary Log No: 09

Date: 12/3/08

Location: [redacted]

People involved: [redacted]

### What happened today?

Points of day's main activities:

- Some changes to the concept drawings were made.
  - Had to do idea sketches & study sketches to further evaluate details. The sketches were then developed into information sketches & refinements input to the concept drawings.
- idea sketch → study sketch → concept drawing

### Use of Design Representation cards:

Any interactions / events related to the use of cards / feedback ?

- Cards helped to determine that information sketches showed information on mechanism.
- information sketches & study sketches used for [redacted] mechanism
- used "mechanism" card & found information sketches would help to present information clearer.



Technical Information  
Card Used



# Design Diary

## End-of-the-Day Diary



Design Representation  
Quality Management

Eujin Pei  
Loughborough University  
Department of Design & Technology

Diary Log No: 10

Date: 13/3/08

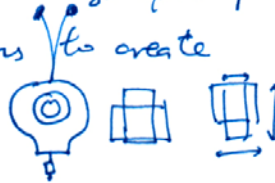
Location:

People involved:

### What happened today?

Points of day's main activities:

- continued lineart on illustrator to create concept drawings for accessories.
- referred to functional concept models to determine components.
- referred to technical drawings ~~not~~ provided by engineer for dimensions to create auto - cord winder.



### Use of Design Representation cards:

Any interactions / events related to the use of cards / feedback ?

- Referred to technical drawings & discussed with engineer if the tech. dwgs & the concept drawings in illustrator matched.
- used the cards to explain the concept drawings.
- used the tech. dwg card to find what other information could be "extracted".

Design Representation  
Card Used

# Design Diary

## End-of-the-Day Diary



Design Representation  
Quality Management

Eujin Pei  
Loughborough University  
Department of Design & Technology

Diary Log No: 11

Date: 14/3/08.

Location: [redacted]

People involved: [redacted]

### What happened today?

Points of day's main activities:

- Rendered lineart into concept drawings (continuation of work).
- added details such as reflections, translucent, material texture, logo, etc.
- dimensions checked with actual technical drawings.

### Use of Design Representation cards:

Any interactions / events related to the use of cards / feedback ?

- cards were used to double check the output that the concept drawings were up to detail with relevant information within.
- used cards to see what information could be found from the concept drawings. (cross-checked with project leader & ED).

Design Representation  
Card Used

# Design Diary

## End-of-the-Day Diary



Design Representation  
Quality Management

Eujin Pei  
Loughborough University  
Department of Design & Technology

Diary Log No: 12

Date: 17/3/08

Location: [redacted]

People involved: [redacted]

### What happened today?

Points of day's main activities:

- Concept drawings presented into presentation drawings.
- The final 2D renderings were graphically created into presentation drawings as final artwork for the client.

### Use of Design Representation cards:

Any interactions / events related to the use of cards / feedback ?

- used the cards to check with project leader (card 33) that presentation drawings were what was required. clarified with him.

Design Representation  
Card Used



# Design Diary

## End-of-the-Day Diary



Design Representation  
Quality Management

Eujin Pei  
Loughborough University  
Department of Design & Technology

Diary Log No: 13

Date: 18/3/08

Location: [redacted]

People involved: [redacted]

### What happened today?

Points of day's main activities:

- printed out the final artwork in A3.
- [redacted] would present the 3 concepts to the client.
- need to get client feedback in a weeks' time before further developing into 3D CAD.

### Use of Design Representation cards:

Any interactions / events related to the use of cards / feedback ?

- Nil.

### 13.15 Final Tool Design

The following pages show the final design of the CoLab cards that were refined after the validation study.



Design Stages pack – Concept Design card



## Concept Development

Application towards Design Representations | Rating

Card 32		Concept Drawings	80
Card 28		Information Sketches	70
Card 31		Prescriptive Sketches	60
Card 41		3D Sketch Models	60
Card 33		Presentation Drawings	60
Card 42		Design Development Models	60
Card 34		Scenarios & Storyboards	50
Card 29		Renderings	40
Card 24		Study Sketches	30
Card 36		Single View Drawings	30
Card 23		Idea Sketches	30
Card 27		Coded Sketches	30



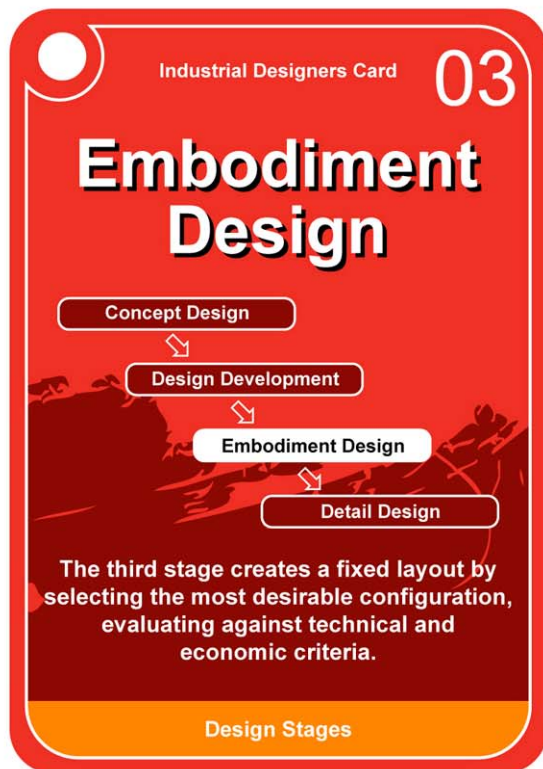
## Concept Development

Application towards Design Representations | Rating

Card 37		Multi View Drawings	30
Card 31		Prescriptive Sketches	20
Card 44		Functional Concept Models	20
Card 53		Experimental Prototypes	10
Card 38		General Arrangement Drawings	10
Card 23		Idea Sketches	10
Card 28		Information Sketches	10
Card 29		Renderings	10
Card 32		Concept Drawings	10
Card 33		Presentation Drawings	10
Card 34		Scenarios & Storyboards	10
Card 41		3D Sketch Models	10

Design Stages pack – Concept Development card

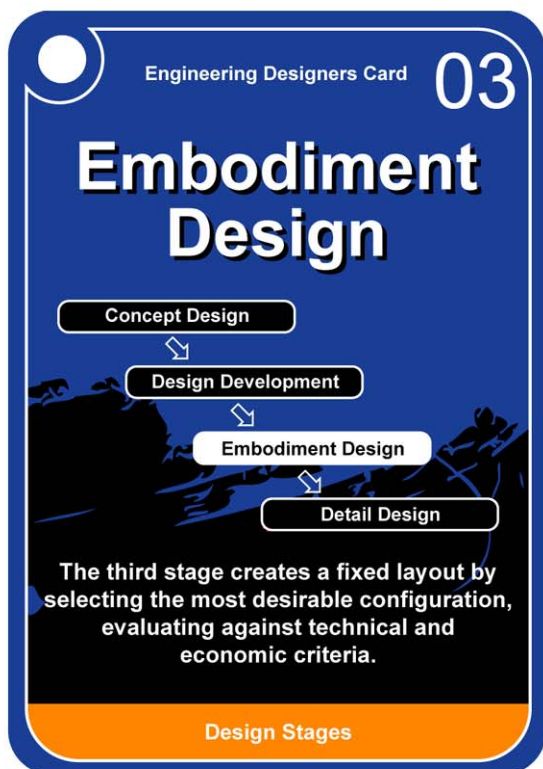




## Embodiment Design

Application towards Design Representations | Rating

Card 37		Multi View Drawings	60
Card 43		Appearance Models	60
Card 31		Prescriptive Sketches	30
Card 32		Concept Drawings	30
Card 41		3D Sketch Models	30
Card 44		Functional Concept Models	30
Card 49		Appearance Prototypes	30
Card 33		Presentation Drawings	20
Card 38		General Arrangement Drawings	20
Card 39		Technical Drawings	20
Card 36		Single View Drawings	20
Card 23		Idea Sketches	20



## Embodiment Design

Application towards Design Representations | Rating

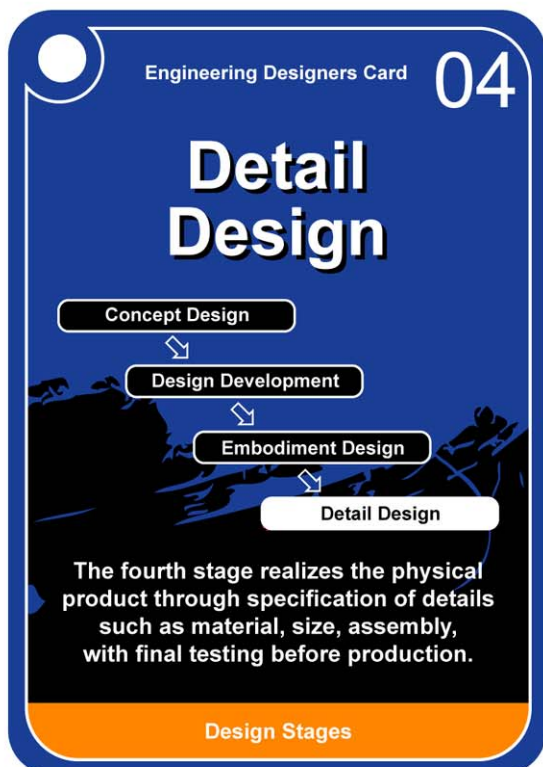
Card 39		Technical Drawings	60
Card 43		Appearance Models	30
Card 37		Multi View Drawings	20
Card 41		3D Sketch Models	20
Card 44		Functional Concept Models	20
Card 49		Appearance Prototypes	20
Card 53		Experimental Prototypes	20
Card 54		System Prototypes	20
Card 28		Information Sketches	10
Card 31		Prescriptive Sketches	10
Card 33		Presentation Drawings	10
Card 38		General Arrangement Drawings	10

Design Stages pack – Embodiment Design card



## Detail Design

Source	Application towards Design Representations	Rating
Card 49	Appearance Prototypes	60
Card 43	Appearance Models	40
Card 37	Multi View Drawings	40
Card 31	Prescriptive Sketches	30
Card 38	General Arrangement Drawings	30
Card 32	Concept Drawings	20
Card 33	Presentation Drawings	20
Card 52	Pre-Production Prototypes	20
Card 23	Idea Sketches	20
Card 24	Study Sketches	20
Card 39	Technical Drawings	20
Card 40	Technical Illustrations	20

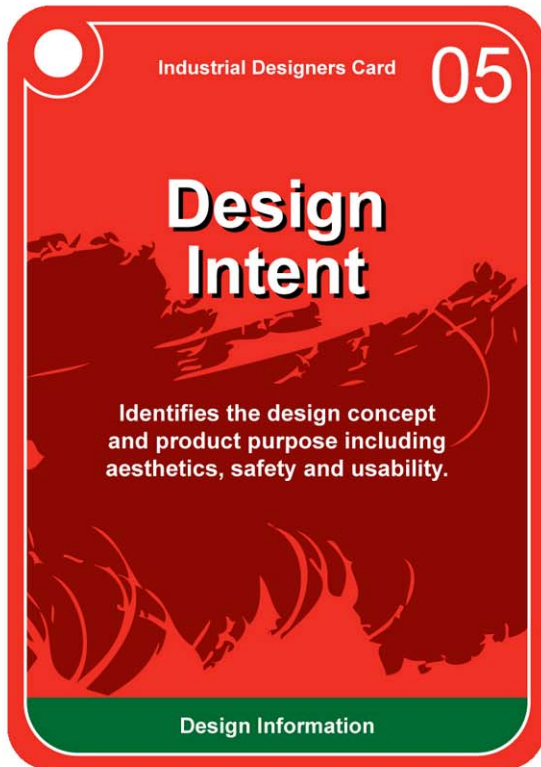


## Detail Design

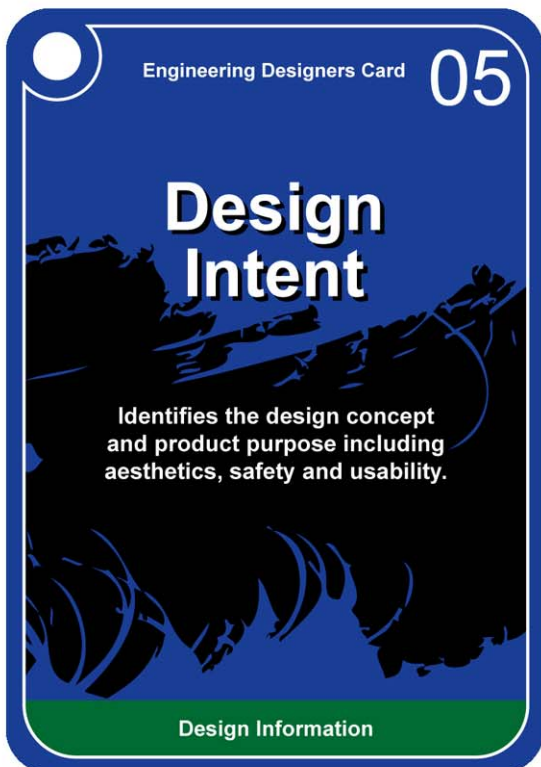
Source	Application towards Design Representations	Rating
Card 49	Appearance Prototypes	30
Card 55	Final Hardware Prototypes	30
Card 39	Technical Drawings	20
Card 37	Multi View Drawings	20
Card 46	Production Concept Models	20
Card 52	Pre-Production Prototypes	20
Card 54	System Prototypes	20
Card 56	Tooling Prototypes	20
Card 57	Off-Tool Prototypes	20
Card 43	Appearance Models	10
Card 47	Assembly Concept Models	10
Card 48	Service Concept Models	10

Design Stages pack – Detail Design card





Design Intent		
Source	Application towards Design Representations	Rating
Card 23	Idea Sketches	90
Card 28	Information Sketches	60
Card 49	Appearance Prototypes	50
Card 24	Study Sketches	40
Card 32	Concept Drawings	40
Card 25	Referential Sketches	30
Card 26	Memory Sketches	30

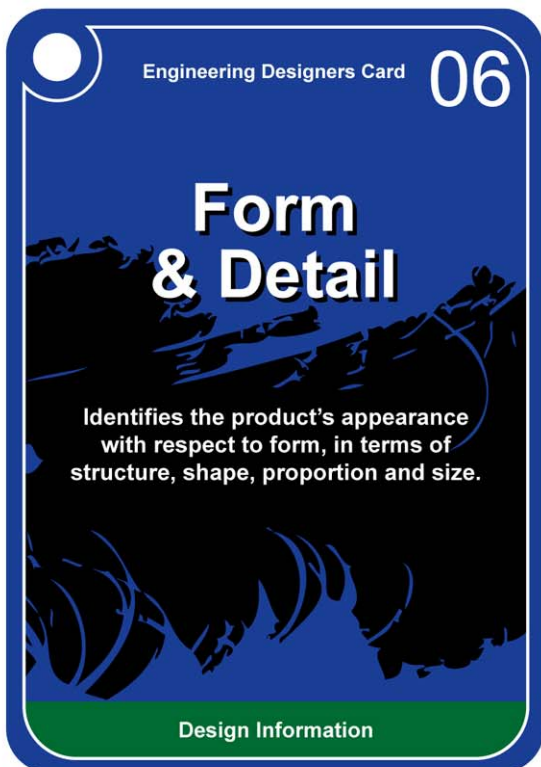


Design Intent		
Source	Application towards Design Representations	Rating
Card 49	Appearance Prototypes	30
Card 23	Idea Sketches	20
Card 24	Study Sketches	20
Card 25	Referential Sketches	10
Card 28	Information Sketches	10
Card 35	Diagrams	10
Card 43	Appearance Models	10
Card 42	Design Development Models	10
Card 41	3D Sketch Models	10
Card 44	Functional Concept Models	10

Design Information pack – Design Intent card

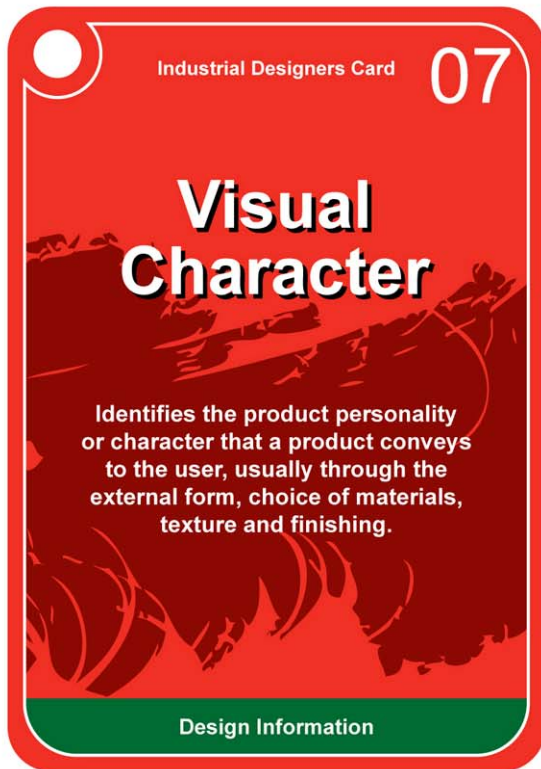


Form & Detail		
Source	Application towards Design Representations	Rating
Card 28	Information Sketches	90
Card 32	Concept Drawings	80
Card 23	Idea Sketches	70
Card 24	Study Sketches	50
Card 26	Memory Sketches	40
Card 31	Prescriptive Sketches	40
Card 43	Appearance Models	40
Card 41	3D Sketch Models	40
Card 49	Appearance Prototypes	40

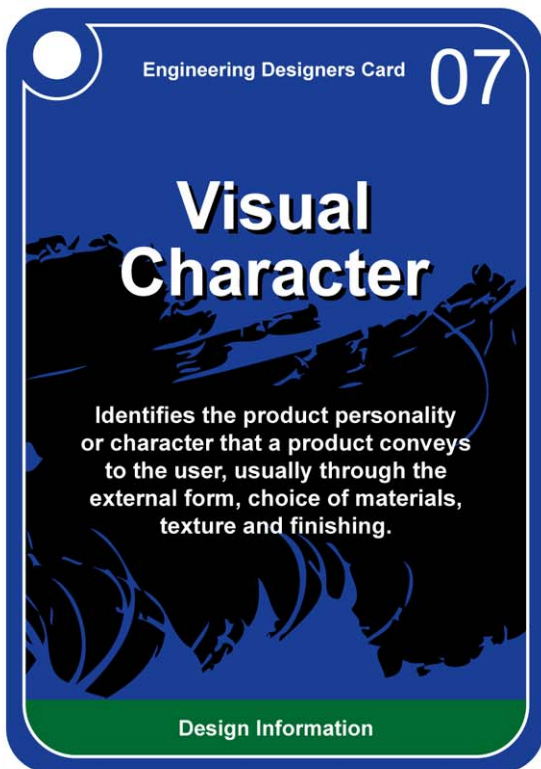


Form & Detail		
Source	Application towards Design Representations	Rating
Card 23	Idea Sketches	30
Card 49	Appearance Prototypes	30
Card 24	Study Sketches	20
Card 43	Appearance Models	20
Card 28	Information Sketches	10
Card 31	Prescriptive Sketches	10
Card 37	Multi View Drawings	10
Card 42	Design Development Models	10
Card 41	3D Sketch Models	10
Card 57	Off-Tool Prototypes	10

Design Information pack – Form and Detail card



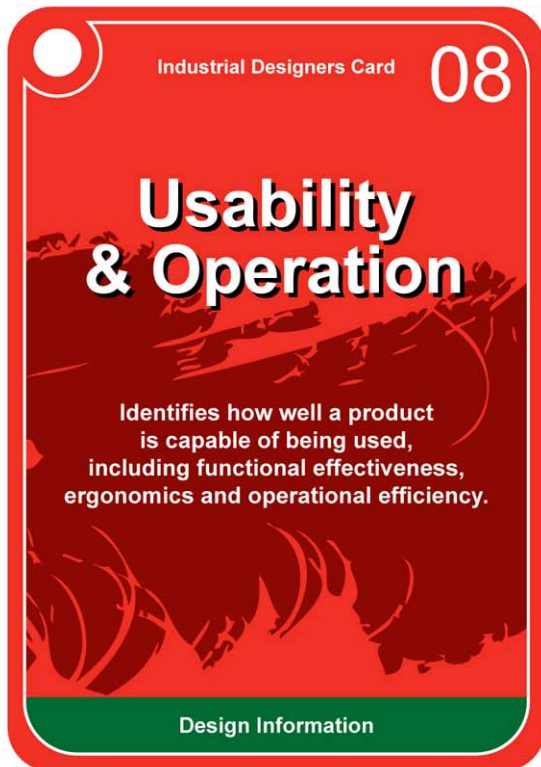
Visual Character		
Source	Application towards Design Representations	Rating
Card 23	Idea Sketches	30
Card 28	Information Sketches	20
Card 32	Concept Drawings	20
Card 29	Renderings	10
Card 25	Referential Sketches	10
Card 49	Appearance Prototypes	10
Card 24	Study Sketches	10
Card 26	Memory Sketches	10
Card 43	Appearance Models	10



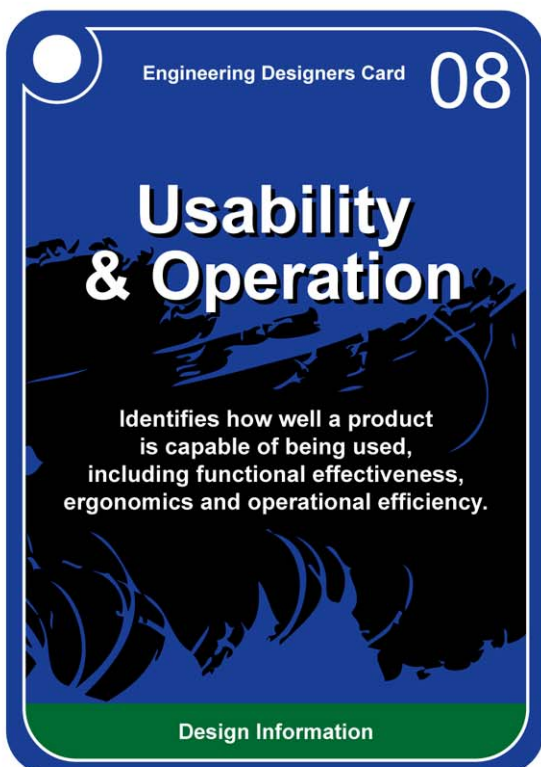
Visual Character		
Source	Application towards Design Representations	Rating
Card 43	Appearance Models	30
Card 49	Appearance Prototypes	30
Card 23	Idea Sketches	20
Card 28	Information Sketches	10

Design Information pack – Visual Character card



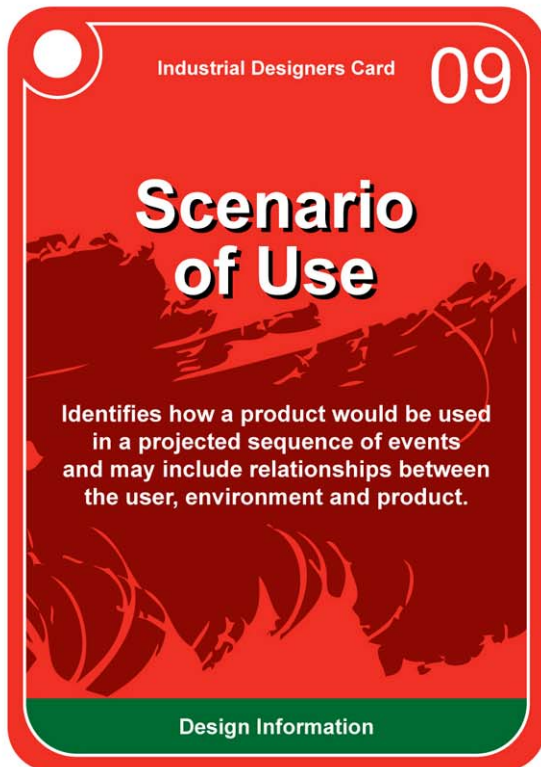


Usability & Operation		
Source	Application towards Design Representations	Rating
Card 28	Information Sketches	60
Card 34	Scenarios & Storyboards	60
Card 44	Functional Concept Models	40
Card 41	3D Sketch Models	30
Card 23	Idea Sketches	20
Card 27	Coded Sketches	20
Card 35	Diagrams	20
Card 42	Design Development Models	20
Card 45	Concept of Operation Models	20

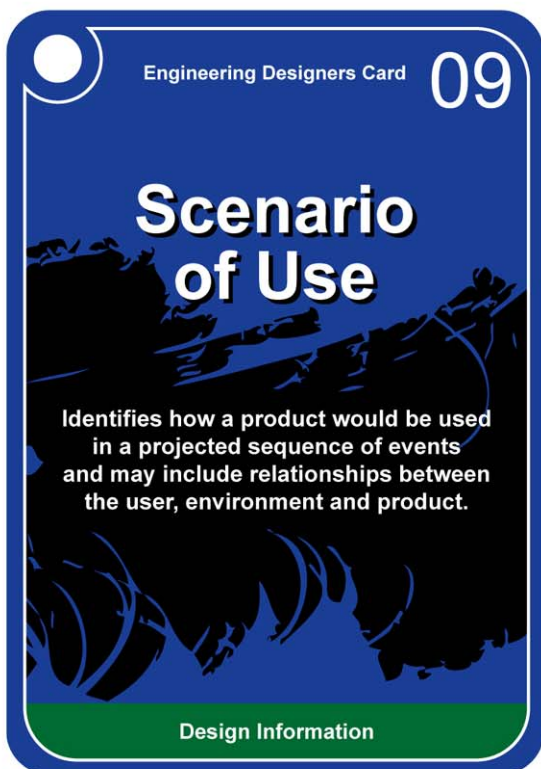


Usability & Operation		
Source	Application towards Design Representations	Rating
Card 44	Functional Concept Models	80
Card 23	Idea Sketches	30
Card 45	Concept of Operation Models	30
Card 34	Scenarios & Storyboards	20
Card 41	3D Sketch Models	20
Card 53	Experimental Prototypes	20
Card 24	Study Sketches	10
Card 28	Information Sketches	10
Card 32	Concept Drawings	10
Card 35	Diagrams	10
Card 42	Design Development Models	10

Design Information pack – Usability and Operation card

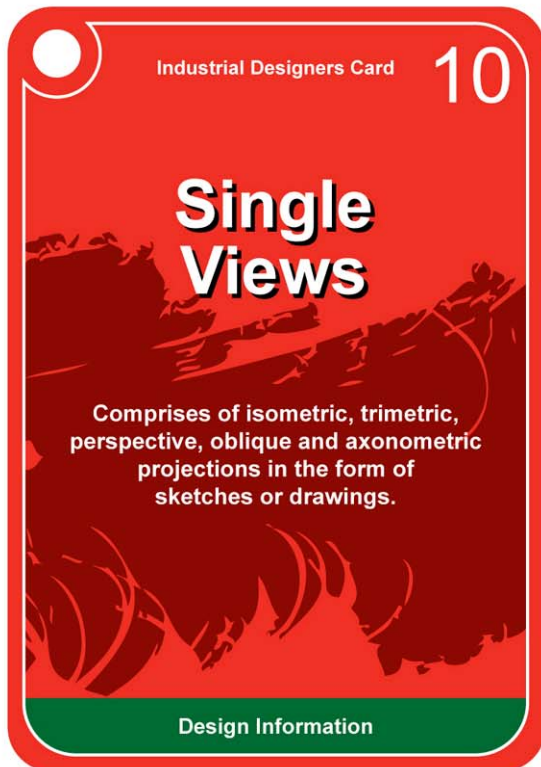


Scenario of Use		
Source	Application towards Design Representations	Rating
Card 34	Scenarios & Storyboards	30
Card 44	Functional Concept Models	20
Card 45	Concept of Operation Models	20
Card 23	Idea Sketches	10
Card 24	Study Sketches	10
Card 28	Information Sketches	10
Card 32	Concept Drawings	10

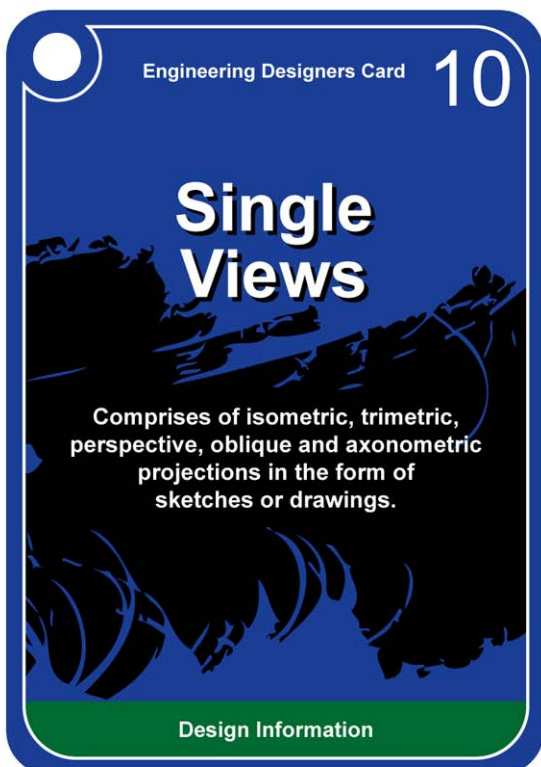


Scenario of Use		
Source	Application towards Design Representations	Rating
Card 34	Scenarios & Storyboards	80
Card 28	Information Sketches	20
Card 23	Idea Sketches	10
Card 25	Referential Sketches	10
Card 26	Memory Sketches	10
Card 41	3D Sketch Models	10
Card 44	Functional Concept Models	10

Design Information pack – Scenario of Use card



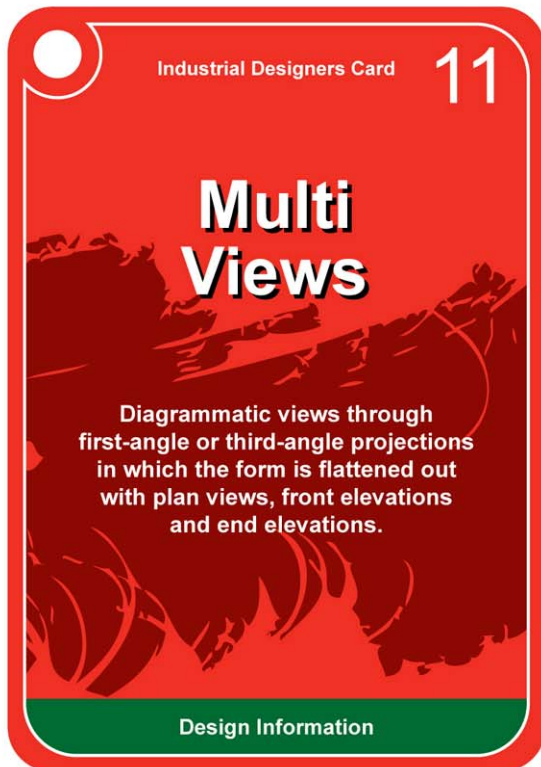
Single Views		
Source	Application towards Design Representations	Rating
Card 36	Single View Drawings	40
Card 28	Information Sketches	30
Card 33	Presentation Drawings	30
Card 23	Idea Sketches	20
Card 24	Study Sketches	10
Card 30	Inspiration Sketches	10
Card 29	Renderings	10
Card 31	Prescriptive Sketches	10
Card 40	Technical Illustrations	10



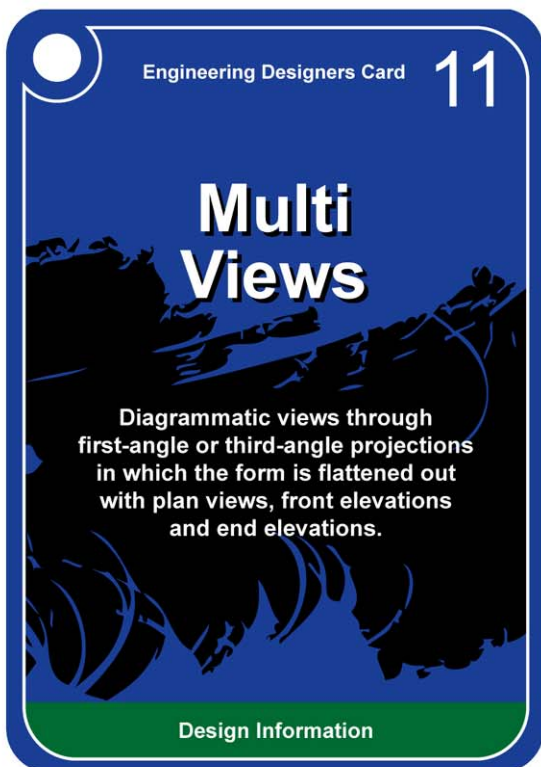
Single Views		
Source	Application towards Design Representations	Rating
	Single Views are not commonly	
	used by engineering designers	

Design Information pack – Single Views card



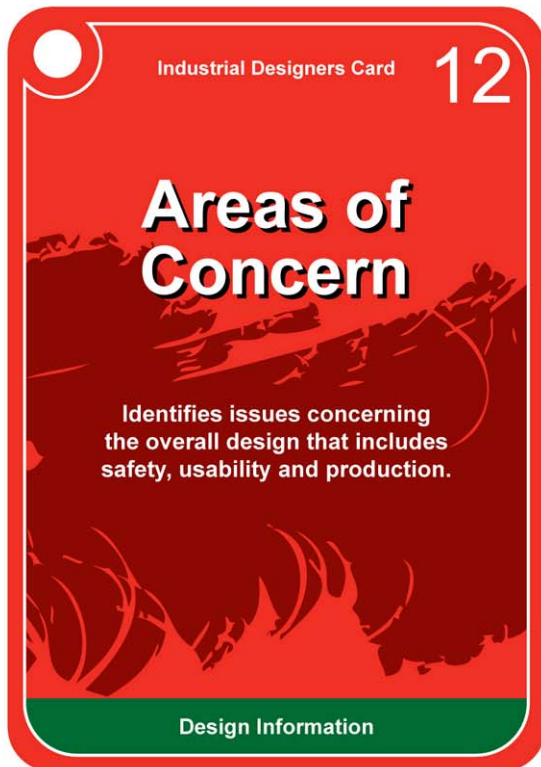


Multi Views		
Source	Application towards Design Representations	Rating
Card 37	Multi View Drawings	70
Card 32	Concept Drawings	60
Card 31	Prescriptive Sketches	30
Card 33	Presentation Drawings	30
Card 24	Study Sketches	10
Card 39	Technical Drawings	10

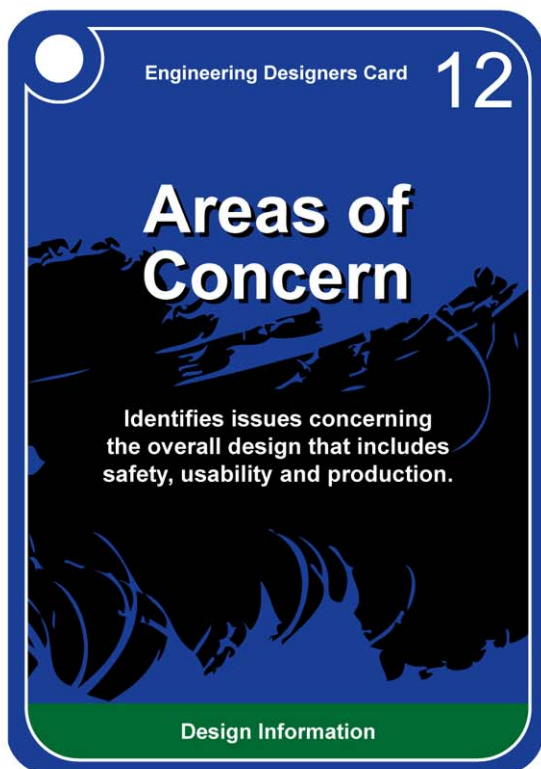


Multi Views		
Source	Application towards Design Representations	Rating
Card 37	Multi View Drawings	40
Card 24	Study Sketches	10
Card 31	Prescriptive Sketches	10
Card 32	Concept Drawings	10
Card 38	General Arrangement Drawings	10
Card 39	Technical Drawings	10

Design Information pack – Multi Views card

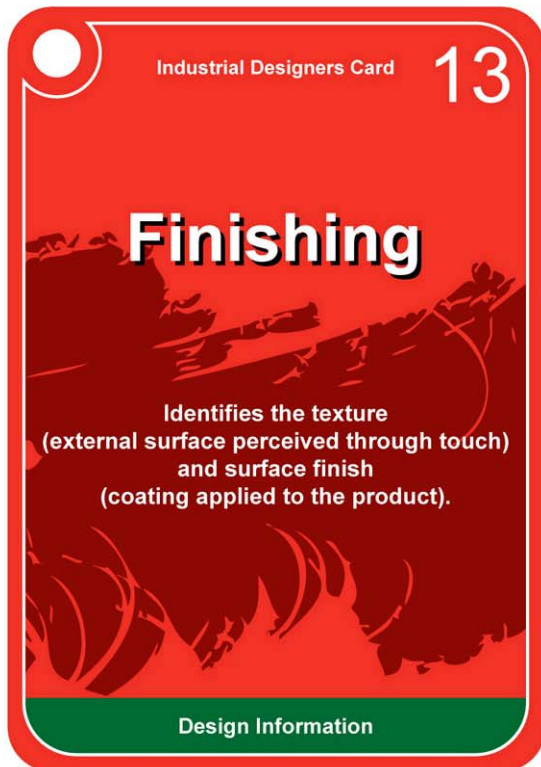


Areas of Concern		
Source	Application towards Design Representations	Rating
Card 24	Study Sketches	90
Card 41	3D Sketch Models	30
Card 55	Final Hardware Prototypes	20
Card 23	Idea Sketches	10
Card 35	Diagrams	10
Card 42	Design Development Models	10
Card 44	Functional Concept Models	10
Card 50	Alpha Prototypes	10
Card 53	Experimental Prototypes	10
Card 54	System Prototypes	10
Card 56	Tooling Prototypes	10

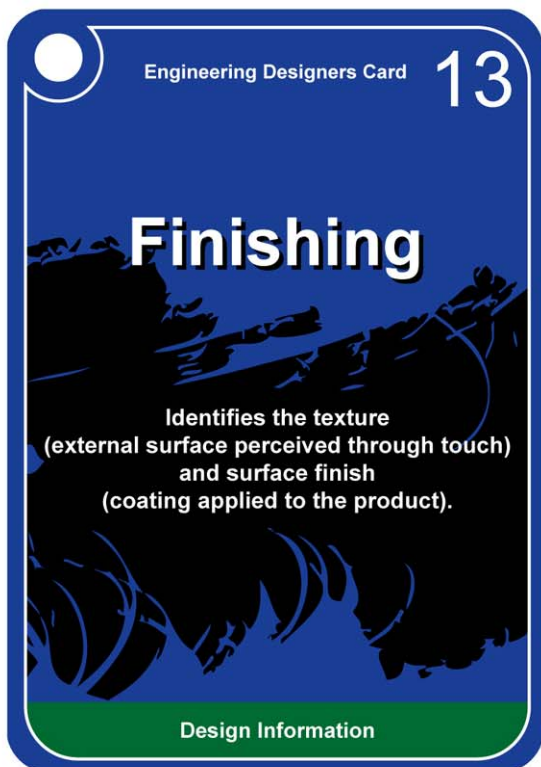


Areas of Concern		
Source	Application towards Design Representations	Rating
Card 24	Study Sketches	60
Card 28	Information Sketches	30
Card 42	Design Development Models	30
Card 41	3D Sketch Models	30
Card 26	Memory Sketches	20
Card 23	Idea Sketches	10
Card 25	Referential Sketches	10
Card 34	Scenarios & Storyboards	10

Design Information pack – Areas of Concern card



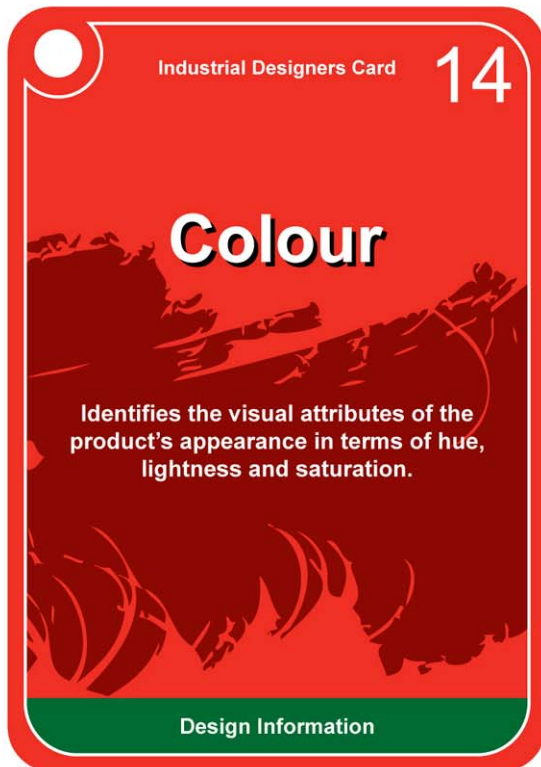
Finishing		
Source	Application towards Design Representations	Rating
Card 32	Concept Drawings	90
Card 28	Information Sketches	70
Card 29	Renderings	60
Card 49	Appearance Prototypes	60
Card 43	Appearance Models	50
Card 30	Inspiration Sketches	20









Finishing		
Source	Application towards Design Representations	Rating
Card 49	Appearance Prototypes	40
Card 28	Information Sketches	30
Card 43	Appearance Models	30
Card 32	Concept Drawings	20
Card 50	Alpha Prototypes	20
Card 52	Pre-Production Prototypes	20
Card 57	Off-Tool Prototypes	20
Card 40	Technical Illustrations	10
Card 51	Beta Prototypes	10
Card 55	Final Hardware Prototypes	10
Card 56	Tooling Prototypes	10












Design Information pack – Finishing card



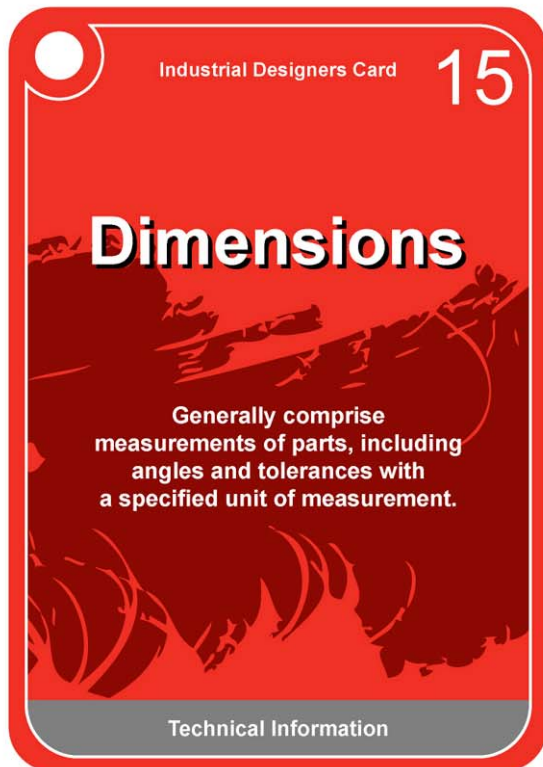


Colour		
Source	Application towards Design Representations	Rating
Card 32	 Concept Drawings	70
Card 28	 Information Sketches	60
Card 49	 Appearance Prototypes	50
Card 29	 Renderings	40
Card 43	 Appearance Models	40
Card 30	 Inspiration Sketches	20

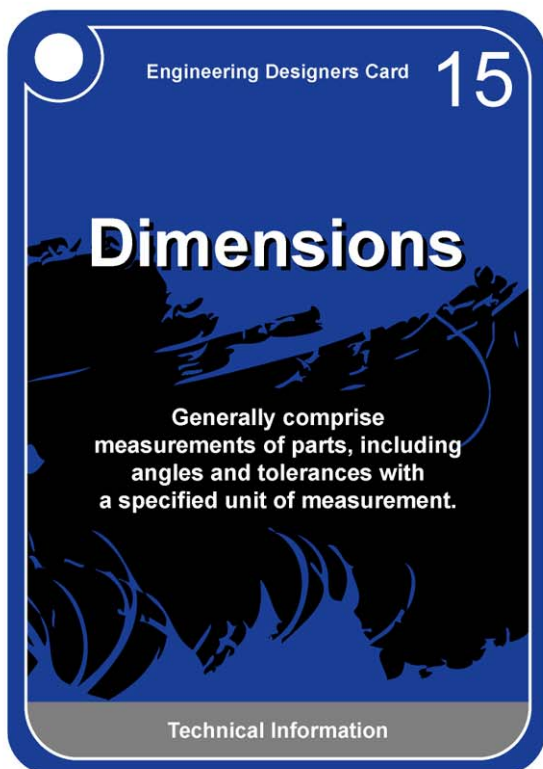


Colour		
Source	Application towards Design Representations	Rating
Card 49	 Appearance Prototypes	40
Card 28	 Information Sketches	30
Card 43	 Appearance Models	30
Card 32	 Concept Drawings	20
Card 50	 Alpha Prototypes	20
Card 52	 Pre-Production Prototypes	20
Card 57	 Off-Tool Prototypes	20
Card 40	 Technical Illustrations	10
Card 51	 Beta Prototypes	10
Card 55	 Final Hardware Prototypes	10
Card 56	 Tooling Prototypes	10

Design Information pack – Colour card



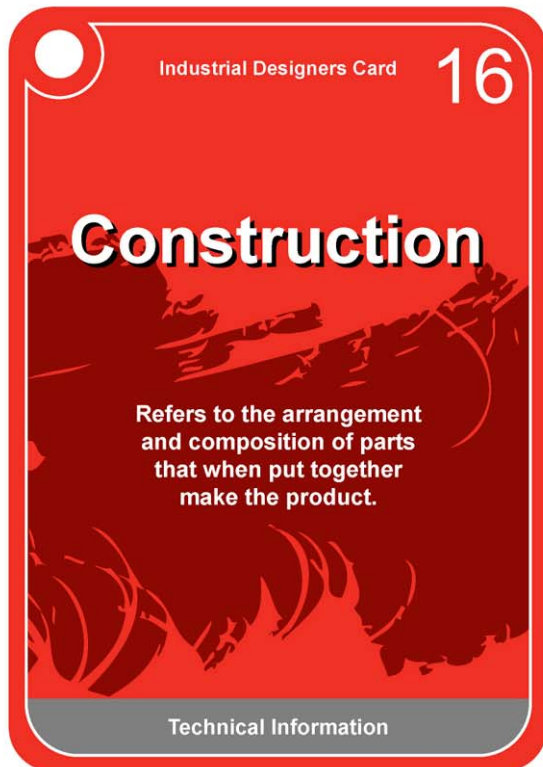
Dimensions		
Source	Application towards Design Representations	Rating
Card 31	Prescriptive Sketches	70
Card 32	Concept Drawings	70
Card 37	Multi View Drawings	40
Card 49	Appearance Prototypes	40
Card 38	General Arrangement Drawings	30
Card 39	Technical Drawings	30
Card 43	Appearance Models	30
Card 28	Information Sketches	20
Card 33	Presentation Drawings	20
Card 41	3D Sketch Models	20







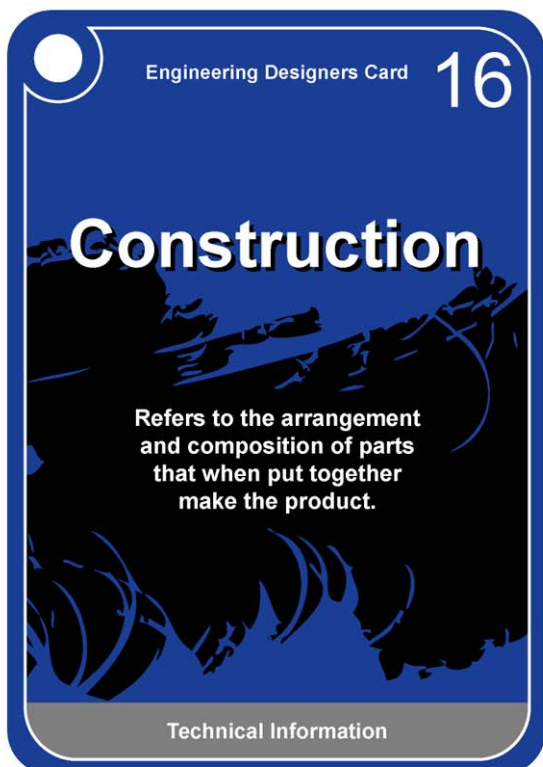
Dimensions		
Source	Application towards Design Representations	Rating
Card 37	Multi View Drawings	90
Card 31	Prescriptive Sketches	80
Card 39	Technical Drawings	70
Card 24	Study Sketches	40
Card 38	General Arrangement Drawings	30
Card 49	Appearance Prototypes	30
Card 55	Final Hardware Prototypes	30










Technical Information pack – Dimensions card



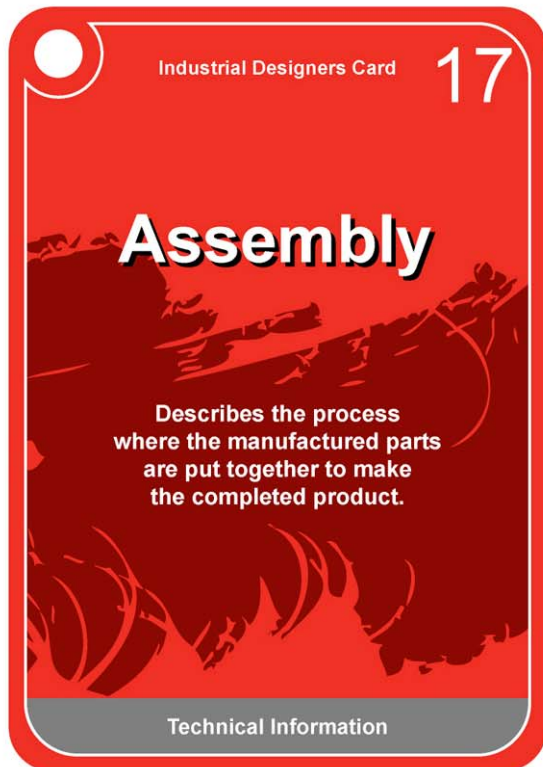


Construction		
Source	Application towards Design Representations	Rating
Card 31	 Prescriptive Sketches	30
Card 33	 Presentation Drawings	30
Card 38	 General Arrangement Drawings	30
Card 49	 Appearance Prototypes	30
Card 39	 Technical Drawings	20
Card 37	 Multi View Drawings	20

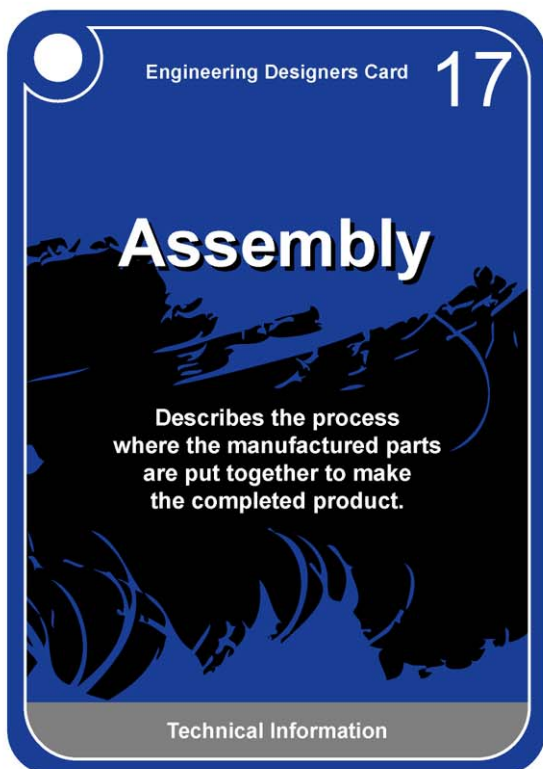


Construction		
Source	Application towards Design Representations	Rating
Card 24	 Study Sketches	70
Card 39	 Technical Drawings	70
Card 37	 Multi View Drawings	60
Card 31	 Prescriptive Sketches	30
Card 38	 General Arrangement Drawings	30
Card 49	 Appearance Prototypes	30
Card 23	 Idea Sketches	20
Card 46	 Production Concept Models	20
Card 53	 Experimental Prototypes	20
Card 55	 Final Hardware Prototypes	20

Technical Information pack – Construction card

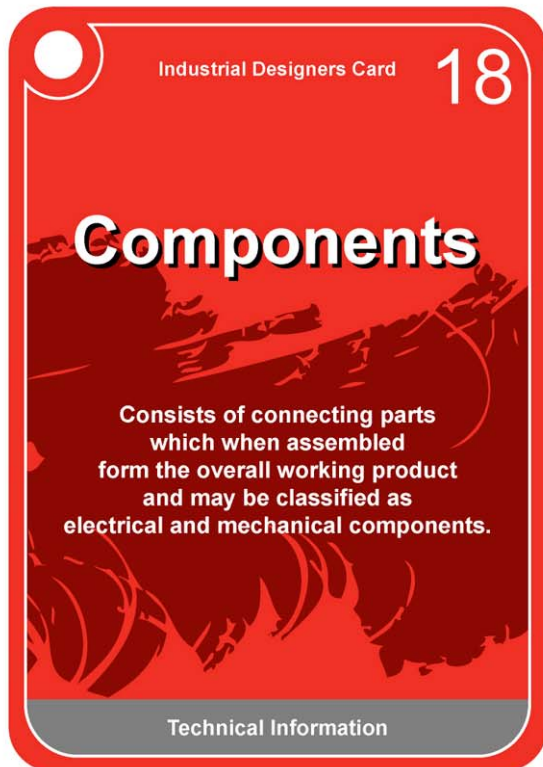


Assembly		
Source	Application towards Design Representations	Rating
Card 33	Presentation Drawings	30
Card 28	Information Sketches	20
Card 31	Prescriptive Sketches	20
Card 38	General Arrangement Drawings	20
Card 39	Technical Drawings	20
Card 40	Technical Illustrations	20
Card 37	Multi View Drawings	20
Card 44	Functional Concept Models	20
Card 49	Appearance Prototypes	20

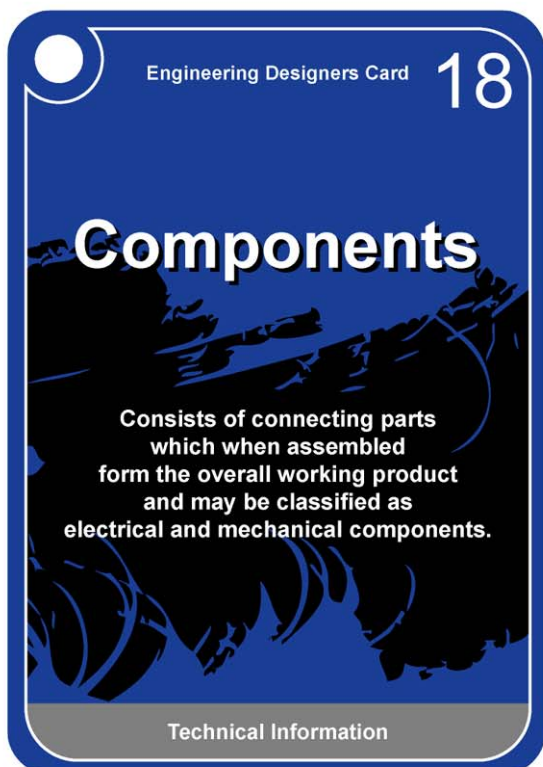


Assembly		
Source	Application towards Design Representations	Rating
Card 24	Study Sketches	70
Card 37	Multi View Drawings	60
Card 31	Prescriptive Sketches	40
Card 39	Technical Drawings	40
Card 38	General Arrangement Drawings	30
Card 49	Appearance Prototypes	30
Card 23	Idea Sketches	20
Card 43	Appearance Models	20
Card 44	Functional Concept Models	20
Card 46	Production Concept Models	20
Card 53	Experimental Prototypes	20
Card 55	Final Hardware Prototypes	20

Technical Information pack – Assembly card



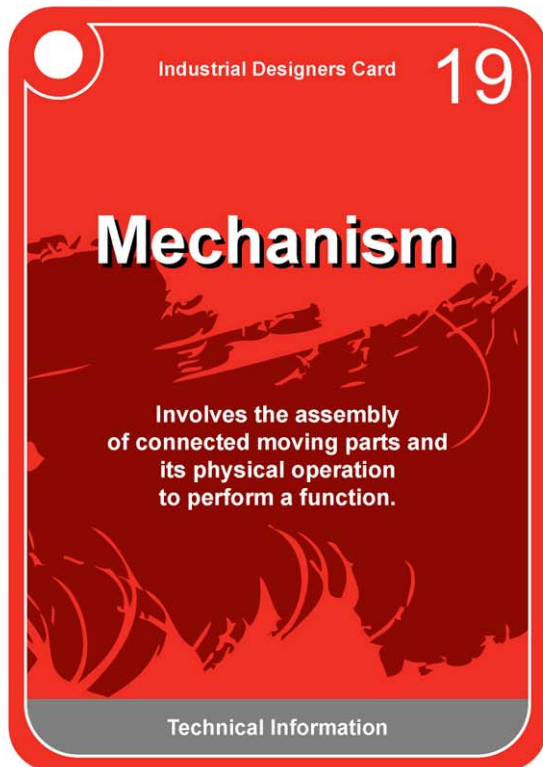
Components		
Source	Application towards Design Representations	Rating
Card 31	Prescriptive Sketches	50
Card 32	Concept Drawings	50
Card 24	Study Sketches	40
Card 28	Information Sketches	40
Card 44	Functional Concept Models	40
Card 49	Appearance Prototypes	40
Card 27	Coded Sketches	30
Card 33	Presentation Drawings	30
Card 39	Technical Drawings	30
Card 43	Appearance Models	30
Card 42	Design Development Models	30



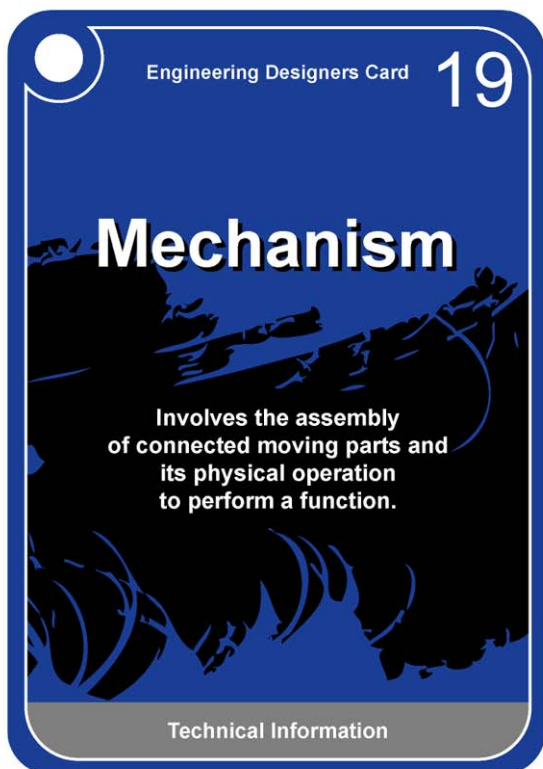
Components		
Source	Application towards Design Representations	Rating
Card 44	Functional Concept Models	80
Card 24	Study Sketches	70
Card 31	Prescriptive Sketches	70
Card 37	Multi View Drawings	70
Card 39	Technical Drawings	60
Card 23	Idea Sketches	40
Card 49	Appearance Prototypes	40
Card 53	Experimental Prototypes	40
Card 28	Information Sketches	30
Card 38	General Arrangement Drawings	30
Card 54	System Prototypes	30
Card 55	Final Hardware Prototypes	30

Technical Information pack – Components card



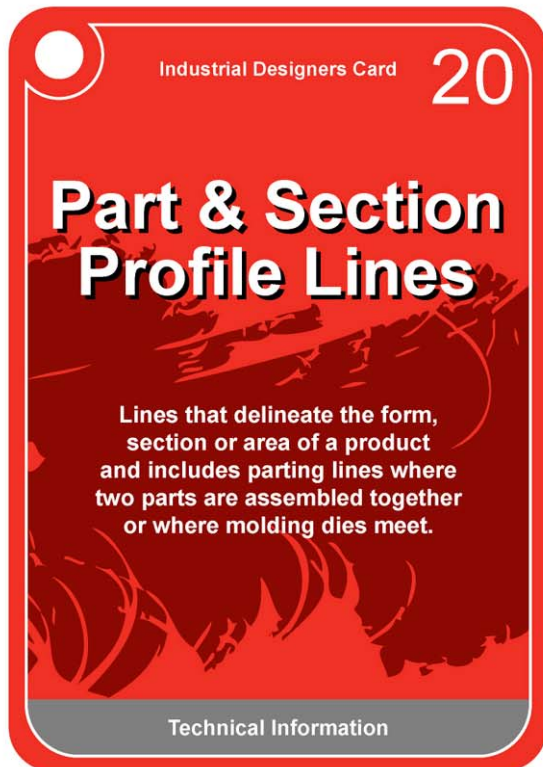


Mechanism		
Source	Application towards Design Representations	Rating
Card 28	Information Sketches	40
Card 49	Appearance Prototypes	40
Card 24	Study Sketches	30
Card 31	Prescriptive Sketches	20
Card 42	Design Development Models	20

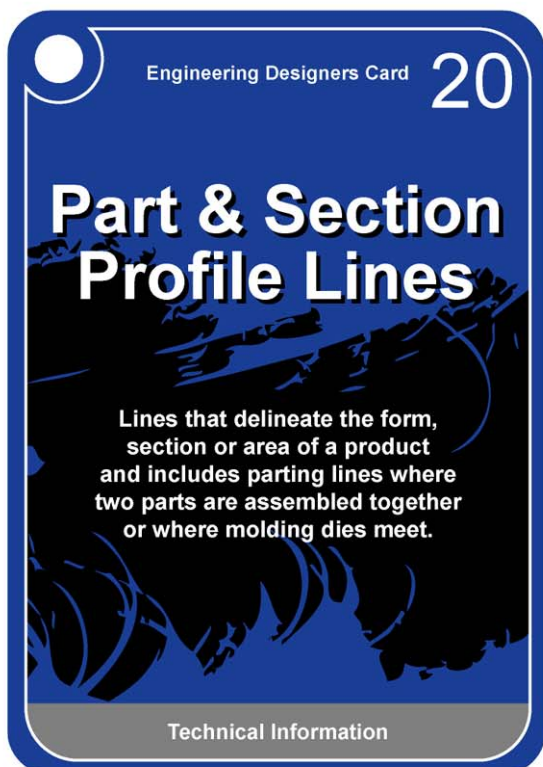


Mechanism		
Source	Application towards Design Representations	Rating
Card 44	Functional Concept Models	80
Card 24	Study Sketches	70
Card 23	Idea Sketches	40
Card 31	Prescriptive Sketches	40
Card 39	Technical Drawings	40
Card 53	Experimental Prototypes	40
Card 28	Information Sketches	30
Card 49	Appearance Prototypes	30
Card 54	System Prototypes	30
Card 55	Final Hardware Prototypes	30

Technical Information pack – Mechanism card

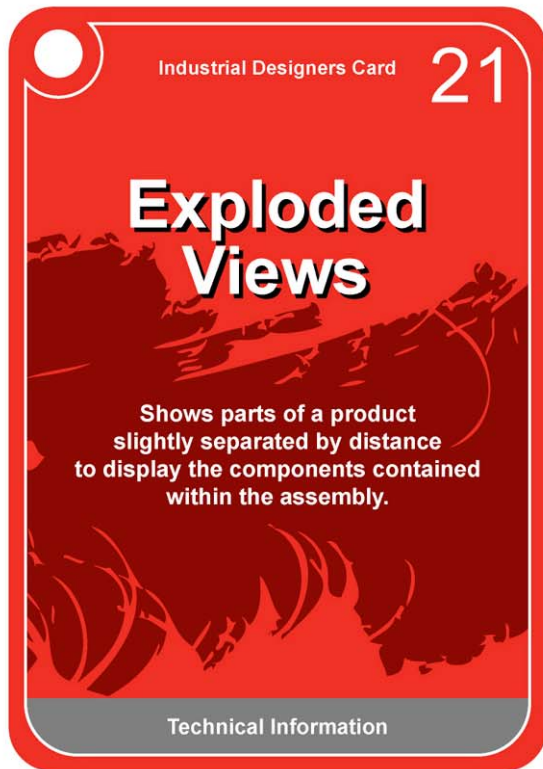







Part & Section Profile Lines		
Source	Application towards Design Representations	Rating
Card 49	Appearance Prototypes	10
Card 38	General Arrangement Drawings	10
Card 39	Technical Drawings	10
Card 43	Appearance Models	10
Card 42	Design Development Models	10
Card 41	3D Sketch Models	10

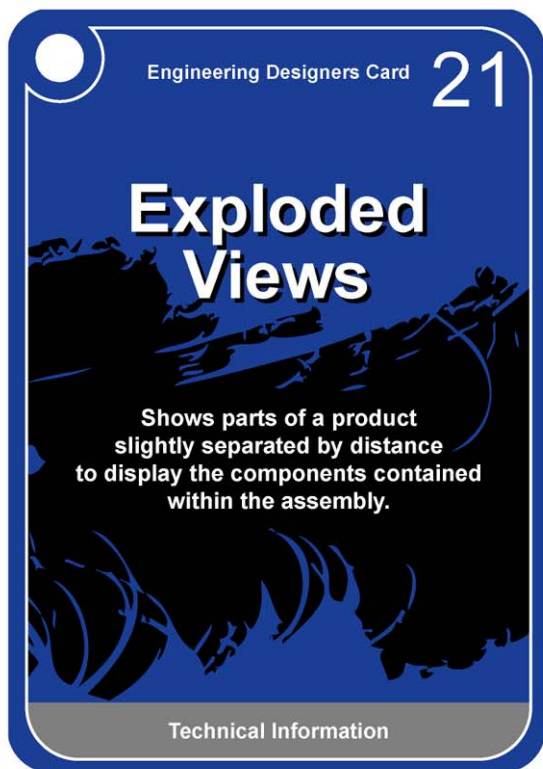




Part & Section Profile Lines		
Source	Application towards Design Representations	Rating
Card 39	Technical Drawings	10
Card 49	Appearance Prototypes	10

Technical Information pack – Part and Section Profile Lines card



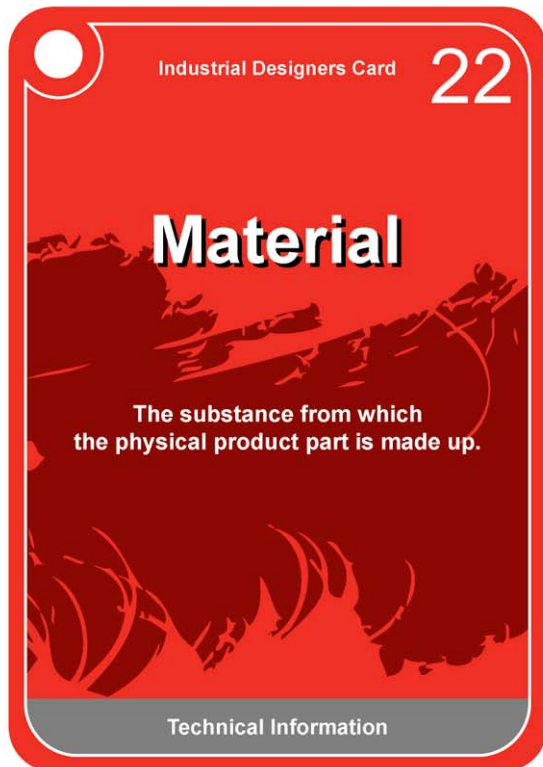
Exploded Views		
Source	Application towards Design Representations	Rating
Card 33	 Presentation Drawings	40
Card 31	 Prescriptive Sketches	10
Card 24	 Study Sketches	10
Card 28	 Information Sketches	10
Card 38	 General Arrangement Drawings	10



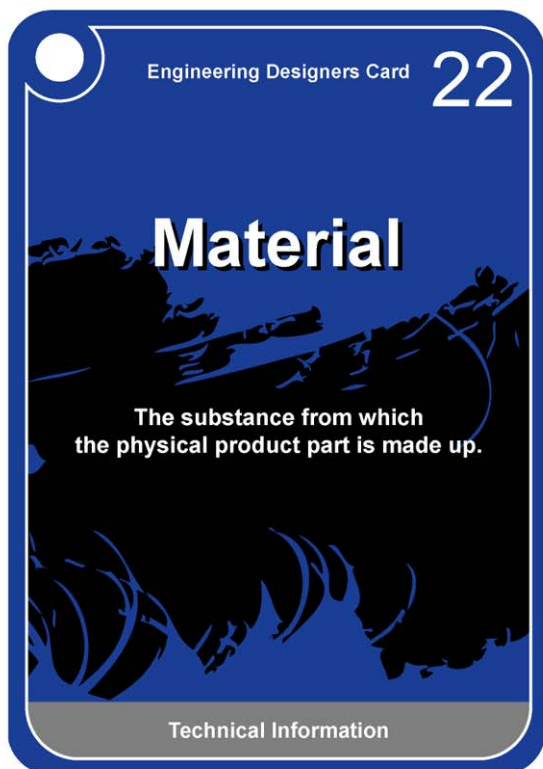
Exploded Views		
Source	Application towards Design Representations	Rating
Card 39	 Technical Drawings	10
Card 40	 Technical Illustrations	10

Technical Information pack – Exploded Views card





Material		
Source	Application towards Design Representations	Rating
Card 28	Information Sketches	80
Card 32	Concept Drawings	70
Card 29	Renderings	60
Card 49	Appearance Prototypes	50
Card 43	Appearance Models	40
Card 30	Inspiration Sketches	20



Material		
Source	Application towards Design Representations	Rating
Card 49	Appearance Prototypes	40
Card 28	Information Sketches	30
Card 39	Technical Drawings	30
Card 43	Appearance Models	30
Card 32	Concept Drawings	20
Card 50	Alpha Prototypes	20
Card 52	Pre-Production Prototypes	20
Card 57	Off-Tool Prototypes	20

Technical Information pack – Material card

Industrial Designers Card

23

Idea Sketch

Shows what design ideas look like as physical objects and are used at a personal level to externalise thoughts quickly. Also known as thumbnail, thinking or napkin sketches.

Personal Sketches

Idea Sketch

Relevance to Design & Technical Information

Source		Rating
Card 05	Design Intent	90
Card 07	Visual Character	80
Card 06	Form & Detail	70
Card 10	Single Views	20
Card 08	Usability & Operation	20

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	90
Card 02	Design Development	30
Card 03	Embodiment Design	20
Card 04	Detail Design	20

Engineering Designers Card

23

Idea Sketch

Shows what design ideas look like as physical objects and are used at a personal level to externalise thoughts quickly. Also known as thumbnail, thinking or napkin sketches.

Personal Sketches

Idea Sketch

Relevance to Design & Technical Information

Source		Rating
Card 18	Components	40
Card 19	Mechanism	40
Card 06	Form & Detail	30
Card 08	Usability & Operation	30
Card 17	Assembly	20
Card 16	Construction	20
Card 05	Design Intent	20
Card 07	Visual Character	20
Card 12	Areas of Concern	10
Card 09	Scenario of Use	10

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	80
Card 02	Design Development	10
Card 03	Embodiment Design	0
Card 04	Detail Design	0

Design Representations pack – Idea Sketch card



Industrial Designers Card

24

Study Sketch

Used to investigate appearance and the visual impact of ideas such as geometric proportion, configuration, scale, layout and mechanism.

Personal Sketches

Study Sketch

Relevance to Design & Technical Information

Rating

Card 12	Areas of Concern	60
Card 06	Form & Detail	50
Card 18	Components	40
Card 05	Design Intent	40
Card 07	Visual Character	40
Card 19	Mechanism	30

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	70
Card 02	Design Development	30
Card 03	Embodiment Design	20
Card 04	Detail Design	20

Engineering Designers Card

24

Study Sketch

Used to investigate appearance and the visual impact of ideas such as geometric proportion, configuration, scale, layout and mechanism.

Personal Sketches

Study Sketch

Relevance to Design & Technical Information

Rating

Card 12	Areas of Concern	90
Card 17	Assembly	70
Card 18	Components	70
Card 16	Construction	70
Card 19	Mechanism	70
Card 15	Dimensions	40
Card 05	Design Intent	20
Card 06	Form & Detail	20

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	90
Card 02	Design Development	0
Card 03	Embodiment Design	0
Card 04	Detail Design	0

Design Representations pack – Study Sketch card

Industrial Designers Card

25

Referential Sketch

Used as a diary  
to record observations  
for future reference or as a metaphor.

Personal Sketches

Referential Sketch

Relevance to Design

Source | & Technical Information | Rating

Card 07

Visual Character

50

Card 05

Design Intent

30

Card 06

Form & Detail

20

Card 12

Areas of Concern

10

Card 18

Components

10

Card 09

Scenario of Use

10

Card 08

Usability & Operation

10

Source

Relevance to Design Stages

Rating

Card 01

Concept Design

70

Card 02

Design Development

10

Card 03

Embodiment Design

0

Card 04

Detail Design

0

Engineering Designers Card

25

Referential Sketch

Used as a diary  
to record observations  
for future reference or as a metaphor.

Personal Sketches

Referential Sketch

Relevance to Design

Source | & Technical Information | Rating

Card 05

Design Intent

10

Card 18

Components

10

Source

Relevance to Design Stages

Rating

Card 01

Concept Design

90

Card 02

Design Development

0

Card 03

Embodiment Design

0

Card 04

Detail Design


0

Design Representations pack – Referential Sketch card

Industrial Designers Card

26

Memory Sketch



Helps users recall thoughts and elements from previous work and usually include notes and text annotations.

Personal Sketches

Memory Sketch

Relevance to Design & Technical Information

Rating


Card 06	Form & Detail	40
Card 07	Visual Character	40
Card 05	Design Intent	30
Card 12	Areas of Concern	20
Card 17	Assembly	10
Card 18	Components	10
Card 22	Material	10
Card 19	Mechanism	10
Card 09	Scenario of Use	10
Card 13	Texture & Surface Finish	10
Card 08	Usability & Operation	10

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	70
Card 02	Design Development	20
Card 03	Embodiment Design	10
Card 04	Detail Design	10

Engineering Designers Card

26

Memory Sketch



Helps users recall thoughts and elements from previous work and usually include notes and text annotations.

Personal Sketches

Memory Sketch

Relevance to Design & Technical Information

Rating

	Memory Sketches are not	
	commonly used by	
	engineering designers	

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	0
Card 04	Detail Design	0

Design Representations pack – Memory Sketch card



Industrial Designers Card

27

Coded Sketch

SYMBOLS

WHEEL

MOTOR

OPERATOR

Informal representations that categorise information, usually to show an underlying principle or a scheme.

Shared Sketches

Coded Sketch

Relevance to Design & Technical Information

Source		Rating
Card 18	Components	30
Card 08	Usability & Operation	20
Card 12	Areas of Concern	10
Card 05	Design Intent	10
Card 19	Mechanism	10

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	30
Card 02	Design Development	30
Card 03	Embodiment Design	10
Card 04	Detail Design	0

Engineering Designers Card

27

Coded Sketch

SYMBOLS

WHEEL

MOTOR

OPERATOR

Informal representations that categorise information, usually to show an underlying principle or a scheme.

Shared Sketches

Coded Sketch

Relevance to Design & Technical Information

Source		Rating
Card 17	Assembly	10
Card 18	Components	10
Card 16	Construction	10
Card 19	Mechanism	10

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	10
Card 02	Design Development	0
Card 03	Embodiment Design	0
Card 04	Detail Design	0

Design Representations pack – Coded Sketch card

623

Industrial Designers Card

28

Information Sketch

Allows stakeholders to understand the designer's intentions by explaining information clearly and to provide a common graphical setting. Also known as explanatory or talking sketches.

Shared Sketches

Information Sketch

Relevance to Design

Source | & Technical Information | Rating

Card 06	Form & Detail	90
Card 22	Material	80
Card 13	Texture & Surface Finish	70
Card 07	Visual Character	70
Card 05	Design Intent	60
Card 08	Usability & Operation	60
Card 14	Colour	60

Source | Relevance to Design Stages | Rating

Card 01	Concept Design	60
Card 02	Design Development	70
Card 03	Embodiment Design	10
Card 04	Detail Design	10

Engineering Designers Card

28

Information Sketch

Allows stakeholders to understand the designer's intentions by explaining information clearly and to provide a common graphical setting. Also known as explanatory or talking sketches.

Shared Sketches

Information Sketch

Relevance to Design

Source | & Technical Information | Rating

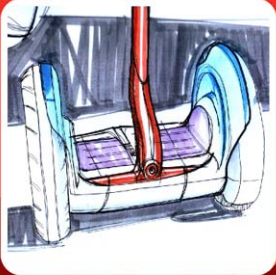
Card 18	Components	30
Card 14	Colour	30
Card 22	Material	30
Card 19	Mechanism	30
Card 13	Texture & Surface Finish	30
Card 17	Assembly	10
Card 16	Construction	10
Card 05	Design Intent	10
Card 15	Dimensions	10
Card 06	Form & Detail	10
Card 09	Scenario of Use	10
Card 08	Usability & Operation	10

Source | Relevance to Design Stages | Rating

Card 01	Concept Design	10
Card 02	Design Development	10
Card 03	Embodiment Design	10
Card 04	Detail Design	0

Industrial Designers Card
29

# Renderings



Formal proposals of design concepts that involve application of colour, tone and detail for realism. Also known as sketch renderings or first concepts.

Persuasive Sketches

## Renderings

Relevance to Design & Technical Information

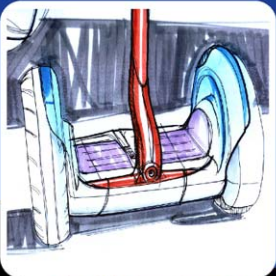
Source		Rating
Card 22	Material	60
Card 13	Texture & Surface Finish	60
Card 07	Visual Character	60
Card 14	Colour	40
Card 06	Form & Detail	30
Card 05	Design Intent	20

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	10
Card 02	Design Development	40
Card 03	Embodiment Design	10
Card 04	Detail Design	10

Engineering Designers Card
29

# Renderings



Formal proposals of design concepts that involve application of colour, tone and detail for realism. Also known as sketch renderings or first concepts.

Persuasive Sketches

## Renderings

Relevance to Design & Technical Information

Source		Rating
	Renderings are not	
	commonly used by	
	engineering designers	


  

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	0
Card 04	Detail Design	0



Industrial Designers Card 30

# Inspiration Sketch



Form-orientated sketches used to communicate the look or feel of a product by setting the tone of a design, brand or product range. Also known as emotional or inspiration sketches.

Persuasive Sketches

Inspiration Sketch		
Relevance to Design		
Source	& Technical Information	Rating
Card 14	Colour	20
Card 22	Material	20
Card 13	Texture & Surface Finish	20
Card 07	Visual Character	20
Card 05	Design Intent	10
Card 06	Form & Detail	10
Card 10	Single Views	10
Source	Relevance to Design Stages	Rating
Card 01	Concept Design	10
Card 02	Design Development	10
Card 03	Embodiment Design	10
Card 04	Detail Design	0

The image shows a blue presentation card with a white circular punch-hole at the top left. In the top right corner, the text 'Engineering Designers Card' is followed by a large '30'. The main title 'Inspiration Sketch' is written in large, bold, white letters with a black drop shadow. Below the title is a central rectangular image of a green and white Shinkansen train. Underneath the image, a paragraph of text explains the purpose of form-orientated sketches. At the bottom of the card, a purple band contains the text 'Persuasive Sketches'.

Engineering Designers Card 30

# Inspiration Sketch



Form-orientated sketches used to communicate the look or feel of a product by setting the tone of a design, brand or product range. Also known as emotional or inspiration sketches.

Persuasive Sketches

<b>Inspiration Sketch</b>	<b>Relevance to Design &amp; Technical Information</b>	<b>Rating</b>
<b>Source   Inspiration Sketches are not</b>		
<b>commonly used by</b>		
<b>engineering designers</b>		

<b>Source</b>	<b>Relevance to Design Stages</b>	<b>Rating</b>
<b>Card 01 Concept Design</b>		<b>0</b>
<b>Card 02 Design Development</b>		<b>0</b>
<b>Card 03 Embodiment Design</b>		<b>0</b>
<b>Card 04 Detail Design</b>		<b>0</b>


## Design Representations pack – Inspiration Sketch card





Industrial Designers Card **32**

# Concept Drawing



Shows the finished product using precise line drawings. Also known as layout drawings.

Industrial Design Drawings

## Concept Drawing

Relevance to Design & Technical Information | Rating


Card 13	Texture & Surface Finish	90
Card 06	Form & Detail	80
Card 14	Colour	70
Card 15	Dimensions	70
Card 22	Material	70
Card 07	Visual Character	70
Card 11	Multi Views	60

Source | Relevance to Design Stages | Rating

Card 01	Concept Design	40
Card 02	Design Development	80
Card 03	Embodiment Design	30
Card 04	Detail Design	20

Engineering Designers Card **32**

# Concept Drawing



Shows the finished product using precise line drawings. Also known as layout drawings.

Industrial Design Drawings

## Concept Drawing

Relevance to Design & Technical Information | Rating

Card 14	Colour	20
Card 18	Components	20
Card 15	Dimensions	20
Card 22	Material	20
Card 13	Texture & Surface Finish	20
Card 16	Construction	10
Card 09	Scenario of Use	10
Card 11	Multi Views	10
Card 08	Usability & Operation	10

Source | Relevance to Design Stages | Rating


Card 01	Concept Design	10
Card 02	Design Development	10
Card 03	Embodiment Design	0
Card 04	Detail Design	0

Design Representations pack – Concept Drawing card

Industrial Designers Card

33

Presentation Drawing



Final drawings for clients and other stakeholders. They can be used for reference and may include exploded views with technical details.

Industrial Design Drawings

Presentation Drawing

Relevance to Design

Source | & Technical Information | Rating

Card 21	Exploded Views	40
Card 17	Assembly	30
Card 18	Components	30
Card 16	Construction	30
Card 06	Form & Detail	30
Card 11	Multi Views	30
Card 10	Single Views	30
Card 15	Dimensions	20
Card 07	Visual Character	20


Source | Relevance to Design Stages | Rating

Card 01	Concept Design	20
Card 02	Design Development	60
Card 03	Embodiment Design	20
Card 04	Detail Design	20

Engineering Designers Card

33

Presentation Drawing



Final drawings for clients and other stakeholders. They can be used for reference and may include exploded views with technical details.

Industrial Design Drawings

Presentation Drawing

Relevance to Design

Source | & Technical Information | Rating

	Presentation Drawings are	
	not commonly used by	
	engineering designers	


Source | Relevance to Design Stages | Rating

Card 01	Concept Design	0
Card 02	Design Development	10
Card 03	Embodiment Design	10
Card 04	Detail Design	0

Design Representations pack – Presentation Drawing card

Industrial Designers Card **34**

# Scenario & Storyboard



Used to suggest user and product interaction, and to portray use in the context of artefacts, people and relationships

Industrial Design Drawings

## Scenario & Storyboard

Relevance to Design Source | & Technical Information | Rating


Card 05	Design Intent	80
Card 07	Visual Character	60
Card 06	Form & Detail	10
Card 10	Single Views	10

Source | Relevance to Design Stages | Rating

Card 01	Concept Design	60
Card 02	Design Development	50
Card 03	Embodiment Design	0
Card 04	Detail Design	0

Engineering Designers Card **34**

# Scenario & Storyboard



Used to suggest user and product interaction, and to portray use in the context of artefacts, people and relationships

Industrial Design Drawings

## Scenario & Storyboard

Relevance to Design Source | & Technical Information | Rating

Card 09	Scenario of Use	20
Card 08	Usability & Operation	20

Source | Relevance to Design Stages | Rating

Card 01	Concept Design	10
Card 02	Design Development	10
Card 03	Embodiment Design	0
Card 04	Detail Design	0

Design Representations pack – Scenario and Storyboard card



Industrial Designers Card
35

# Diagram

Abstract representations of the underlying principles of an idea or represents relationships between objects. Also known as schematic or diagrammatic drawings.

Engineering Design Drawings

## Diagram

Relevance to Design & Technical Information
Rating

Card 18	Components	20
Card 08	Usability & Operation	20
Card 12	Areas of Concern	10
Card 19	Mechanism	10

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	10
Card 02	Design Development	20
Card 03	Embodiment Design	10
Card 04	Detail Design	10

Engineering Designers Card
35

# Diagram

Abstract representations of the underlying principles of an idea or represents relationships between objects. Also known as schematic or diagrammatic drawings.

Engineering Design Drawings

## Diagram

Relevance to Design & Technical Information
Rating


Card 12	Areas of Concern	10
Card 05	Design Intent	10
Card 08	Usability & Operation	10

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	20
Card 02	Design Development	0
Card 03	Embodiment Design	0
Card 04	Detail Design	0

Design Representations pack – Diagram card

Industrial Designers Card **36**

# Single View Drawing



Comprises of isometric, trimetric, perspective, oblique and axonometric projection drawings.

Engineering Design Drawings

## Single View Drawing


Relevance to Design

Source	& Technical Information	Rating
Card 06	Single Views	40
Card 12	Form & Detail	20
Card 08	Design Intent	10

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	20
Card 02	Design Development	30
Card 03	Embodiment Design	20
Card 04	Detail Design	20

Engineering Designers Card **36**

# Single View Drawing



Comprises of isometric, trimetric, perspective, oblique and axonometric projection drawings.

Engineering Design Drawings

## Single View Drawing

Relevance to Design

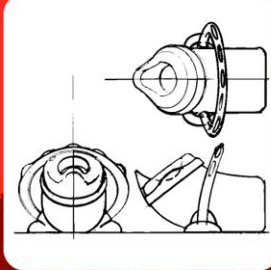
Source	& Technical Information	Rating
	Single View Drawings are	
	not commonly used by	
	engineering designers	

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	10
Card 02	Design Development	0
Card 03	Embodiment Design	0
Card 04	Detail Design	0

Design Representations pack – Single View Drawing card

Industrial Designers Card **37**

# Multi View Drawing



Diagrammatic views through first-angle or third-angle projections in which the form is flattened out with plan views, front elevations and end elevations.

Engineering Design Drawings

## Multi View Drawing

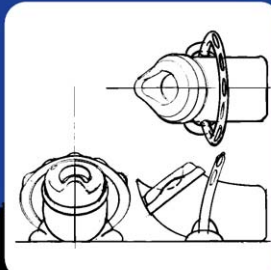
Relevance to Design

Source	& Technical Information	Rating
Card 11	Multi Views	70
Card 15	Dimensions	40
Card 17	Assembly	20
Card 18	Components	20
Card 16	Construction	20
Card 06	Form & Detail	20
Card 12	Areas of Concern	20
Card 05	Design Intent	10
Card 19	Mechanism	10

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	10
Card 02	Design Development	20
Card 03	Embodiment Design	60
Card 04	Detail Design	40

Engineering Designers Card **37**

# Multi View Drawing



Diagrammatic views through first-angle or third-angle projections in which the form is flattened out with plan views, front elevations and end elevations.

Engineering Design Drawings

## Multi View Drawing

Relevance to Design

Source	& Technical Information	Rating
Card 15	Dimensions	90
Card 18	Components	70
Card 17	Assembly	60
Card 16	Construction	60
Card 11	Multi View	40

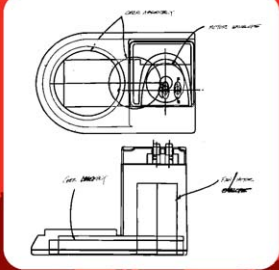
Source	Relevance to Design Stages	Rating
Card 01	Concept Design	40
Card 02	Design Development	80
Card 03	Embodiment Design	20
Card 04	Detail Design	20

Design Representations pack – Multi View Drawing card



Industrial Designers Card **38**

## General Arrangement Drawing



Embodies the refined design but omits internal details. Used in the production of an appearance model with limited details. Also known as model making drawings.

Engineering Design Drawings

## General Arrangement Drawing

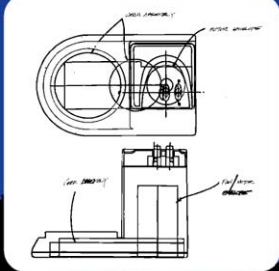
Relevance to Design

Source	& Technical Information	Rating
Card 16	Construction	30
Card 15	Dimensions	30
Card 17	Assembly	20
Card 18	Components	20
Card 21	Exploded Views	10
Card 20	Part & Section Profile Lines	10

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	0
Card 02	Design Development	20
Card 03	Embodiment Design	20
Card 04	Detail Design	30

Engineering Designers Card **38**

## General Arrangement Drawing



Embodies the refined design but omits internal details. Used in the production of an appearance model with limited details. Also known as model making drawings.

Engineering Design Drawings

## General Arrangement Drawing

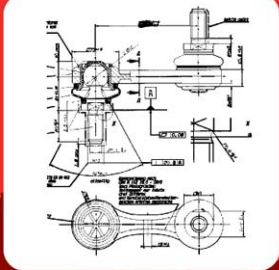
Relevance to Design

Source	& Technical Information	Rating
Card 17	Assembly	30
Card 18	Components	30
Card 16	Construction	30
Card 15	Dimensions	30
Card 19	Mechanism	20
Card 22	Material	10
Card 11	Multi Views	10

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	0
Card 02	Design Development	20
Card 03	Embodiment Design	10
Card 04	Detail Design	0

Industrial Designers Card **39**

# Technical Drawing



Represents the built object and covers every product detail for manufacture. Also known as engineering, production or construction drawings.

Engineering Design Drawings

## Technical Drawing

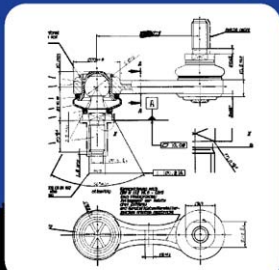
Relevance to Design

Source	& Technical Information	Rating
Card 18	Components	30
Card 15	Dimensions	30
Card 17	Assembly	20
Card 16	Construction	20
Card 22	Material	20
Card 06	Form & Detail	10
Card 19	Mechanism	10
Card 11	Multi Views	10
Card 20	Part & Section Profile Lines	10

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	0
Card 02	Design Development	10
Card 03	Embodiment Design	20
Card 04	Detail Design	20

Engineering Designers Card **39**

# Technical Drawing



Represents the built object and covers every product detail for manufacture. Also known as engineering, production or construction drawings.

Engineering Design Drawings

## Technical Drawing

Relevance to Design

Source	& Technical Information	Rating
Card 16	Construction	70
Card 15	Dimensions	70
Card 18	Components	60
Card 19	Mechanism	40
Card 22	Material	30

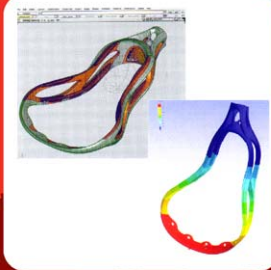
Source	Relevance to Design Stages	Rating
Card 01	Concept Design	10
Card 02	Design Development	0
Card 03	Embodiment Design	60
Card 04	Detail Design	20

Design Representations pack – Technical Drawing card



Industrial Designers Card **40**

# Technical Illustration



Graphical illustrations to explain technical details and use conventions of engineering drawings incorporating signs and symbols within the illustration.

Engineering Design Drawings

## Technical Illustration

Relevance to Design Source | & Technical Information | Rating

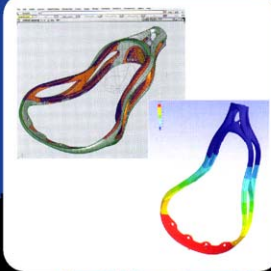
Card 17	Assembly	20
Card 18	Components	20
Card 16	Construction	20
Card 06	Form & Detail	10
Card 19	Mechanism	10
Card 10	Single Views	10

Source | Relevance to Design Stages | Rating

Card 01	Concept Design	0
Card 02	Design Development	10
Card 03	Embodiment Design	20
Card 04	Detail Design	20

Engineering Designers Card **40**

# Technical Illustration



Graphical illustrations to explain technical details and use conventions of engineering drawings incorporating signs and symbols within the illustration.

Engineering Design Drawings

## Technical Illustration

Relevance to Design Source | & Technical Information | Rating

Card 17	Assembly	10
Card 14	Colour	10
Card 18	Components	10
Card 21	Exploded View	10
Card 22	Material	10
Card 13	Texture & Surface Finish	10

Source | Relevance to Design Stages | Rating

Card 01	Concept Design	10
Card 02	Design Development	0
Card 03	Embodiment Design	0
Card 04	Detail Design	0

Design Representations pack – Technical Illustration card

Industrial Designers Card

41

3D Sketch Model

Informal three dimensional block representations that represents the design idea. Also known as foam models, sketch models or 3D sketches.

Industrial Design Models

3D Sketch Model

Relevance to Design & Technical Information

Source		Rating
Card 06	Form & Detail	40
Card 12	Areas of Concern	30
Card 08	Usability & Operation	30
Card 18	Components	20
Card 05	Design Intent	20
Card 15	Dimensions	20
Card 07	Visual Character	20
Card 17	Assembly	10
Card 16	Construction	10
Card 19	Mechanism	10
Card 20	Part & Section Profile Lines	10
Card 09	Scenario of Use	10

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	20
Card 02	Design Development	60
Card 03	Embodiment Design	30
Card 04	Detail Design	10

Engineering Designers Card

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3D Sketch Model

Informal three dimensional block representations that represents the design idea. Also known as foam models, sketch models or 3D sketches.

Industrial Design Models

3D Sketch Model

Relevance to Design & Technical Information

Source		Rating
Card 12	Areas of Concern	30
Card 18	Components	20
Card 08	Usability & Operation	20
Card 17	Assembly	10
Card 16	Construction	10
Card 05	Design Intent	10
Card 06	Form & Detail	10

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	0
Card 02	Design Development	10
Card 03	Embodiment Design	20
Card 04	Detail Design	0

Design Representations pack – 3D Sketch Model card



Industrial Designers Card **42**

## Design Development Model



Used to increase understanding of relationships between components, cavities, interfaces, structure and form.

Industrial Design Models

## Design Development Model

Relevance to Design Source | & Technical Information | Rating


Card 12	Areas of Concern	30
Card 18	Components	30
Card 16	Construction	20
Card 05	Design Intent	20
Card 06	Form & Detail	20
Card 19	Mechanism	20
Card 08	Usability & Operation	20

Source | Relevance to Design Stages | Rating

Card 01	Concept Design	30
Card 02	Design Development	60
Card 03	Embodiment Design	10
Card 04	Detail Design	0

Engineering Designers Card **42**

## Design Development Model



Used to increase understanding of relationships between components, cavities, interfaces, structure and form.

Industrial Design Models

## Design Development Model

Relevance to Design Source | & Technical Information | Rating

Card 12	Areas of Concern	10
Card 17	Assembly	10
Card 18	Components	10
Card 05	Design Intent	10
Card 06	Form & Detail	10
Card 08	Usability & Operation	10

Source | Relevance to Design Stages | Rating


Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	10
Card 04	Detail Design	0

Design Representations pack – Design Development Model card

Industrial Designers Card

43

Appearance Model



Exact visual representations of the design proposal defining the product form and use, but do not contain working mechanisms. Also known as block, iconic or qualitative models.

Industrial Design Models

Appearance Model

Relevance to Design


Source	& Technical Information	Rating
Card 13	Texture & Surface Finish	50
Card 14	Colour	40
Card 06	Form & Detail	40
Card 22	Material	40
Card 07	Visual Character	40
Card 18	Components	30
Card 15	Dimensions	30
Card 05	Design Intent	20

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	0
Card 02	Design Development	20
Card 03	Embodiment Design	60
Card 04	Detail Design	40

Engineering Designers Card

43

Appearance Model



Exact visual representations of the design proposal defining the product form and use, but do not contain working mechanisms. Also known as block, iconic or qualitative models.

Industrial Design Models

Appearance Model

Relevance to Design

Source	& Technical Information	Rating
Card 14	Colour	30
Card 22	Material	30
Card 13	Texture & Surface Finish	30
Card 07	Visual Character	30
Card 17	Assembly	20
Card 18	Components	20
Card 06	Form & Detail	20
Card 05	Design Intent	10
Card 15	Dimensions	10
Card 19	Mechanism	10

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	30
Card 04	Detail Design	10

Design Representations pack – Appearance Model card



Industrial Designers Card

44

Functional Concept Model

Shows functionality and highlights important functional parameters including yield and performance factors.

Engineering Design Models

Functional Concept Model

Relevance to Design

Source | & Technical Information | Rating

Card 18

Components

40

Card 08

Usability & Operation

40

Card 17

Assembly

20

Card 16

Construction

20

Card 12

Areas of Concern

10

Card 15

Dimensions

10

Card 05

Design Intent

10

Card 19

Mechanism

10

Card 09

Scenario of Use

10

Card 07

Visual Character

10

Source | Relevance to Design Stages | Rating

Card 01

Concept Design

20

Card 02

Design Development

30

Card 03

Embodiment Design

30

Card 04

Detail Design

20

Engineering Designers Card

44

Functional Concept Model

Shows functionality and highlights important functional parameters including yield and performance factors.

Engineering Design Models

Functional Concept Model

Relevance to Design

Source | & Technical Information | Rating

Card 18

Components

80

Card 19

Mechanism

80

Card 08

Usability & Operation

80

Card 17

Assembly

20

Card 09

Scenario of Use

20

Card 12

Areas of Concern

10

Card 16

Construction

10

Card 05

Design Intent

10

Card 15

Dimensions

10

Source | Relevance to Design Stages | Rating

Card 01

Concept Design

40

Card 02

Design Development

60

Card 03

Embodiment Design

20

Card 04

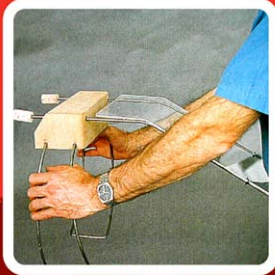
Detail Design

0

Design Representations pack – Functional Concept Model card

Industrial Designers Card **45**

## Concept of Operation Model



Helps communicate understanding of operational strategies and usage procedures relating to the product.

Engineering Design Models

## Concept of Operation Model

Relevance to Design

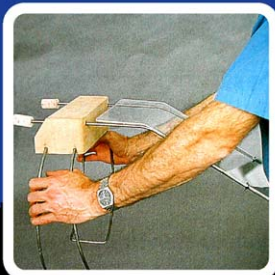
Source	& Technical Information	Rating
Card 08	Usability & Operation	20
Card 18	Components	10
Card 05	Design Intent	10
Card 19	Mechanism	10
Card 09	Scenario of Use	10

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	10
Card 02	Design Development	20
Card 03	Embodiment Design	10
Card 04	Detail Design	10

Engineering Designers Card **45**

## Concept of Operation Model



Helps communicate understanding of operational strategies and usage procedures relating to the product.

Engineering Design Models

## Concept of Operation Model

Relevance to Design

Source	& Technical Information	Rating
Card 08	Usability & Operation	30
Card 18	Components	20
Card 19	Mechanism	20
Card 09	Scenario of Use	20


Source	Relevance to Design Stages	Rating
Card 01	Concept Design	0
Card 02	Design Development	10
Card 03	Embodiment Design	10
Card 04	Detail Design	10

Design Representations pack – Concept of Operation Model card



Industrial Designers Card **46**

## Production Concept Model



Used to help assist the evaluation of production processes or manufacturing technologies for final production.

Engineering Design Models

## Production Concept Model


Relevance to Design Source | & Technical Information | Rating

Card 17	Assembly	10

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	0
Card 04	Detail Design	0

Engineering Designers Card **46**

## Production Concept Model



Used to help assist the evaluation of production processes or manufacturing technologies for final production.

Engineering Design Models

## Production Concept Model

Relevance to Design Source | & Technical Information | Rating

Card 17	Assembly	20
Card 16	Construction	20
Card 15	Dimensions	10

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	0
Card 04	Detail Design	20

Design Representations pack – Production Concept Model card

Industrial Designers Card **47**

# Assembly Concept Model




**Shows component relationships to provide confidence in assembly, cost and investment.**

Engineering Design Models



Industrial Designers Card 48

# Service Concept Model



Illustrates how the product is serviced and maintained, and may be in the form of exploded views to show the disassembly of parts with servicing information.

Engineering Design Models

## Service Concept Model

Relevance to Design


Source	& Technical Information	Rating
<b>Card 18</b>	<b>Components</b>	<b>10</b>
<b>Card 19</b>	<b>Mechanism</b>	<b>10</b>

Source	Relevance to Design Stages	Rating
<b>Card 01</b>	<b>Concept Design</b>	<b>0</b>
<b>Card 02</b>	<b>Design Development</b>	<b>0</b>
<b>Card 03</b>	<b>Embodiment Design</b>	<b>0</b>
<b>Card 04</b>	<b>Detail Design</b>	<b>0</b>

Engineering Designers Card 48

# Service Concept Model



Illustrates how the product is serviced and maintained, and may be in the form of exploded views to show the disassembly of parts with servicing information.

Engineering Design Models

The image shows a white rectangular area containing an exploded view diagram of a mechanical assembly. The assembly consists of several colored components: a large blue dome-shaped top, a yellow rectangular block, a green rectangular block, an orange rectangular block, a purple rectangular block, and a blue rectangular block. Various small yellow pins and screws are shown around the components, indicating their assembly points. The background of the slide is dark blue with a silhouette of a person working on a machine.

Service Concept Model

Relevance to Design


Source	& Technical Information	Rating
Card 17	Assembly	10

Source	Relevance to Design Stages	Rating
Card 01	Concept Design	0
Card 02	Design Development	10
Card 03	Embodiment Design	10
Card 04	Detail Design	0

## Design Representations pack – Service Concept Model card

Industrial Designers Card **49**

# Appearance Prototype



Highly detailed, full-sized models that combine functionality with product appearance.

Industrial Design Prototypes

## Appearance Prototype

Relevance to Design Source | & Technical Information | Rating


Card 13	Texture & Surface Finish	60
Card 14	Colour	50
Card 05	Design Intent	50
Card 22	Material	50
Card 07	Visual Character	50
Card 18	Components	40
Card 15	Dimensions	40
Card 05	Form & Detail	40
Card 19	Mechanism	40
Card 16	Construction	30

Source | Relevance to Design Stages | Rating

Card 01	Concept Design	10
Card 02	Design Development	10
Card 03	Embodiment Design	30
Card 04	Detail Design	60

Engineering Designers Card **49**

# Appearance Prototype



Highly detailed, full-sized models that combine functionality with product appearance.

Industrial Design Prototypes

## Appearance Prototype

Relevance to Design Source | & Technical Information | Rating

Card 14	Colour	40
Card 18	Components	40
Card 22	Material	40
Card 13	Texture & Surface Finish	40
Card 17	Assembly	30
Card 16	Construction	30
Card 05	Design Intent	30
Card 15	Dimensions	30
Card 06	Form & Detail	30
Card 19	Mechanism	30
Card 07	Visual Character	30
Card 20	Part & Section Profile Lines	10

Source | Relevance to Design Stages | Rating


Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	20
Card 04	Detail Design	30

Design Representations pack – Appearance Prototype card

Industrial Designers Card

50

Alpha Prototype



The first construction of the sub-systems that have been individually proven and accepted. Fabricated using materials, design and layout that will be used for the actual product.

Industrial Design Prototypes

Alpha Prototype

Relevance to Design & Technical Information

Rating

Card 16	Construction	20
Card 17	Assembly	10
Card 14	Colour	10
Card 18	Components	10
Card 05	Design Intent	10
Card 15	Dimensions	10
Card 06	Form & Detail	10
Card 22	Material	10
Card 19	Mechanism	10
Card 13	Texture & Surface Finish	10
Card 08	Usability & Operation	10
Card 07	Visual Character	10

Source

Relevance to Design Stages

Rating

Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	10
Card 04	Detail Design	10

Engineering Designers Card

50

Alpha Prototype



The first construction of the sub-systems that have been individually proven and accepted. Fabricated using materials, design and layout that will be used for the actual product.

Industrial Design Prototypes

Alpha Prototype

Relevance to Design & Technical Information

Rating

Card 14	Colour	20
Card 18	Components	20
Card 15	Dimensions	20
Card 22	Material	20
Card 12	Areas of Concern	10
Card 17	Assembly	10
Card 16	Construction	10

Source

Relevance to Design Stages

Rating

Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	10
Card 04	Detail Design	10

Design Representations pack – Alpha Prototype card



Industrial Designers Card **51**

# Beta Prototype



The first full-scale and fully-functional prototypes constructed from the actual materials as in the final product.

Industrial Design Prototypes

## Beta Prototype

Relevance to Design & Technical Information | Rating

Card 16	Construction	20
Card 17	Assembly	10
Card 14	Colour	10
Card 18	Components	10
Card 15	Dimensions	10
Card 22	Material	10
Card 19	Mechanism	10
Card 13	Texture & Surface Finish	10
Card 08	Usability & Operation	10
Card 07	Visual Character	10

Source | Relevance to Design Stages | Rating

Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	10
Card 04	Detail Design	10

Engineering Designers Card **51**

# Beta Prototype



The first full-scale and fully-functional prototypes constructed from the actual materials as in the final product.

Industrial Design Prototypes

## Beta Prototype

Relevance to Design & Technical Information | Rating

Card 17	Assembly	10
Card 14	Colour	10
Card 18	Components	10
Card 16	Construction	10
Card 15	Dimensions	10
Card 22	Material	10
Card 19	Mechanism	10
Card 13	Texture & Surface Finish	10


Source | Relevance to Design Stages | Rating

Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	10
Card 04	Detail Design	0

Design Representations pack – Beta Prototype card

Industrial Designers Card **52**

## Pre-Production Prototype



Final prototypes used to perform production and assembly assessment using production tooling for small batches.

Industrial Design Prototypes

## Pre-Production Prototype

Relevance to Design Source | & Technical Information | Rating

Card 16	Construction	20
Card 17	Assembly	10
Card 14	Colour	10
Card 18	Components	10
Card 15	Dimensions	10
Card 05	Design Intent	10
Card 06	Form & Detail	10
Card 22	Material	10
Card 19	Mechanism	10
Card 13	Texture & Surface Finish	10
Card 08	Usability & Operation	10
Card 07	Visual Character	10

Source | Relevance to Design Stages | Rating

Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	10
Card 04	Detail Design	20

Engineering Designers Card **52**

## Pre-Production Prototype



Final prototypes used to perform production and assembly assessment using production tooling for small batches.

Industrial Design Prototypes

## Pre-Production Prototype

Relevance to Design Source | & Technical Information | Rating

Card 14	Colour	20
Card 18	Components	20
Card 15	Dimensions	20
Card 22	Material	20
Card 13	Texture & Surface Finish	20
Card 17	Assembly	10
Card 16	Construction	10
Card 19	Mechanism	10


Source | Relevance to Design Stages | Rating

Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	0
Card 04	Detail Design	20

Design Representations pack – Pre-Production Prototype card

Industrial Designers Card **53**

# Experimental Prototype



Physical prototypes used to perform or parameterize physical properties of the product. Also known as Design-of-Experiment Prototypes.

Engineering Design Prototypes

## Experimental Prototype

Relevance to Design Source | & Technical Information | Rating


Card 18	Components	10
Card 16	Construction	10
Card 15	Dimensions	10
Card 19	Mechanism	10
Card 08	Usability & Operation	10

Source | Relevance to Design Stages | Rating

Card 01	Concept Design	0
Card 02	Design Development	10
Card 03	Embodiment Design	10
Card 04	Detail Design	10

Engineering Designers Card **53**

# Experimental Prototype



Physical prototypes used to perform or parameterize physical properties of the product. Also known as Design-of-Experiment Prototypes.

Engineering Design Prototypes

## Experimental Prototype

Relevance to Design Source | & Technical Information | Rating

Card 18	Components	40
Card 19	Mechanism	40
Card 17	Assembly	20
Card 16	Construction	20
Card 08	Usability & Operation	20
Card 12	Areas of Concern	10
Card 15	Dimensions	10

Source | Relevance to Design Stages | Rating

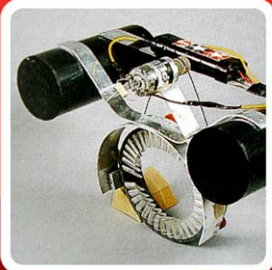
Card 01	Concept Design	30
Card 02	Design Development	30
Card 03	Embodiment Design	20
Card 04	Detail Design	10



Industrial Designers Card

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System Prototype



Combines the numerous components specified for the final product. Used to test and assess assembly, mechanism and performance.

Engineering Design Prototypes

System Prototype

Relevance to Design

Source | & Technical Information | Rating

Card 17	Assembly	10
Card 18	Components	10
Card 19	Mechanism	10

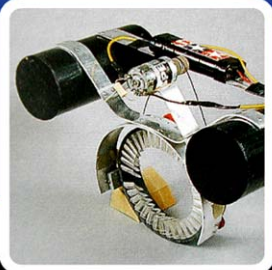
Source | Relevance to Design Stages | Rating

Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	0
Card 04	Detail Design	10

Engineering Designers Card

54

System Prototype



Combines the numerous components specified for the final product. Used to test and assess assembly, mechanism and performance.

Engineering Design Prototypes

System Prototype

Relevance to Design

Source | & Technical Information | Rating

Card 18	Components	30
Card 19	Mechanism	30
Card 12	Areas of Concern	10
Card 17	Assembly	10
Card 16	Construction	10
Card 15	Dimensions	10


Source | Relevance to Design Stages | Rating

Card 01	Concept Design	0
Card 02	Design Development	20
Card 03	Embodiment Design	20
Card 04	Detail Design	20

Design Representations pack – System Prototype card

Industrial Designers Card **55**

## Final Hardware Prototype



Assists in the design and evaluation of product fabrication and assembly issues.

Engineering Design Prototypes

## Final Hardware Prototype

Relevance to Design Source | & Technical Information | Rating


Card 17	Assembly	10
Card 18	Components	10
Card 22	Material	10
Card 19	Mechanism	10

Source | Relevance to Design Stages | Rating

Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	0
Card 04	Detail Design	10

Engineering Designers Card **55**

## Final Hardware Prototype



Assists in the design and evaluation of product fabrication and assembly issues.

Engineering Design Prototypes

## Final Hardware Prototype

Relevance to Design Source | & Technical Information | Rating

Card 18	Components	30
Card 15	Dimensions	30
Card 19	Mechanism	30
Card 12	Areas of Concern	20
Card 17	Assembly	20
Card 16	Construction	20
Card 14	Colour	10
Card 22	Material	10
Card 13	Texture & Surface Finish	10

Source | Relevance to Design Stages | Rating


Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	10
Card 04	Detail Design	30

Design Representations pack – Final Hardware Prototype card



Industrial Designers Card **56**

# Tooling Prototype



The physical tooling allows potential problems to be intercepted before any discrepancies of form or fit occur.

Engineering Design Prototypes

## Tooling Prototype

Relevance to Design & Technical Information | Rating


Card 18	Components	20
Card 17	Assembly	10
Card 14	Colour	10
Card 16	Construction	10
Card 15	Dimensions	10
Card 06	Form & Detail	10
Card 22	Material	10
Card 19	Mechanism	10
Card 13	Texture & Surface Finish	10

Source | Relevance to Design Stages | Rating

Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	10
Card 04	Detail Design	20

Engineering Designers Card **56**

# Tooling Prototype



The physical tooling allows potential problems to be intercepted before any discrepancies of form or fit occur.

Engineering Design Prototypes

## Tooling Prototype

Relevance to Design & Technical Information | Rating

Card 18	Components	20
Card 15	Dimensions	20
Card 12	Areas of Concern	20
Card 17	Assembly	10
Card 16	Construction	10
Card 14	Colour	10
Card 22	Material	10
Card 13	Texture & Surface Finish	10


Source | Relevance to Design Stages | Rating

Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	10
Card 04	Detail Design	20

Design Representations pack – Tooling Prototype card

Industrial Designers Card **57**

## Off-Tool Prototype



Components produced using the tooling and materials intended for the final product.

Engineering Design Prototypes

## Off-Tool Prototype

Relevance to Design & Technical Information | Rating


Card 17	Assembly	10
Card 18	Components	10
Card 16	Construction	10
Card 15	Dimensions	10
Card 13	Texture & Surface Finish	10
Card 19	Mechanism	10

Source | Relevance to Design Stages | Rating

Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	0
Card 04	Detail Design	10

Engineering Designers Card **57**

## Off-Tool Prototype



Components produced using the tooling and materials intended for the final product.

Engineering Design Prototypes

## Off-Tool Prototype

Relevance to Design & Technical Information | Rating

Card 14	Colour	20
Card 18	Components	20
Card 15	Dimensions	20
Card 22	Material	20
Card 19	Mechanism	20
Card 13	Texture & Surface Finish	20
Card 17	Assembly	10
Card 16	Construction	10
Card 06	Form & Detail	10

Source | Relevance to Design Stages | Rating

Card 01	Concept Design	0
Card 02	Design Development	0
Card 03	Embodiment Design	0
Card 04	Detail Design	20

Design Representations pack – Off-Tool Prototype card

## 13.16 Correspondence

### 13.16.1 Email from IDSA

The email below shows a correspondence email from Frank M. Tyneski, Executive Director of the Industrial Designers Society of America (IDSA). His letter shows a positive response and keenness to co-develop the CoLab cards with the author and his research supervisors for commercialization.

```
On Tue, 10 Feb 2009 12:14:07 -0500
  "Frank Tyneski" <____@idsa.org> wrote:
>
> Hello Mark,
> I received your package of ColLab sample materials. I
> think the Design Stages, Information and Representation
> cards are just brilliant. There's no doubt in my mind
> that the CoLab cards will be extremely valuable to our
> IDSA members. So, I'd like to aggressively move to next
> steps. Are you available to discuss next week? If so,
> please send your available time slots to Annette Butler,
> who is our office manager. Larry Hoffer and I will do
> our best to accommodate your schedule.
> Many Thanks,
>
> Frank
>
>
> Frank M. Tyneski / Executive Director
> Industrial Designers Society of America (IDSA)
> 45195 Business Court, Suite 250
> Dulles, VA 20166-6717
> www.idsa.org
>
>
>
```

### **13.17      *References to the Appendix***

- Bucciarelli, L. (1994). Designing engineers. Cambridge, MA, MIT Press.
- Conklin, J. and M. Begeman (1988). A Hypertext Tool for Policy Discussion: ACM Transactions on Office Information Systems Vol. 6 No. 4 pp 303-331. In: Lowgren, J. and Stolterman, E. (1999) "Design methodology and design practice," Interactions Vol. 6 No. 1. pp. 13-20.
- Cross, N. (2000). Engineering Design Methods - Strategies for Product Design (3rd ed.). Chichester, John Wiley and Sons Ltd.
- Cross, N. and R. Roy (1975). Design Methods Manual. Milton Keynes, The Open University Press.
- de Bono, E. (1993). Serious Creativity: Using the Power of Lateral Thinking To Create New Ideas. Quoted in: Lowgren, J. and Stolterman, E. (1999) "Design methodology and design practice," Interactions Vol. 6 No. 1. pp. 13-20.
- Dominick, P. G., J. T. Demel, et al. (2001). Tools and Tactics of Design. New York, John Wiley & Sons, Inc.
- Dym, C. L. and P. Little (2003). Engineering Design - A Project-based Introduction (2nd ed.). New Jersey, John Wiley & Sons Inc.
- Eide, A. R., R. D. Jenison, et al. (2001). Introduction to Engineering Design & Problem Solving (2nd ed.). New York, McGraw Hill.
- Erhorn, C. and J. Stark (1994). Competing by Design - Creating Value and Market Advantage in New Product Development. Vermont, Oliver Wight Publications, Inc.
- Erlhoff, M. (1987). "Kopfüber zu Füßen. Prolog für Animatoren," In: documenta 8, Vol. 1 Kassel. Quoted in: Bürdek, Erhard E. (2005) "Design - History, theory and practice of product design," Basel: Birkhauser.
- Fleischer, M. and J. K. Liker (1997). Concurrent Engineering Effectiveness - Integrating Product Development Across Organisations. Cincinnati, OH, Hanser Gardner Publications.
- Gibson, J. E. (1968). Introduction to Engineering Design. New York, Holt, Rinehart and Winston Inc.
- Hawkes, B. and R. Abinett (1985). The Engineering Design Process. London, Pitman Publishing Limited.
- Hein, L. (1994). "Design Methodology in Practice." Journal of Engineering Design Vol. 5(No. 2).

Horenstein, M. N. (1999). Engineering Design - A Day in the Life of Four Engineers. New Jersey, Prentice-Hall Inc.

Huang, G. Q. (1996). Design for X: Concurrent Engineering Imperatives. London, Chapman & Hall.

Hubka, V. (1983). "Design tactics = methods + working principles for design engineers." Design Studies Vol. 4(No. 3).

Hurst, K. (1999). Engineering Design Principles. New York, Arnold Publishers.

Jones, C. J. (1992). Design Methods (2nd Ed.). New York, John Wiley & Sons.

Löwgren, J. and E. Stolterman (1999). "Design methodology and design practice." Interactions Vol. 6(No. 1): pp. 13-20.

Osborn, A. F. (1957). "Applied Imagination," New York: Scribners. Quoted in: Shetty, Devdas (2002) "Design for Product Success," Dearborn, Michigan: Society of Manufacturing Engineers (SME).

Pahl, G. and W. Beitz (1996). Engineering Design - A Systematic Approach (2nd ed.). New York, Springer-Verlag.

Pugh, S. (1981). "Concept selection - A method that works," In: Proceedings of ICED '81 held in Rome, Techniche Nuove pp. 497-506. Quoted in: Pugh, Stuart (1991) "Total Design: Integrated Methods for Successful Product Engineering," Essex: Pearson Education Limited / Addison-Wesley Publishers Ltd.

Roozenburg, N. F. M. and J. Eekels (1995). Product Design: Fundamentals and Methods. Chichester, John Wiley and Sons Ltd.

Rosenthal, S. R. (1992). Effective Product Design and Development - How to cut lead time and increase customer satisfaction. Homewood, IL, Business One Irwin.

Schneider, W. (1990). "Generation of Assembly Orientated Design," In: Proceedings of Institution of Mechanical Engineering Seminar on Design for Manufacture and Quality within Integrated Product Development held in London April 1990. Quoted in: Syan, Chanan S. and Menon, Unny (1994) "Concurrent Engineering - Concepts, Implementation and Practice".

Shetty, D. (2002). Design for Product Success. Dearborn, Michigan, Society of Manufacturing Engineers (SME).

Souder, W. E. (1987). "Managing New Product Innovations," Lexington, MA: Lexington Books. Quoted in: Griffin, Abbie and Hauser, John R. (1996)

"Integrating R&D and Marketing: A Review and Analysis of the Literature,"  
Journal of Product Innovation Management No. 13.

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

Syan, C. S. and U. Menon (1994). Concurrent Engineering - Concepts, Implementation and Practice. London, Chapman & Hall.

Taguchi, G. (1986). Introduction to Quality Engineering: Designing Quality Products and Processes. Quoted in: Syan, Chanan S. and Menon, Unny (1994) "Concurrent Engineering - Concepts, Implementation and Practice".

Wright, I. (1998). Design Methods in Engineering and Product Design. Berkshire, McGraw Hill Publishing Company.

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